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CitA BIM Gathering Conference 2019
Preface

This is the fourth edition of paper proceedings presented at the CitA BIM Gathering conference. Since our inaugural conference in 2013, the Irish economy and construction sector has continued to recover at a rapid pace. In 2019 there is the looming threat of Brexit, a poor record of productivity in construction and a general shortage of skilled and talented graduates. This recovery has triggered an increased realisation that BIM is important for an efficiently operating industry going forward.

The papers presented in these proceedings cover a variety of BIM related topics but collectively have a common theme that BIM can Deliver Better Project Outcomes for Irish Construction.

It is encouraging to see a number of papers that are addressing public sector BIM adoption in Ireland. The Construction Sector Group ,with the support of the Department of Public Expenditure and Reform (DPER), have recently commissioned a study on construction productivity in the Irish construction industry. DPER have reported that Ireland has one of the poorest performing construction industries within the 27 European member states and that policy interventions are needed to remedy the problem.

The CitA team

As we approach 2020 it is hoped that the Irish government will look to fund the implementation of the National BIM Council Roadmap for Digital Transition of the Irish Construction Industry, as both industry and government need a structured programme to support the wider adoption of BIM on Irish construction projects.

CitA was delighted with the support we received in bringing the Gathering to Galway city in 2019 and hope to continue this focus on regional reach in its planning of the BIM Gathering in 2021.

I would like to thank all of the participating partners, the scientific committee, the organisation committee, the authors, the speakers, the sponsors and most importantly the CitA events team for their fantastic efforts in delivering another high quality event that will be remembered fondly by all those that attended.

Dr. Alan V Hore,
Conference Chair

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BIM and Lean Procurement Practices

Assessing the viability of applying Lean, Green & BIM principles in Office Fit-out Projects

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Abstract—The benefits of BIM in large 'from the ground up' projects are well documented. However, in the global office-market, the majority of deals for the take up of space are for occupancies of less than 1,000 square metres (69% in 2015). Can a full Level 2 BIM process be applied effectively to improve the fit-out of these spaces? At the same time many of these projects require rapid deployment whilst at the same time embracing 'Green' and 'Wellness' principles. Can the BIM process help to support the principles of LEED, WELL Standards and Lean Project Management and ultimately lead to better office fit-out projects, with better long-term outcomes?

Keywords—Building Information Modelling (BIM), Lean, Green, Wellness, Fit-out. LEED, WELL

I. INTRODUCTION

The office fit-out market continues to grow. In the UK, total contractor revenue for the fit-out market has surged by more than 20% to £3,717m (2017: £3,060.3m) and total pre-tax profit for the top 20 contractors has grown from £68.9m in 2017 to £97.9m – an increase of more than 42% [1]. It is clear therefore that this is an important market for all members of the construction industry. This large market has a high potential to impact the immediate environment around the location as well as the building users and the global environment.

The Building Information Modelling / Management (BIM) process was introduced, in the UK, to improve the efficiency of delivering and operating built assets through improvement of collaboration between project team members and effective use of data generated during the asset lifecycle, as outlined in PAS 1192 and in response to the UK Government Construction Strategy which was aimed at reducing the cost of public sector assets by up to 20% by 2016 [2] .

Leadership in Energy and Environmental Design (LEED), is the most widely used green building rating system in the world and provides a framework to create healthy, highly efficient and cost-saving green buildings [3]. LEED and other similar rating systems such as BREEAM and GreenStar aim to reduce the environmental impact of a built asset on the environment. In this aspect these rating systems are focussed on the building.

The WELL Building Standard (WELL) is a tool for advancing health and well-being in buildings globally [4]. The assessment follows a similar process to LEED but is focussed on the users of the building.

Lean construction focusses on the reduction in waste, increase in value to the customer, and continuous improvement [5].

This paper seeks to investigate the practical application of these processes and rating systems concurrently with BIM to improve office fit-out project delivery from inception to ‘in-use’.

II. METHODOLOGY

For this study, BIM has been identified as an enabler and a process for achieving lean and green outcomes on commercial office fit-out construction projects. Based on a detailed literature review, this paper identifies the organizational capabilities needed by the architecture, engineering and construction organizations to effectively implement BIM on construction projects. The study has been conducted through a sequential mixed-method approach involving semi structured interviews and qualitative comparative analyses.

III. BIM

BIM is described in the glossary of ISO 19650-1 as ‘use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions’ [6]. BIM is further advised in the BIM Handbook to describe tools, processes and technologies that are facilitated by digital, machine-readable documentation about a building, its performance, its planning, its construction and later its operation [7].

A summary of these two descriptions might simply note that BIM is a digital process for documenting and assessing a building's performance. However, BIM also facilitates a more integrated design and construction process that results in better quality buildings, at lower cost and reduced project duration [7].

IV. LEED

LEED is a framework to allow assessment of the environmental impact of buildings.

LEED is available for various building types. The Interior Design and Construction framework for Commercial Interiors is most applicable to the subject matter of this paper. The framework is split into a number of credit categories described by the US Green Building Council as [3] including: Location and Transportation; Water Efficiency; Energy and Atmosphere; Materials and Resources; Indoor Environmental Quality; Innovation; Regional Priority

The assessment of a particular fit-out project against the framework relies on comparing project data against a set of 'best practise' criteria. Much of the required parameters can be obtained effectively from a BIM model and the assessment process itself can be embedded within the overall BIM process [8].

V. WELL

Similarly to the LEED framework, WELL is a standard that assesses the impact of a building however while other green building rating systems consider health as a component of the larger holistic system, the WELL Building Standard is focused solely on the health of the building occupants [9].

WELL is available for:

- New & Existing Buildings
- Interiors
- Core & Shell

Assessment is based on a number of features which are either mandatory (preconditions) or optional (optimisations) which will increase the assessment outcome.

The Interiors project type is most relevant to this paper and consists of 36 Preconditions and 62 Optimisations. Assessment categories cover[4]: Air Quality ; Water Quality; Nourishment ; Light quality ; Fitness options; Comfort conditions; Mind related aspects which promote mental wellbeing

As with the LEED process the assessment process relies on data regarding the design and specification of the various features of the above conditions, many of which can again be drawn from a BIM model and built into the BIM process.

VI. LEAN

'Lean' was first used in connection with production in 1988 by John Krafcik [10] to describe the Toyota Production System, which was implemented in Japan by Toyota to improve the efficiency of their car production process.

The Toyota production system sought to eliminate waste from the car production process [11]. The focus in lean construction is on reduction in waste, increase in value to the customer and continuous improvement [5].

'Lean Construction' is a phrase first recorded by Koskela in 1992 [12] and used to describe the application of 'just in time' and 'total quality control' principles to construction.

Adapting the Toyota production system for construction [13] we see waste as: Overproduction; Waiting; Transport; Over-Processing; Excess Inventory; Unnecessary Movement; Defects; Unused Creativity

The application of Lean Construction principles can be achieved through implementation of The Last Planner System [14].

Ballard et al [15] observe that implementation of lean at a project level requires twelve key component steps which all require a high level of collaboration which is again in alignment with a BIM process.

VII. BIM & Lean

The alignment of BIM and Lean processes is well researched.

Koskela and Howell [16] observe that, typically, customer requirements are poorly investigated at the outset of a project, which leads to requirement clarification (request for information) and change (variations) whilst the works and on site which in turn leads to disruption and delay in the progress of the project.

This view highlights that the BIM and Lean process must start at the outset of the project and encompass the design process in entirety. Kestle et al [17] reviewed the integration of lean design management and design management thinking and found that an appropriate model for this could be developed. They recorded that a shared understanding of what is valued in a project has an impact on how critical design decisions are made [17] and that understanding what constitutes value is a difficult process[18]. Given these observations is essential to engage all relevant stakeholders at the outset of a project and agree what value constitutes for that particular project.

Building information modelling (BIM) and lean construction are two initiatives that are being developed in order to increase productivity, efficiency and quality in construction by implementing various procedures[19].

AEC organisations often take a 'one at a time' view of environment-related improvements (green initiatives) and process-related (lean principles based initiatives, BIM implementation) improvements [20] however it is observed that there are benefits to implementing aligned initiatives at the same time.

The common benefits of BIM and Lean are discussed in the CIRIA Report 'Lean construction and BIM' [21] which notes that Lean construction has two main goals :

1. Minimise physical and process waste
2. Improve value generation to the client.

The CIRIA report observes that there are four major interactions between BIM and Lean:

1. BIM contributes directly to Lean goals – for example clash detection which allows virtual detection of issues before they occur physically on site
2. BIM contributes indirectly to Lean goals – the collaborative approach championed in the Lean process is a key component of the BIM process
3. Auxiliary information systems, enabled by BIM, contribute to Lean goals – using the BIM model to streamline sub-processes e.g. cost management, design assessment and handover to operations
4. Lean processes facilitate the introduction of BIM – the Lean emphasis on clarity drives the need for BIM

Sacks et al [5] found 56 unique interactions between BIM and Lean and concluded that Lean and BIM and not only synergistic during the design and planning stages of a project but span the entire project lifecycle. The 56 interactions were collated, and the study found that the three most prevalent interactions between Lean and BIM were:

1. Reduction is waste due to enhanced level of detail and coordination in the design leading to less request-for-information on site and less design changes
2. Improved information flow and reduced programme uncertainty
3. Reduction in overall construction time

These observations are supported by a UK Office of General Contractor (OGC) report citied in the CIRIA report [21] that estimated that, on single projects, 2 to 10 per cent savings could be made on construction costs.

VIII. BIM & Green

Wong and Zhou [22] catalogued previous research on green BIM and summarised green BIM as "a model based process of generating and managing coordinated and consistent building data during its project lifecycle that enhance building energy efficiency performance, and facilitate the accomplishment of established sustainability goals".

Corfe [23] observes that there is a growing awareness of the link between a Lean approach and sustainability.

The UK Government has previously recognised this and notes[24]:

'The current financial climate highlights the need to apply well-honed techniques like 'lean' thinking and value engineering to review all aspects of project design and delivery.'

Corfe further notes that by adopting this philosophy several areas can be helped, specifically within the processes that have an effect on the targets and goals of sustainability.

As has already been discussed in this paper, many of these Lean approaches are directly linked with BIM recommendations.

With specific reference to formulated sustainability assessment processes, it has previously been concluded that a BIM process can be incorporated with LEED rating generation to streamline the assessment and certification process and reduce waste in the form of resource time when compared with traditional approaches to this [25].

Although, not specifically researched to date, it is conceivable, since the processes of LEED and WELL are similar, that a WELL Building Standard Assessment could be similarly supported by BIM.

El-Dirbya et al observe that BIM models are large and complex yet they currently have little focus on green-oriented features and they offer a means to compare the energy performance of alternative designs and model features which they have called Green 2.0 [26]. This demonstrates that a direct link between a 'green assessment' and a BIM process can be made.

Wong and Zhou [22] observe that Green BIM has been advocated for its potential to support environmentally sustainable building development and conclude, from a thorough review of the available research and commentary, that green BIM has emerged as a popular energy performance analysis tool during a concept design stage, however, green BIM development has only started to scratch the surface, and its full potential is yet to be explored in practice.

Alwan et al [27] produced a case study into the development of LEED inputs from BIM outputs and concluded that key credits in LEED can be integrated within the BIM design process thereby tackling environmental design issues in parallel to building design.

This observation was further developed by Ilhan and Yaman [28] who propose the green building assessment tool (GBAT), which implements their proposed model of integrating BIM and Green Assessment.

From the above review of previous research it is clear that directly linking the BIM process and Green building assessment, in the proposed case LEED, is achievable and beneficial.

IX. BIM & Lean & Green

Further to the alignment of BIM & Lean and BIM & Green as individual combinations the alignment of the three initiatives is also reasonably well researched.

BIM has been identified as an enabler for lean and green initiatives and provides a process to achieve this. A study [8] discovered that, to attain desired project outcomes, a whole organization adoption of BIM culture was required, not only within its project teams. The study also concluded improved project outcomes, particularly those targeting lean and green improvements can be achieved through BIM deployment.

A review by Saieg et al [29] found that previous research found that there is an untapped potential for operational, technological and eco-efficient process improvements in the AEC industry. They further note that, as observed in the literature, the systematic and integrated use of BIM and lean construction has the potential to ease the sustainable pressures and improve productivity.

From the foregoing and integrated approach to BIM, Lean and Green building is not only viable but recommended to achieve:

- limitation of environmental impact and resultant benefit to building users
- more efficient project delivery through removal of waste
- improved project delivery through collaborative approach promoted by BIM process.

X. DISCUSSION

Throughout the research for this paper it was observed that, whilst there was a body of research across BIM, Lean and Green initiatives, there appeared to be no published reviews specifically relating to the application of BIM, Lean and Green approaches to office fit-out projects.

In addition to the authors own experience, gained over more than 25 years in the construction industry working across Europe, Middle East and Africa, and to gain further industry insights, interviews were held with a cross-industry selection of UK & Ireland based personnel from Client, Contractor and Consultant backgrounds.

i. The Client View

Two Client bodies, one a real estate investment trust (REIT), active in the UK and Irish markets, and one a large, US headquartered, corporation with 2,000+ global offices, were interviewed and their views recorded.

The client bodies expressed a real belief that implementation of BIM across their existing and future portfolio will drive business efficiencies in terms of accuracy of data for acceptance of build / fit-out projects, operation of the building and housed assets and disposal of the building and assets.

The REIT is implementing BIM in their contracts for all new build properties, which are generally developed as ‘shell & core’ ready for tenant fit-out, where the REIT will remain as the Landlord.

In these contracts the base building is developed with a BIM process and the tenancy lease contracts require the fit-outs to be carried out with BIM.

Whereas the CIC BIM Protocol [30] can be used to ensure that direct appointed contractors and consultants are obliged to conform to a BIM process, when this requirement is transposed to tenancy agreements the legal framework with regards common data environment, model ownership data accuracy are not well developed. It appears that there are no ‘off the shelf’ lease contracts or clauses that adequately cover this transition from ‘build’ to ‘tenant fit-out’.

The REIT is also including a BIM requirement for the retro-fit of existing properties whether owned and being refurbished or acquired ‘fully fitted’ and being retrofitted / modernised. Their experience is that the ‘additional work’ required at the start of a retrofit fit-out project in design detailing pays off during construction through avoidance of clashes and rework delays (or wastes in Lean language) and that the data rich handover material assists them in the ongoing operation and maintenance of the facility, driving efficiencies across the FM team which can then reflect in the FM Service Level Agreement thereby generating cost savings. The BIM information can also be delivered to any buyer when the building is disposed of. The accuracy of the model enhances the acquisition due diligence process thereby ensuring that the level of risk built into a purchase price can be reduced thereby maximising value for the selling REIT and giving better comfort to the buyer.

The Corporate Client also sees the value of BIM at an overall level however is struggling with the best approach to dispersing this across a global portfolio, which spans most developed countries in the world, where levels of understanding of BIM and skills in use of BIM vary greatly.

Lean management and LEED principles are regularly applied to their projects however the values of BIM, beyond architectural visualisation, has not been exploited.

At a high level the Corporate Client sees the benefit of accuracy of data transposed into their CAFM system as well as the interlink of the BIM model to ongoing Internet-of-Things deployments and other building user experience enhancements, including environmental impact and wellness factors however putting this into a standard (Organisational Information Requirement) is a challenge ‘in theory’.

As a result of these challenges the Corporate Client plans to implement BIM, Lean and Green assessments on a pilot basis in an upcoming 1,000sqm fit-out project in Cairo, Egypt to assess the full viability.

ii. The Contractor View

Four prominent fit-out contractors, operating primarily in the UK & Irish markets, with some operations in EMEA, were interviewed and their views recorded.

All of the contractors noted that they had been implementing Lean principles in their fit-out projects. One contractor confirmed that they utilised Lean on 95% of projects due to proven and demonstratable efficiency gains in terms of manhours and defects.

Most of the contractors advised that they were implementing BIM, when requested by Client, on fit-out projects from 2,000sqm and upwards – real benefits observed in terms of clarity in design and coordination and reduction in defects.

One of the contractors noted that they used BIM on all projects whether requested by the Client or not, specifically to assist with coordination whereas another noted that they would not normally consider BIM for ‘simple’ projects (such as office fit-out) if the Client did not specifically request it. Although this same contractor had observed a 10% efficiency gained in labour requirement via use of BIM on more complex projects.

One contractor, who had recently completed an aligned Lean and BIM office fit-out project for a prominent software manufacturer, recommended that an integrated design and build schedule was required from the outset of the project to ensure success. This requires early engagement of the contractor and a collaborative approach from all team members and therefore drives the procurement strategy towards a more ‘integrated project delivery’ [31] methodology.

This Contractor, noted that, whilst the benefits of the application of a BIM platform was clear (in the example 2,500sqm office fit-out project), to deliver the project within the full capability of the available software ‘from a standing start’, and to meet the full recommendations of Level 2 BIM, it is very challenging whilst at the same time operating ‘commercially’ in a competitive marketplace and whilst working to a ‘traditional’ programme. This was observed to be due to lack of experienced and effective operators of the various software packages (specifically Autodesk Revit and BIM360). It was however noted that the best learning on this application was gained on a live project ‘in the field’ where known theories could be put into practise.

All of the Contractors observed that a lack of detailed specification requirements regarding Facilities Management (FM) requirements in amy Employers Information Requirements (EIR) documents limited the use of COBie or IFC data transfer into FM software and that the request for such data transfer was not currently the normal practice in the Irish market.

Similarly, all Contractors stated that a clear, shared, vision of the value of application of BIM and Lean (and other initiatives) is essential at the outset of the project, across all suppliers and operatives for these initiatives to be a success. In addition, they believe it is essential to include the FM team at the very start of the project to get clear understanding of deliverables. This can be a challenge for the REIT clients who are building from the ground up or taking over a new building and there is no FM team in place.

During one of their early BIM lead projects one Contractor observed that the appointment of a knowledgeable 'champion', who had experience in the application of various new processes and software was essential to guide other team members. If everyone is learning at the same time then efficiency is compromised.

All Contractors noted that, specific to fit-out projects, the availability of a base build model or a model generated from a 3D scan of the existing space is essential to achieve the benefits of BIM. It was observed that there can be legal issues in ownership of the base-build model which can hinder the transfer from 'base-build' to 'fit-out' as discussed above.

It was highlighted during discussions that clarity in the BIM Protocol was essential for all parties. Clear, unambiguous, language was necessary particularly with regards Model Information Delivery Template (MIDT), Level of Detail (LOD) and Responsibility Matrix (RM) to ensure that each party to the collaborative effort was aligned in expectations of deliverables.

Various Contractor had experience working on projects with a LEED requirement however it was observed that the greatest impact of LEED is generally assessed prior to contractor involvement. This was due to the contracting model whereby the contractors were only brought onboard after competitive tender and therefore the contractors ability to impact the LEED scoring was limited. The contractors did note however that the BIM model was utilised to calculate operational energy requirements for the LEED assessment and therefore had a direct interaction with this process.

It was observed by all Contractors that Soft Landings / Post Occupancy Evaluation (POE) have not been applied on any contracts to date. Typically the contractors operated to a standard defects liability process whereby 'snags' or 'defects' arising post-contract over a specific period were addressed, however no document POE process was followed. It was discussed that, should this be implemented, clarity on the specific requirements of a POE period, and the responsibilities during the period, were necessary to ensure these aspects are included in contracts at procurement stage.

iii.The Consultant View

Four consultants covering Architectural, MEP and FM services, were interviewed and their views recorded.

In general, the Consultants were implementing BIM when requested specifically by Clients.

Some consultants, particularly in the architectural fields, were working in 3D software, as a small aspect of BIM, however this was to aid their workflow and client presentation ability and the benefits of collaboration were not being exploited.

The reasons for the slow uptake of BIM was blamed on the lack of cross industry skills hampering the efficiency of BIM deployment at the moment and increasing cost and time to produce first designs, although all participants observed that they believed they would start to utilise a more 'full' BIM process in the foreseeable future.

XI. CONCLUSIONS

As discussed above, the coordinated deployment of BIM and Lean construction methods, with integrated energy, environmental and wellness measures is very viable and is indeed recommended.

In line with observations made by interviewed contributors to this paper CIRIA [21] outline Lean and BIM (and Green, by extension of the links to green assessments discussed in this paper) adoption strategies with important points noted as:

- Appointing a top-level champion – the pull for this implementation, at this time, is driven by the Client body most often
- Take the people and process view and select technologies to support them – there is no 'one size fits all' approach
- Start with a pilot project
- Develop an integrated process flow – existing processes need to be adapted to accommodate BIM and Lean – this may in itself generate efficiencies
- Take a life cycle view – maximum benefits can be obtained when taking a 'inception-to-extinction' view of the project.

Published research to date supports this approach from a theoretical perspective on projects in general and industry feedback from practical application indicates that Lean Green BIM processes would improve the efficiency and effectiveness of office fit-out projects.

Furthermore, from the published data, research carried out for this paper and with acknowledgement of the ongoing impact of climate change to the world environment it is evident that construction industry can play an important part in limiting the impact on the environment from real estate activities.

Reducing the environmental impact of real estate projects can be achieved by : the application of BIM processes, which add clarity on the programme, cost and asset data for a building; Lean delivery, which reduces waste in process and materials and Green Wellness initiatives which simultaneously limit the impact of a real estate project on the environment whilst improving the user wellness.

i. Recommendations

From the theoretical and industry research carried out, it is clear that the application of BIM, Lean and Green initiatives across the construction industry, and specifically for office fit-out projects, has benefits to all parties in the process at each stage in the process, in terms of efficiencies of operations, whilst also reducing environmental impact.

Applying Lean, Green or BIM initiatives individually show demonstratable benefits however a coordinated application of these processes in parallel generates the most efficiency improvements and it is the recommendation of this paper that all office fit-out projects are processed in this manner.

ii.Further Research

During the research and production of this paper it has become clear that there is a wealth of theoretical research addressing BIM, Green and Lean initiatives individually or in pairs however there is little published research on the application of these in triplicate.

Further research is recommended, perhaps via case studies and pilot projects, on the application of Lean, Green, BIM on office fit-out projects to identify process efficiencies.

Additionally, there is little published data on the application of Internet-of-Things solutions in office spaces to benefit the users from a wellness perspective, or the owners from an operation perspective or the application of data to support Post-Occupancy-Evaluations. These aspects would benefit from further research.

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Using Technology as a means of Verifying the Positioning of Cavity Barriers in a Building Wall Envelope

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Abstract - Addressing the well publicised build quality issues within the construction sector is arguably the greatest challenge facing the industry at present. Issues can arise from a lack of proper on-site inspection leading to inadequate workmanship detailing along with substitution of materials from those originally specified at the technical design stage. Whilst such deviances from original technical design intent can have negative consequences in relation to building performance, such as a reduction in thermal and acoustic properties, this pails into insignificance compared to potential life safety issues. One of the most obvious threats to life safety within a building is fire, and the identified areas of workmanship, detailing and inspection are critically important in ensuring sound details are constructed, none more so than in ventilated facades. Ventilated façade systems have become popular over recent years due to the range of colours, styles and profiles which allow most aesthetical intentions to be realised. This, coupled with the general robust performance and ease of construction, means they are a popular choice for contemporary buildings and in retrofitting projects. However, with ventilated facades, like with any envelope, there is the potential for passive fire protection issues, with the performance in a fire dependent on the workmanship detailing, especially with regards to cavity barriers, and the materials used during the constriction. This becomes critical in light of reported issues relating to fire safety inspection. This paper focuses on verifying the positioning of cavity barriers in ventilated facades. The research firstly triangulates the stated issues relating to quality via a focus group discussion with industry professionals, with a focus on fire safety, before the potential for a technological solution is presented in the form of a clash detection analysis using captured point cloud data of in-progress construction work linked to a project BIM. The conclusion suggests that technological interventions have the potential to assist inspectors in more robustly verifying positioning in relation to fire safety, whilst acknowledging that this is only one component of a verification workflow which must also include material and detail verification.

Keywords - Digital Technology, Verification, Inspection

I HISTORICAL PRECEDENT & INDUSTRY SHIFT

Knaack *et al.* [1] outline that the wall and façade makeups we are familiar with today are a result of a lengthy process of development. Traditional methods of building enclosure for walls made use of materials such as brick and stone. However, the use of such materials along with solid or cavity wall construction methods were not realistic for buildings of larger scale due to the sheer amount of materials needed to achieve adequate wall depths for structural stability. This resulted in the need for alternative construction techniques for taller buildings, leading to the development of more advanced façade systems. Depending on individual ideology, the façade can either be viewed upon in practical terms, as a necessity to achieve the performance requirements in a building, or as an art form [2] [3].

With a growing recognition of the importance of building performance [4], a demand for increased efficiencies in façade design has occurred [5], with the purpose of a façade primarily for architectural expression becoming discredited. This has possibly been influenced by the emergence of the Architectural Technology profession with professionals providing a more analytical approach to the design process governing material selection, detailing and technical performance, coinciding with regulatory requirements which place an increased focus on aspects such as acoustics, thermal performance and life safety. Modern façade systems offer a way for older buildings to upgrade their overall performance in line with regulatory requirements via retrofitting. This is becoming a necessity considering the assertion that 97% of the European Union building stock requires upgrading [6]. A 2003 study discussing the UK perspective highlighted issues with tower blocks built during the early 1960s such as thermal bridging and water ingress resulting from poor quality materials, workmanship, supervision and inadequate services. It was foreseen that such issues could potentially be remedied by "adopting 'high tech' components involving composite cladding methods" [7]. One of the most common systems in both new and retrofit situations is the ventilated rainscreen, comprising of an outer cladding material, behind which is an air gap, insulation and fixings [8] with additional materials such as cavity barriers also placed. With the rise in popularity and comprehensive use of such systems, proper construction is essential in not only ensuring the performance improvements are realised, but more importantly, in ensuring that life safety is not compromised.

II Life Safety & Ventilated Rainscreen Systems

The greatest life safety consideration in buildings is undoubtedly fire. Despite periodic revision of the legislation there persists a continued reliance on visual inspection to ensure compliance is achieved on-site. This is not only logistically difficult on large projects, but brings with it the risk of human error. Concerns have been raised in relation to compartmentation, especially in concealed spaces and in terms of inspection of fire barriers [9]. Ventilated rainscreen systems introduce concealed spaces and thus passive fire protection must be considered. Ventilated rainscreen systems have become popular over recent years due to the range of colours, styles and profiles which allow most aesthetical intentions to be realised. This, coupled with the general robust performance and ease of construction, means they are a popular choice for contemporary buildings and in retrofitting projects. However, like with any wall envelope, there is the potential for issues in relation to passive fire protection, with the performance in a fire dependent on workmanship detailing, especially with regards to cavity barriers, and the materials used during the construction.

Ventilated rainscreen systems rely on passive fire protection measures, the first stage of which is "*slowing down the development of a fire and its rapid spread by using construction materials with low flammability and combustibility*" [10]. The building regulations throughout the UK require cavity barriers to be installed for buildings in all purpose groups with concealed spaces. Such cavity barriers are required to be placed at regular intervals both vertically and horizontally to provide compartmentation and around openings in the wall envelope. Littlewood *et al*. [9] citing the work of others (Shipp *et al*. 2015; Shipp *et al*. 2016; Littlewood & Smallwood, 2015; Gorse *et al*. 2016) outline that compartmentation can be affected by defects in construction detailing. It has been suggested that key technical details and materials can be changed during construction [11], this could potentially lead to inappropriate construction materials or detail makeups being used for fire-protection. Littlewood *et al*. [9] conducted a study with Fire and Rescue Service professionals which found the vast majority of respondents experienced difficulty in assessing the effectiveness of building compartmentation as part of fire risk audits and assessments. The study stated:

> *"When asked about inspection of fire and smoke barriers in concealed spaces in buildings, 25% of respondents never inspect concealed spaces while 63% inspect the concealed spaces. Among all the respondents who inspect the concealed spaces, the majority rely on limited non-intrusive visual inspection alone..."*

The serious implications of less than optimum passive fire protection measures have been demonstrated in cases such as the Knowlesy Heights fire, where defects or the absence of fire barriers contributed to fire spread [12]. More recent investigations have illustrated the need for a focus to be placed on on-site cavity barrier detailing due to the potential for installation issues [13, 14, 15 & 16]. The Hackitt Report made reference to the regulatory system and the need for change to better ensure fire safety: *"The current regulatory system for ensuring fire safety in high-rise and complex buildings is not fit for purpose"*. The same report also called for a *"golden thread"* to ensure *"the original design intent, and any subsequent changes or refurbishment, are recorded and properly reviewed, along with regular reviews of overall building integrity"*. Such a process would help ensure that there would not be, what Littlewood *et al*. [9] describes as, "*inadequate transfer of construction details from Architect/Design team to Building Contractor's site operative*."

In aiming to realise this ambition the potential for technological solutions must be investigated. The current digital transformation within the construction sector means there is potential for technology to be applied in helping to devise a more rigorous inspection and verification process. Project Verify, a research project at Ulster University, is investigating the potential for data collection technologies to potentially link to the BIM workflow for the purposes of closing the identified quality gap. It is focusing on ventilated rainscreen details and aiming to use data collection technologies for the purposes of verification of on-site materials, their positioning and aspects of workmanship detailing. The work to date would suggest that no one technology will serve as a panacea, but rather, a combined technological approach, aligning with the suggestions of O'Kane *et al*. [17] may be required. The alignment of the findings of [9] with the work being undertaken at Ulster University would suggest that there is merit in evaluating if a technological workflow could be applied to ensure a more robust approach to inspection of passive fire protection measures.

III The Changing Construction Site Environment

The realisation of the BIM mandate which was published in the 2011 Government Construction Strategy [18] has contributed to an increased use of digital technologies on construction sites. It is routine to now witness individuals with tablet devices on-site, using these to interrogate models and commission installed components. Indeed, things are moving at pace, with technological advances facilitating faster site inductions and allowing for safer working environments. A project which is embracing such technological change is the new build Southern Regional College (SRC) Campus located in Armagh, Northern Ireland (Fig 1).

Fig. 1: Project Building Information Model for the SRC Campus

The main contractor on the SRC Campus project, Felix O'Hare & Co Ltd, have been proactive in their use of technology to both inform decision making and the overall build progress. They have recognised that specific roles, such as a Head of Digital Construction and Site BIM Implementation Coordinator, are required to assist with technology driven culture change and implementation, with the latter a type of soft landing for site personnel. They have implemented the use of SignOnSite [19] to apply technologically driven management of safety and have worked closely with their design team in the development of the project BIM, using this to manage on site operations in conjunction with the Dalux suite of applications [20]. This has seen numerous benefits, some of which include assigning digital snag lists to sub-contractors who can instantly access these via their mobile device along with the most up to date model ensuring unbroken information flow and enhancing coordination. Other technological implementations include the use of total stations by the main contractor to aid setting out, using points taken from the federated model. Regular laser scans have also been taken to check accuracy and to benchmark progress against the project BIM (Fig. 2).

Fig. 2: Use of technology on the SRC Campus

In addition, virtual and augmented reality tools are being utilized to aid the end user understanding and indeed enhancing the clarity and understanding for the main contracting team. The use of laser scanning is now becoming common practice amongst larger contractors to validate the presence and correct location of major construction elements such as beams and columns.

A review of literature would suggest a lack of focus on the use of this technology as a means of checking positioning of vital minor components on site, minor in terms of scale as opposed to importance, which make up intricate and critical construction details and have a profound impact on life safety. This paper aims to triangulate the issues relating to construction quality issues before the potential for a technological solution is presented in the form of a clash detection analysis using captured point cloud data of in-progress construction work linked to a project BIM.

IV Research Methodology & Data Analysis

This mixed method study [21] is an example of real-world research, identifying and focusing on a specific issue within the construction sector with the aim of finding a potential solution. This aligns with the definition of Sekaran & Bougie (2013) cited in [22] who define research in the real world as being a "*systematic and organized effort to investigate a specific problem that needs a solution*".

A qualitative approach will be used in the form of a focus group [23], to gain insights from industry professionals on matters relating to fire safety and the potential for technological interventions relating to inspection. The focus group participants were purposively selected due to their knowledge and experience in the area under investigation. Using a focus group allows participants to "*explore and clarify their views in ways that would be less easily accessible in a one to one interview*" [24]. NVivo software was used to assist with the analysis of the focus group transcripts [25]. In addition, data will be gathered and analysed by trialing the use of a remote sensing technology, aligned to a project BIM, for the purposes of determining positioning of as-constructed cavity barriers. The Toulmin model of argument [26] will be employed to analyse the solution presented. Ethical approval was sought and obtained for the study.

V Professional Insight & Analysis

A focus group discussion took place with five industry professionals, all building control surveyors, and focused on aspects relating to passive fire protection and inspection processes. It should be noted that only the summarised key findings are presented in this paper. The dialogue led to agreement in relation to visual inspection not being conducive to ensuring correct location of components and specification of materials. A strong emphasis was placed on building control surveyors only seeing a 'snapshot' in time and cannot be relied upon to inspect every element of the building fabric. Participants referred to situations where materials are not specified by designers, such as in performance based specifications. It was highlighted that in some instances it is left up to the contractor to decide on material selection during the project. Hence, such decisions are potentially taken by individuals not suitably qualified or who are unaware of the potential ramifications. It was stated that whilst material substitution was not uncommon, it was less frequent on large projects. There was a feeling that contractors sometimes see it as their duty to cut costs and, in certain scenarios, will deviate from approved plans if they find a 'similar' product at a reduced cost. The conversations suggested that material verification can be an issue in certain circumstances, especially when numerous components go into a complex detail makeup. Sometimes checking the integrity of the detail in relation to product defects or gaps is the only viable means of inspection given time and other constraints.

It was highlighted that third party accreditation of cavity barriers on external wall facades was being offered by some distributers where companies visually inspect sub-contractors installation and provide certification. Additional discussions suggested that on-site workmanship can be problematic with tradesmen under minimal supervision and sometimes unaware as to why specific components, critical to detail integrity and life safety, require exact installation as per manufacturers specification. The need for a competent clerk of works, someone providing non-biased inspections and not accountable to the contractor, was outlined. However, there was a realisation that this may only gain traction if it became a legislative requirement due to incurred costs.

Conversations focused on the regulatory system being unable to guarantee that a building being inspected is safe in all aspects of construction and the realisation that designers sometimes 'use' the plan assessment process as a checklist as opposed to designing for compliance. It was made evident that the potential for a technological approach to assist with verification of on-site detailing would be welcomed, but it was unclear as to what would be required to drive such a process due to the constant focus on reducing costs. A transcript of the full focus group dialogue was entered into NVivo and a word cloud generated of the frequently occurring words in the data (Fig. 3).

Fig. 3: A word cloud of frequently occurring words generated by NVivo

VI Material Positioning

The review of literature highlighted the critical nature of cavity barriers in containing fire spread in addition to issues with their inspection. This, coupled with the potential benefit of a technological means of assisting inspection, led to the following aims for the stage two case study. To develop a technological workflow to:

(1) Automate the process of detecting the presence of cavity barriers during on-site operations

(2) Capture the exact positioning of the cavity barrier prior to envelope closure, assisting with robust asset information model development

The remote sensing technology selected for investigation was laser scanning with the new build SRC project used as a hypothetical case study. It should be noted that this study was not inspecting the veracity of the work on this project. Primary data was collected by visiting the site and conducting a laser scan using the Leica RTC360 3D Laser Scanner [27] on the front façade (Fig. 4).

Fig. 4: Front façade of the SRC Project under construction

The captured scan was firstly imported into Autodesk Recap and registered before being exported into Revit. The quality of the front elevation scan was ideal for this project, with a close up view demonstrating the ability to identify the cavity barrier positioning (Fig. 5).

Fig. 5: Horizontal cavity barrier displayed in Recap

For the purpose of the experiment, the proposed cavity barrier positions were identified from the two-dimensional technical drawings and added to the Revit model as components (Fig. 6). This allowed for the point cloud and project BIM to be overlaid to check positioning (Fig. 7).

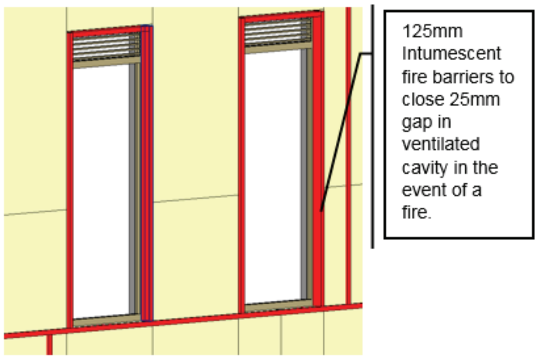

Fig. 6: Revit Model

Fig. 7: Imported Point Cloud

This not only allowed for checking if any cavity barriers were missing, but provided a means to record exact positioning of cavity barriers for robust asset information capture. For this study only a visual comparison was made between the Point Cloud data and the Revit model as seen in Fig 8. However, it is evident that positioning of fire barriers can be confirmed via this process, with the potential for automation via the use of clash detection.

Fig. 8: Imported Point Cloud & Revit Model

VII Discussion & Conclusion

The claim of inadequacies relating to visual inspection of passive fire protection for life safety has been corroborated by the review of literature and the findings of the focus group. The findings suggest that the current means of visual inspection, whether it be from a regulatory body or third-party accreditor, is not adequate for ensuring the in-built performance of fire safety measures. Therefore, there is a need for increased supervision on construction sites or others means which can verify the veracity on constructed details.

Such failings have serious implications, as, in the event of a fire, missing, damaged or use of the incorrect type of cavity barrier, not flagged by inspectors, can undermine the passive fire strategy leading to the spread of smoke and flame outside of the designed compartment. The building regulations and inspection processes are in place to help ensure life safety in built assets, with guidance provided on both active and passive fire measures. It is important that adequate regulation is followed by robust inspection processes to ensure on-site compliance and protect building occupants. Littlewood *et al*. [9] called for non-intrusive and non-destructive test methods for assessing passive fire protection. A testing method as identified in this study could seamlessly align with and contribute to the BIM process for the purposes of validating and verifying Asset Information Models for facilities management purposes. Whilst inspection to verify correct placement of cavity barriers alone will not act as a panacea, it is a key component in the overall strategy. The 'threat' alone of using such technological processes may also be sufficient to discourage the practice of altering or changing details on site as reported in [17]. With the fast paced technological advancements evident in the construction sector it could be an ideal time to promote and utilize digital technologies and processes to help improve construction quality.

Construction failings could in part be due to procurement practices which place less of an emphasis on quality, certainly in comparison to time and cost, Bowen *et al*. [28] citing Bennett and Grice, 1990. This is evident from the focus group findings presented in this study which highlighted the possibility of contractors reducing construction costs without giving holistic consideration to key construction details potentially impacting on life safety. Broadly it could be an indication that the construction sector fails to recognise itself as a service industry delivering products to end users.
As outlined by Hackitt (2017), "*The focus must shift from achieving lowest cost to providing buildings which are safe and fit for people to live in for years to come*."

Whilst the potential for using a remote sensing technology to verify the position of cavity barriers in a project BIM has been identified, this is only one part of the equation as the verification procedure against a project BIM is reliant upon the model being developed to a level of detail in which components such as fire barriers are modelled. Presently the level of model development varies greatly in projects. Future research projects which investigate this area and the extent to which such components are currently modelled and the level of detail stipulated in Employer Information Requirement documents would be valuable. Other practicalities would need to be considered such as the most appropriate method of capturing data on wall envelopes under construction but concealed behind protective sheeting on-site.

This paper could be considered as an early stage scoping study, hence the recommendations presented should be considered in this context. However, it highlights an area worthy of further investigation. The findings suggest there is a need for on-site verification of critical details from a life safety perspective, with technological approaches potentially playing a significant part in future implementation. It is evident that there is a lack of communication between designers, contractors and inspectors. Whilst technological intervention won't necessarily fix the communication void, the use of remote sensing technologies linked to a project BIM has shown potential in verifying positioning of critical components. The findings from the focus group would suggest that real change requires legislation to enforce a new regulatory system which embraces digital approaches and aligns with the BIM Level 2 process. This is required to ensure important life safety aspects of buildings and other performance related details are constructed as per designers' intentions.

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What is a BIM design model?

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Abstract– The recent report into Building Information Management or BIM, by construction law experts May Winfield and Sarah Rock [1] gives reason to state that the UK architectural, engineering and construction industry or AEC, is hindered by the absence of a clear definition of Level 2 BIM. The ISO 19650-2 standard published in 2019 is based upon the PAS 1192-2:2013. The purpose of ISO 19650-2 is to provide a roadmap to facilitate the standardisation of BIM process in a uniformed fashion. A key pillar of ISO 19650 is the "information cycle" and central to this is a federated set of design intent models, commonly referred to as the design model. The design model underpins the Level 2 BIM process, however different interpretations by BIM practitioners impact the collaborative process, leading to disagreement and conflict. This paper will research the design model, focusing on design-bid-build or "traditional" projects, where the main contractor is required to develop the design model into a project information model or PIM. With the publication of the ISO 19650 standard, the AEC industry is obliged to abandon the familiarity of the PAS 1192 suite of documents. However, as was the case with the PAS 1192 suite, the new ISO 19650 standards are not intended to, and do not, provide a definitive definition of Level 2 BIM or the design model. Using a mixed methodology, this paper investigates the design model from the perspectives of different AEC stakeholders. A selection of engaged professionals participated in an online survey followed by interviews with a selection of the survey respondents. The interview findings were triangulated with a comprehensive literature review and the online survey results. These are discussed and the paper concludes with valuable insights into BIM in the Irish AEC industry at a time of transition.

Keywords – BIM, Procurement, BIM Process

I INTRODUCTION

The official launch of Ireland's National BIM Council [2] was followed by the publication of the Public Sector BIM Adoption Strategy by the Government Contracts Committee for Construction (GCCC) [3] and the Roadmap to Digital Transition [4]. According to [3], several reports across the EU identify systemic issues in the construction process relating to its levels of collaboration, under-investment in technology and R&D and poor information management. These issues result in poor value for public money and higher financial risk, due to unpredictable cost overruns, late delivery of public infrastructure and avoidable project changes. The recently published report into the escalation of costs at the new National Paediatric Hospital [5] (NPH) makes for sober reading and will, no doubt, be added to the GCCC's list of EU reports. A key component of [3] requires clients to issue a brief that concentrates on required performance and outcome. Montague, a leading BIM expert, believes that "the industry is willing to deliver this through BIM, but many on both the demand and supply sides still aren't able" [6].

The fundamental principles for Level 2 BIM were set out in the now withdrawn PAS 1192 suite of documents, developed in response to the UK government mandate [10]. According to Waterhouse, two years after the introduction of the mandate, the BIM adoption rates were not what the UK government expected. However, he did believe that "the results were still very encouraging, with close to 50% of the industry following PAS 1192-2:2013" [11].

Around the same time in 2016, a national survey in Ireland [12] revealed 55% of organisations were using PAS 1192-2:2013. This suggests that adoption rates of PAS 1192-2:2013 in Ireland exceeded those in the UK in 2016.

The new ISO 19650-2 standard is founded on the now withdrawn publically available standard, PAS 1192-2: 2013 [13]. The "information delivery cycle" is an intrinsic part of ISO 19650-2 – as it was in PAS 1192-2:2013. One of the overarching principles of ISO 19650-2 is that "the delivery of information is progressively delivered by the delivery teams" [14]. This takes the form of a federation of design intent models, commonly referred to as the "design model". PAS 1192-2:2013 requires lean principles, which creates more value, with fewer resources, to be applied where possible [10]. Appointed parties are enabled to produce information in an effective and efficient manner by using ISO 19650-2. The "information model is progressed by subsequent delivery teams for each appointment" [15], typically at design followed by construction stages. This is where the modelling and the management aspects of information converge.

However, there appears to be a contradiction between the results of the most recent surveys [4, 16] and the number of BIM models being issued at tender stage. In [16], researchers Hore, McAuley and West reference a number of recent construction projects, to emphasise the level of BIM uptake in Ireland. Closer examination of a number of projects by the authors, of this paper revealed that several were executed by the same Tier 1 contractor. This prompted the researchers to question the purpose of a design model. Figure 20 on page five of [10], defines a design model at design stage as "A dimensionally correct and co-ordinated model …". The problem is it goes on to state what it "can" be used for. The difficulty is that the scope or model content cannot and is not defined, as this would be impractical. This is where the responsibility matrix becomes so important. This paper examines the practicality of the information delivery cycle from the perspectives of different industry stakeholders and attempts to answer the question if design models are not being issued at tender stage and, if not, why?

II LITERATURE REVIEW

a) *Terminology*

BIM terminology has troubled the industry since Morrell (2011), then the UK's chief construction adviser, recommended that, by April 2016, public policy be based on the use of Level 2 BIM. He warned the industry to keep the complexities of BIM to themselves and not to burden clients with it. Seven years later, Saxon [17] suggests that the industry did not take the warning seriously, stating that the BIM Task Group of 2011 "created a special language for users making the whole subject arcane and opaque to industry outsiders, which includes most clients".

Leading construction lawyers Winfield and Rock [1] provide clear evidence of the pervasiveness of the BIM terminology problem. When asked for their definition of Level 2 BIM, 44 of the UK industry's leading BIM experts each gave a different response. The significance of this was not lost on the authors, who stated, "This goes to the core of industry problems in enabling BIM on projects. It is clear that this contrary perspective and engagement affects how BIM is viewed and therefore defined." [1]

The UK's BIM ambassador for growth, Saxon [17] recommends sticking to the familiar language that had been used by clients, consultants and constructors for decades. Sura suggests a problem with using natural language, maintaining that "it introduces a level of vagueness to communication, a common feature in the area of construction, with or without BIM" [19].

In replacing the PAS1192:2 suite with the ISO 19650-2, the International Standards Organisation (ISO) potentially introduces new barriers by changing the existing and introducing new terminology. Shillcock [18] believes agreement is unlikely, stating that it is no wonder that the ISO committee had to resort to country-specific annexes to clarify language, when they could not agree common terminology between jurisdictions [21].

Rossiter [20], the European and International Standards convenor for BIM terminology, poses the question in "how can we expect to share these new developments if no one understands a word we're saying?"

The solution, according to Saxon, is for clients to invest in their capability to instruct their design team and constructors, to be able to define their requirements contractually [17].

b) *Information requirements*

The terminology in ISO 19650 changes from the PAS 1192-2 document, the term employer is no longer employed, it is replaced by appointing party. Hence the employers information requirements (EIR) become the project information requirements (PIR).

The EIR document is crucial to the BIM process. Developed by the client, it forms part of the appointment. Mordue, Swaddle and Philp [21] note "the EIR is used to describe precisely what models the client requires and what the purpose of those models will be".

c) *The integrity of the design model*

Lockley [22] questions the integrity of the information delivery process stating, "as the uptake of BIM begins to impact, leading-edge organisations have begun to understand the benefits and problems that BIM technologies add to this information exchange arena". Eastman et al. [23] have pointed out that the traditional approach presents the greatest challenge to the use of BIM for the contractor, "because they do not participate in the design process and thus must build a new model after the design is completed".

This reinforces Lockley's examination of design teams' practices stating, "Many have realised that exchanging native models can dramatically increase productivity and efficiency. Others have realised that these models may contain information that they are completely unaware of, and which could invite claims against them". [22] He continues: "some organisations go so far as to develop processes that automate the removal of most data from their models, just in case it may lead to litigation".

d) *The client dilemma*

Eastman et al. [23] point out the dilemma for the client's design team, where "The final design must be coordinated and outputs must contain sufficient detail to facilitate the preparation of a construction bid" and at the same time eliminate liability for construction issues by taking the approach they are only providing design intent. Lockley [22] maintains "Because of potential liability, an architect may choose to include fewer details in the drawings or insert language indicating that the drawings cannot be relied on for dimensional accuracy". Eastman et al. [23] "consider such practices – based strictly on design intent – to be inherently inefficient and irresponsible to clients".
Deeney, Hore, and McAuley in [24], state that the very nature of the Irish construction industry is one of adversities among its stakeholders, where information is closely guarded and knowledge is seen as power. They note that this is an environment where "the less information the contractor has the lesser the opportunity for them to come at you". Kane et al. [25] agree that the client is challenged with this confrontational behaviour, noting that if the potential of BIM is to be realised on a project, "this behaviour must end, as open collaboration among project teams is fundamental to the core understanding of the overall BIM solution for the industry". [30].

Jensen [26] notes, "there is virtually no case law to guide parties should disputes arise". It is worth nothing however that the most recent National Building Specification (NBS) national survey [27], identified model ownership has begun to appear as a key issue in disputes.

Holzer [28], believes that part of the problem resides with the client, stating "Without declared and realistic BIM objectives, project teams usually tap away in the dark as they second-guess the client's requirements". He goes on: "The dilemma for the client is where to turn for guidance". Winfield and Rock [1] recognize that the legal and contractual matters of BIM are in a state of flux and development, noting lawyers cannot engineer their client's instructions; they are limited by the scope of instruction regarding BIM.

e) *The projector integrator*

Sawhney, Khanzode and Tiwari (2017) believe that clients require independent assistance, stating that, "there needs to be an external role of Project Integrator" suggesting that the Royal Institute of Chartered Surveyors should rise to the challenge [29].

Morrell [30], believes that the UK construction industry is challenged to identify the party that should take on the role of "integrator". He suggests that "the natural candidates should be tier one contractors, but the fear is that they've become so used to grinding their margin out of either their customers or their supply chain and that managing margin has now become their core business ... The challenges of developing an integrated proposition for a client, for which they might be held accountable, lacks appeal".

f) *BIM mandate*

Montague [6] believes that, if directly asked, and correctly incentivised, industry would acquire the skills and deliver, but too many people in industry are not being asked. A possible reason that the Irish government has been slow to introduce any form of BIM mandate is that until recently, construction inflation was not only low - for a number of years it was negative [12]. The lack of a mandate is the most likely cause for there being no BIM-friendly public forms of contract. As noted by Deegan [32], firms offering BIM services in Ireland possess no reference documents or standards. However this has now changed somewhat, with the publication of ISO 19650-2:2018 which was published as an Irish standard IS EN 19650-2: 2018 which came into effect simultaneously

III METHODOLOGY AND RESEARCH METHODS

The research question developed from the authors' experience of BIM implementation in the Irish AEC industry. The hypothesis was that BIM implementation is currently not as advanced nor as widespread as suggested in published reports, media publications and at conferences held by the industry. The most suitable research methodology identified, was to employ a sequential mixed research approach to a large population sample, followed by a detailed examination of the subject through interviews.

An extensive literature review was undertaken to develop two set of questions, one for an online survey and one for the interviews. The online survey was issued to 100 members of the AEC industry, with 40 responses. Semi-structured interviews were then held with eight engaged professionals, using a semi-structured interview approach and a series of open-ended questions.

Discipline	Yes	No
Client	0 %	80 %
Design	61 %	39 %
BIM Consultant	27 %	63 %
Contractor	18 %	82 %

IV ONLINE SURVEY FINDINGS

a) Introduction

Survey respondents were guided on a series of questions, depending on the role they selected. The questions were presented in both open and closed formats. The closed questions allowed some statistical analysis while the open questions allowed respondents an opportunity for free expression.

The survey questions focused on the recently withdrawn PAS 1192-2:2013 and the new ISO 19650-2:2019 standards.

The disciplines surveyed, are illustrated in Fig. 1. Over 70% of respondents stated that they had more than five years' experience.

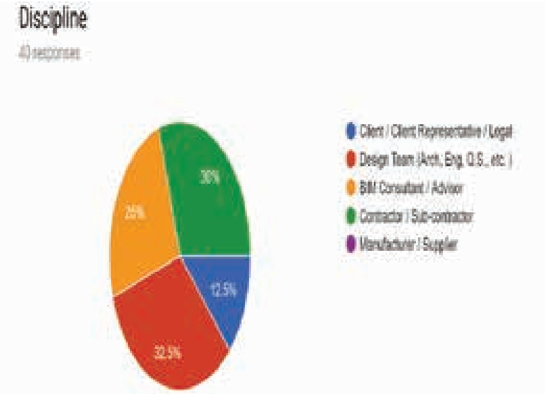

Figure 1: Breakdown of disciplines surveyed

b) Knowledge of BIM

Respondents subjectively attribute their own level of BIM expertise. The proportion of discipline representatives who self-evaluated as having expert status' are detailed in Table 1. One respondent noted that, "there are no experts only people who want to believe they are".

Discipline	Expert Status
Client	20%
Design	33%
BIM Consultant	100%
Contractor	20%

Table 1: Discipline indicating expert status

c) Definition of the design model

The interviewees were asked if they believed PAS 1192-2:2013 adequately defined the design intent model. The results are presented in Table 2. 62% of respondents believed that PAS 1192-2:2013 did not adequately define the design intent model.

Table 2: Definition of design model in PAS 1192-2

When queried about how they would define the design model, there were 33 different responses from 40 respondents.

d) Drivers of BIM Mandate

The clients indicated that they or the contractor were more likely to drive BIM on projects, see Fig. 2. The BIM consultants, however, indicated that the clients' was least likely to drive the BIM mandate on their projects.

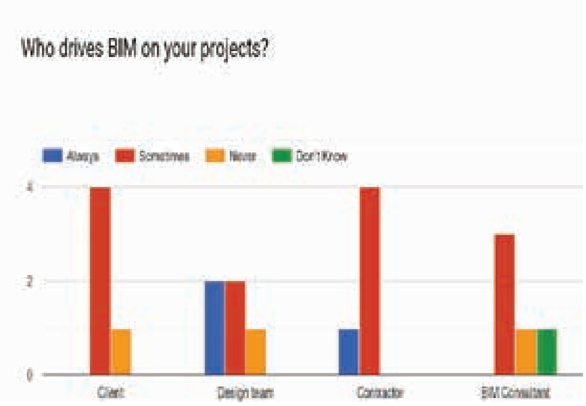

Figure 2: Who drives BIM on your projects (client's response

e) Understanding of BIM terminology

The survey queried the understanding of BIM terminology. The design teams and the BIM consultants had high confidence levels; the clients and contractors' confidence levels were much lower, with 60% of clients identifying themselves as only "familiar". The majority of design teams and BIM consultants claimed they fully understood BIM terminology. Notably both disciplines had occasional to frequent disagreement with the contractor in regard to terminology; which is understandable considering the design teams believed that fewer than 25% of contractors fully understood the terminology, refer to Fig. 3. The BIM consultants, believed only 10% of contractors fully understood BIM terminology.

Respondents used a variety of sources for explanations of BIM terminology, with the majority referencing both ISO 19650-2 and PAS 1192-2:2013 standards. Only one respondent referenced the BIM Dictionary [34].

When queried about disputes related to BIM terminology, over half identified the term LOD (a synonym for multiple terms) as a factor.

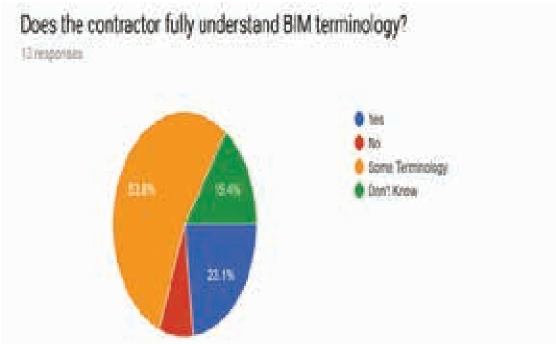

Figure 3: Does the contractor fully understand BIM terminology? (client's response)

f) *The EIR*

Two thirds of the design teams stated that they had only some or little input into the EIR, see Fig. 4. While 80% of BIM consultants had some input, over half reported that they provided considerable input: "It depends on our role. If appointed by the client, we would have a lot of input. If we are appointed by the Main Contractor, our role would shift to understanding the EIR and developing the BIM Execution Plan (BEP) based on this information." One respondent said, "Most EIRs are generated by the design team and not the client – this is gradually changing though".

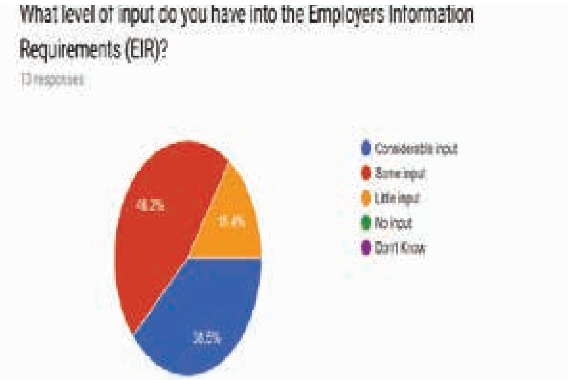

Figure 4: What level of input do you have into the employer's information requirements document (design team response)

g) *Design responsibility matrix*

The design team almost exclusively agreed that the design responsibility matrix should be developed at concept or brief stage. Over 60% of design team respondents stated that they used a bespoke design responsibility matrix; refer to Fig. 5.

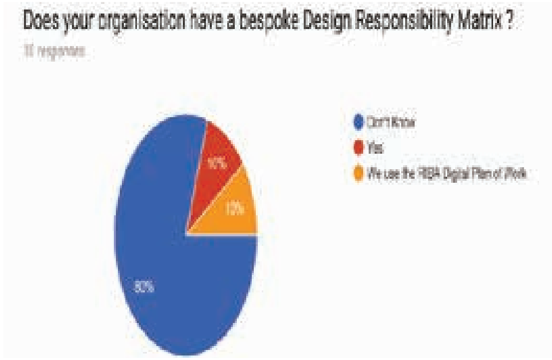

Figure 5: Does your organisation have a bespoke design responsibility matrix (design team response)

Only 20% of BIM consultant's indicated that their organisation used a bespoke design responsibility matrix (DRM); refer to Fig. 6.

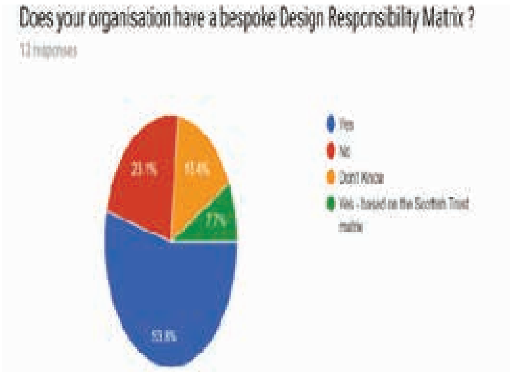

Figure 6: Does your organisation have a bespoke design responsibility matrix (BIM consultant's response)

V Interview Findings

a) *Format of Interview*

An informal semi-structured interview technique allowed discussions to develop with flexibility to follow any emerging threads, and closer examination of topics as they arose.

A selection of responses are documented below, with respondents identified by R1, R2, etc.

b) *Responses*

The responses from some of the interviews highlighted that a number of Level 2 BIM projects were operating very successfully, having been established following the principles of PAS 1192-2:2013. In these projects "the clients clearly set out what is required, with definitions, they have a clear list of what they expect, the contractors fill in the BIM capability forms, and the BEP, they provide a model production delivery table (MPDT), and a responsibility matrix ... These projects are great, but they are rare".

R1 noted, “There are a number of projects out there, with BIM teams that really know what they are doing. These are usually the bigger consultants, where the protocol is issued, and contract is signed, and where the MPDT is developed, reviewed and agreed as part of the contract agreement”.

However, the majority of comments were less than positive about the success of BIM on projects. The reasons for this varied, with the PAS standard coming in for some criticism.

c) The design model definition

R1 believed that there is a definition of the design model in PAS 1192-2:2013, suggesting that it was open to interpretation “I would say that maybe there is a lack of understanding of the definition. This doesn’t change the problem that either a lack of a definition or a lack of understanding of the definition is causing problems”.

R2 had a different opinion; “A lot of people will fall back on the PAS standard and say that this is what it says, that this is what we have to deliver, but the standard doesn't clearly define what has to be delivered in terms of the design model”.

d) *The employer information requirements (EIR)*

The general feeling in relation to the EIR was that “the quality of EIR documents from clients is poor, if they exist at all”. R3 pointed out “I have only been issued with one EIR in the last two and a half years, but I had developed over 20”. A number of the interviewees agreed that terminology was the cause of huge confusion and generating friction, particularly the term LOD.

R1 stated “the EIR is often left to the design team to write, resulting in an immediate lost opportunity to define the client’s requirements”.

e) *PAS 1192-2:2013*

The PAS 1192-2:2013 document came in for both positive and negative criticism from interviewees. Some believed that it was too open to interpretation; another considered that it was a good start, R6 stated that “PAS 1192-2 has more guidance notes than text”.

The general sentiment was that PAS1192-2 would continue to influence BIM in Ireland in the medium term, even if it has been replaced, and the suggested reason for this was that “the PAS document is widely in circulation and the ISO-19650-2 comes with a fee”.

The Royal Institute of Architects of Ireland (RIAI) recently released a set of guidance documents to PAS 1192 suite, known as the RIAI BIM pack. A highly regarded BIM expert R4, referring to the RIAI BIM pack, noted: “these documents are attempting to fill the gap between the standards and industry practice. There is still a need for a BG 6 type document for architecture and structure; that sets out how you technically develop that information”.

f) BEP

R7 speculated: “effort is only put into the BEP if it is going to be part of a technical submission, and then it’s only a box ticking exercise. This is because it is going to be scored against specific marking criteria”.

g) BIM Protocol

The Construction Industry Council’s (CIC) BIM Protocol [35] document was revised in 2018, some five years after the first edition. R8 suggested that if the protocol is to be used with the ISO 19650 suite, its language will need to change, as it is based upon the now superseded PAS 1192-2:2013 terminology.

One interviewee believed that the protocol document is frequently not issued at tender stage, noting “the construction industry council’s BIM protocol is the only document we have, but it is rarely issued”.

h) *MPDT*

The Responsibility Matrix (RM) or MPDT was discussed at some length with a number of interviewees. One interviewee believed that the MPDT “is the most important document stating what has to be delivered by whom, by when and to what detail”. Another interviewee stated that No Protocol, no MPDT, result: no clarity on who is responsible for delivering what information at each project stage. One other comment was that “the GC should submit comments on the MPDT at tender stage, that’s what agreements are about, but it very seldom happens ... this comes down to poor understanding of how stuff works.”

i) *ISO 19650-2 standard*

The ISO 19650-2 document was generally acknowledged as a high-level guidance document not intended to define the Level 2 BIM or the design model. It was generally acknowledged to have less detail than the PAS, yet was regarded as being as good a guide to the BIM process as the PAS 1192-2:2013.

R3 commented that ISO 19650-2 has to be generic; after all, it is an international document. R2 noted, “the standard is the standard, and that over time people will have to come up with their own documents to say this is what we deliver”.

j) *Barriers to issuing of the design model*

A number of issues were put forward as to why the design model is not issued at tender stage, some of which are listed below:-

R3 “All design team appointments are separate; all working to different understanding of what is required.”

R7 “One of the design team is only issuing schematics, usually the mechanical and electrical, so the design is not coordinated.”

R5 "That would be giving the contractor a stick to beat us with, it's the adversarial nature of the business, and GC will use the model to identify problems."

R4 "The form of contract favours lowest price, lowest bidder then comes looking for discrepancies in the design. Even if we have something in four different places, they will say the model did not show that, so we didn't allow for it."

R6 "Completing the design in such short time frames is a Herculean task, almost impossible to be fully coordinated, prefer not to issue it unless it is right."

R1 "Exposing ourselves to risk, when we do not need to, when it was not asked for by the client. This is all about not ending up in court one day."

R5 "The GC is required to produce a Construction Model and that is something that the GC does not understand. They expect that the design intent model will become the construction fabrication models through the design teams. They do not understand that they have a role to produce a means and methods model."

k) From the perspective of the GC

There are issues with the models issued, interviewees noted:-

R2 "No sheets and views are issued with the model, this is possibly because of intellectual property rights."

R6 "If the model is issued without sheets and views, you can't check it and if you can't check the model, then you simply can't trust it."

R7 "The model is useless, unless all the drawings are developed from it."

VI Discussion

The online survey recorded 33 different definitions of the design model from 40 individuals. These results clearly indicate a problem with the definition of the design model, as set out in PAS 1192-2:2013. These results are somewhat comparable to the Winfield and Rock findings of 44 different definitions for Level 2 BIM, when examining the legal and contractual barriers to BIM implementation.

This research set out to examine the barriers to collaboration on traditionally procured BIM projects which caused the design model to not be issued to the GC at tender stage. The concept behind the withdrawn PAS 1192-2:2013 standard and its replacement ISO 19650-2:2018 was and is the efficient use of information. Clients appear to be particularly disadvantaged by the terminology and BIM jargon The special language and terminology that early adopters developed. Clients cannot engage in a process if they do not know what people are talking about.

One of the difficulties of transitioning to ISO 19650-2 is that it is a high-level document, which is light on guidance. Moreover, unlike PAS 1192-2 it does not attempt to define the design model. However, one of the ISO standard's strengths is that it minimises the amount of terminology used.

The online survey indicated a lack of expertise within the client discipline. This manifests itself in a lack of rigour in the application of standards to BIM projects in Ireland. Another theme was the quality of designs expected in the time allowed. Releasing a design model at tender "as a coordinated model" was perceived as risky, unless the design was 100% complete. A particular risk was identified within the design team, if one of the team did not perform, the model could not be fully coordinated. The default position was to issue for "design intent only" or "for supplementary information", as was done in the case of the NPH project [36].

It was suggested by a number of interviewees that an independent BIM advisor should represent the client, tasked solely looking after the interests of the client.

We have now transitioned through PAS 1192-2:2013 to ISO 19650-2. Yet, there is still no mandate from the Irish government on the use of BIM. Although a 2017 consultation, paper did summarise the benefits of BIM as waste reduction, and potential programme and cost savings to the client, the position paper goes on to outline the benefits and risks of BIM. One notable risk is a greater potential for claims, should a poorly prepared model be provided for tender purposes [7].

Leading construction solicitors Hussey Fraser, drawing attention to the PWC guidance notes for an employer designed contract. Which state that the design must be fully developed and go through seven different stages of analysis and assessment before the invitation to tender is issued. Considering this level of scrutiny in the process, they found it difficult to reconcile the poor quality of design information made available to contractors at tender stage [37].

The NPH BIM execution plan was issued as "information supplementary to the contract design information". Despite this, the bill of quantities was developed from the design model, resulting in inconsistent and incomparable measures, compared to those undertaken by the contractors, who only used the 2D drawings.

A number of interviewees suggested much greater rigour should be applied to the development of the BIM Model, for it is to be issued as a contract document. Later on in the process, because the requirements the EIR are unclear they are either watered down, or abandoned.

The author's experience is supported by the interview findings, in which it appears that even when a BIM model has been developed, it is rarely issued at tender stage. The GC is frequently instructed to price the project based on the 2D information only.

Eastman et al. [23] suggest that traditional projects are the most difficult to implement BIM on and issuing a design model "for information only" to be inherently inefficient and irresponsible to clients. The practice of stripping out the sheets and views, as suggested by Lockley thus rendering the design model useless to the GC, is even less efficient or responsible to the client. Eastman et al. [42] maintain that this is disingenuous to the client.

VII Conclusions

The Irish government has struggled to achieve high levels of design completion at tender stage, opening themselves to cost overruns due to inaccurate tender pricing. The BIM process if executed correctly should increase the quality of design at tender stage. The lack of a government mandate has stifled the development of BIM in the Irish AEC industry. Much of the Irish AEC industry has embraced with BIM software tools, what they need now is the government to mandate BIM. There is no excuse as we now have IS EN ISO 19650-1 & 2 enacted. Suitable documents such as NEC 4 or other alliancing type contracts must be introduced, or the government PWC forms adapted.

The ISO 19650-2 standard is a high level, process driven document, which correctly avoids defining the BIM design model. Key to the success of the transition from PAS 1192-2 to ISO 19650-2 will be follow on guidance documents such as those released by BSI [43] and being developed by bodies such as the Centre for Digital Build Britain.

The client should engage independent expert advice prior to appointing their design team. This expert should advise on the implementation of BIM on each project. Each project should be evaluated on its own merits. An experienced design team with the appropriate skills should be appointed; a responsibility matrix should be developed by the design team and agreed with the independent expert before the team is appointed. To ensure collaboration between the teams, the correct contractual agreements and BIM protocols should be implemented.

Above all, BIM should be evaluated as the appropriate solution for each individual project.

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A Qualitative Review of BIM, Sustainability and Lean Construction. Is there a Future for Lean Construction?

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Abstract – The implementation of Building Information Modelling (BIM) is accelerating within architectural practices; however, there is evidence to support the premise that Lean Construction (LC) principles are being underutilised or misunderstood. Therefore, this research concentrates on Lean Construction, centred on the adoption of BIM. Although many studies have been carried out on lean construction, a gap in knowledge has been identified in its application with respect to BIM. The aim of the research is to investigate factors which influence economic decisions in relation to BIM and LC, during the design phase of a construction project. In addressing this aim, a three-tiered sequential qualitative research approach is adopted; in-depth literature review, interviews / focus groups and qualitative analysis. This research is of importance, particularly to the architectural sector, as it can add to the industry's understanding of the design process, while considering the application and integration of lean construction into the design process. It also highlights reasons for the success or failure of a construction project, in terms of Sustainability, at the design stage and identifies areas in which gaps in knowledge exist and enhances our understanding. Results indicate that the potential advantages outweigh disadvantages but uptake within the industry is still slow and that better promotion of the underlying benefits is required. It is shown that there is much less research utilizing BIM and Lean Construction as a collective process and the increased use of BIM in all its levels may lead to the demise of Lean Construction.

Keywords – Building Information Modelling (BIM), Lean Construction, Sustainability.

I INTRODUCTION

The implementation and use of Building Information Modelling (BIM) is growing within architectural practices [1][2][3][4][5][6]. However, this research highlights evidence to support the proposition that Lean Construction (LC) principles are being underutilised and or misunderstood. This research also illustrates that whilst many BIM practitioners are aware of LC, they do not directly utilise it but do so unwittingly due to the similarities in their philosophies, ideals and practices. This paper concentrates on BIM and LC at the design stage. It also examines in conjunction with these topics, if sustainability is given consideration. The aim of this research is to investigate factors which influence economic and sustainability decisions at the design phase of a construction project, focusing and concentrating on BIM and LC only. It will include the exploration of the disadvantages to their introduction and use, against the possible benefits or advantages to be derived. To achieve this aim, the objective will be; to examine relevant literature from as wide a variety of sources as possible and undertake interviews. Investigate any correlation between the results obtained from the literature review, interviews / focus group and highlight links between the areas researched. There are indications that the demand for sustainable buildings with minimal environmental impacts is increasing [7]. Incorporating sustainable principles at the conceptual stage is attained by using sustainable design. [8] 'The objectives of sustainable design are to minimise pollution, reduce the consumption of natural resources, reduce energy during material production, construction and use' [9].

It should also be with these ideals in mind to create a healthy comfortable space to work and live. Research and experience of the construction industry has shown that it is slow and resistant to change [10] [11]. A preliminary examination of industry guides, journal articles and reports, reveals scant information exists on sustainability at the design stage but is mostly considered at other stages such as procurement [12] and construction. It also reveals there is little linkage between BIM, LC and Sustainability.

This study aims to address this gap in knowledge.

II Literature review

Construction projects are increasingly becoming more complex and complicated to manage [13] [14]. One area of complexity is the interdependencies between stakeholders, [15]. In response to this increasing complexity, information and communication technology (ICT) has had to quickly develop [16]. The adoption of BIM has, during the last decade, been a major shift in ICT, for the construction industry. BIM is defined in several ways, the BuildingSMARTalliance [17] who published the National BIM Standard Version Part 1 for the United States, defined BIM as ‘a digital representation of physical and functional characteristics of a facility’. They further state that BIM is ‘a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle; defined as existing from earliest conception to demolition’. The glossary for the BIM Handbook [18] defines BIM as ‘a verb or adjective phrase to describe tools, processes and technologies that are facilitated by digital, machine-readable documentation about a building, its performance, its planning, its construction and later its operation’. Other definitions range from a process-oriented to a product-oriented process. Laiserin in the foreword to the BIM handbook [18], states that the first documented use of the term “Building Modelling”, in the sense that “Building Information Modelling” is used today, appeared in the title of a 1986 paper by Robert Aish and this adapted to “Building Information Model,” the first documented use appearing in a paper by G.A. van Nederveen and F. Tolman in December1992, Automation in Construction [19]. BIM has evolved from 2D CAD and the need for streamlined and collaborative information sharing. The primary difference between BIM and 2D CAD is, the latter portrays a building as independent 2D views, i.e., plans, sections and elevations. Editing one view necessitates the checking and updating of other views, a process prone to errors and a cause of poor documentation. Data [20] in these 2D drawings are graphical entities only, such as lines, arcs and circles, in contrast to CRC Construction Innovation, [21] discussion on the intelligent contextual semantic of BIM models, where objects are defined in terms of building elements and systems. BIM at its’ simplest, is a process to share and communicate information between stakeholders, about every aspect and element within and connected with a building in 3D over the lifecycle of a building from inception to eventual demolition. ‘BIM used progressively reduces the cost, time and uncertainty of design, construction and operation of buildings by making previously laborious and ambiguous processes quicker and more accurate’ [22]. BIM is defined by the BuildingSMARTalliance [17] but also states, ‘A basic premise of the model is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the modelling process to support and reflect the roles of that stakeholder’. This is partly supported by reports such as Contractor’s Business Management Report [23], which suggest that is not just a piece of software but something more akin to a process change to workflow for design teams, contractors, and clients. Whilst true, what most authors do not mention is the fact, it is used a lifecycle management tool for facilities. It is important to look at BIM from the perspective of all stakeholders involved with a project, evidence [24] suggests that BIM technologies and methodologies are set to revolutionize the construction industry because of its potential to drastically improve collaboration among the wide-ranging expertise needed to design and construct a building and to improve efficiency. It may be considered [25] as being about the total information required to manage the facility effectively rather than just model geometry leading to a 3D Model. A model that is constructed virtually, before actual construction on site begins, [26] [27]. This is truer to the definition set out by the BuildingSMARTalliance [17] in which all stakeholders are involved from the outset and is supported by [28] who states ‘it fosters a collaborative effort’ supporting the theory of a collaborative workflow that includes all stakeholders. It is shown, [29] that BIM tools are useful, not only for design but also for the exchange of information between stakeholders. This idea is furthered [30], where it is stated that BIM can be viewed as a virtual process that encompasses all; aspects, disciplines and systems of a facility within a single, virtual model, allowing all design team members to collaborate more accurately and efficiently than using traditional processes. BAM Group Ireland [31] stated in 2014, that for them, BIM is paying real dividends in terms of improved collaboration, improved workflows and improved value to clients, further stating that, “For BAM, BIM is a legitimate form of prototyping which is an extremely powerful way of mitigating risk on a project. A cooperative approach from all project stakeholders delivers better results.”

a) BIM and Sustainability

Sustainable Design has become another buzz word [32] in the construction industry, emerging out of global concern for the state of our natural environment. The use of BIM is increasing among architects and designers as the demand for sustainable building with minimal environmental impact is increasing [1] [2] [3] [4] [5] [22] [32] [33] [34]. Rising energy costs [35] and growing environmental concerns are the catalysts for higher usage. Sustainable design is a philosophy that seeks to maximize the quality of the built environment whilst reducing or eliminating negative impacts on the natural environment [36]. As BIM allows for multi-disciplinary information to be incorporated into one model, it creates an opportunity for sustainability measures to be integrated throughout the design process [37] [38]. Therefore, BIM can be a vital sustainability design tool allowing designers to compare various designs options and their resultant impact on green building performance [39]. BIM may enable many energy-efficient and sustainable designs, such as passive design concepts, to be addressed early in a project, when the building's size, shape, massing and orientation are developed, using real coordinates, to perform in conjunction with the natural elements, substantially reducing requirements for heating, cooling, ventilation and energy [35] [40] [41]. A view supported by [42] and [30] who state that, the early design phase is the most critical time to make decisions on sustainability features. It has been stated [4] ‘the strong growth of the green building market can encourage BIM adoption in the design and construction industry’ and goes on to say that BIM contributes to sustainable outcomes because it supports the use of integrated design. [43] assert that BIM is core to its sustainable design approach. BIM is ideally suited to deliver information needed for improved design and building performance. Two most significant benefits of BIM for sustainable building design are: integrated project delivery (IPD) and design optimization. However, there are also barriers to adopting BIM for sustainable design. [44] [45] highlight that, measuring the sustainability of buildings remains problematic as numerous protocols are currently in use for sustainability assessment. A view supported by [46] because different countries have differing; standards, protocols and sustainability indicators. Improving sustainability performance of buildings can be difficult, due to the difficulties in calculating the improvements of one decision versus another on sustainability and the challenge of trying to predict future performance, during the design stage, when capacity to influence project costs are greatest. BIM cannot provide all the answers, it requires a framework or indicators. [47] state; ‘Sustainability indicators represent a generic expression for quantitative or qualitative sustainability variables’. These indicators are taken from standards or protocols and are created as project parameters or shared parameters and exported to databases. The output can then be used to make informed decisions. It is concluded [35] that BIM-based sustainability software quickly generates results as compared to the traditional methods but warn that discrepancies were recorded between software and manual results. However, it is stated [48] that literature regarding the integration of sustainability tools with BIM has shown improvement in assessment processes and effectiveness through comprehensive and efficient data extraction. This leads to a reduction in the time, effort and cost of an assessment, multi-disciplinary sustainable design decisions made at the design stage that enable relatively fast and inexpensive improvements to be made, relative to changes made during and after construction and a reduction in human error using standardised and authorised information. It is because designers must keep the entire life cycle of the building and its associated materials in mind that promotes sustainable development practices through these rating systems by recognizing projects that implement strategies for better environmental and health performance [49]. A common assessment method used is, Life Cycle Assessment (LCA). This is a tool for evaluating environmental concerns [50] The integration of LCA software and BIM software to automate the process allows not only greater efficiencies in LCA assessment procedures but also enables design changes to be made prior to construction and assist building managers to optimise a building’s environmental footprint throughout its operation [51]. While LCA can be used to assess the sustainability of the built environment, its technique provides comprehensive coverage of the product’s Environmental Impacts (EI), therefore it is very useful to apply it at the conceptual design phase of building projects, [8]. When working on a sustainable design, the focus of designers is on their ability to evaluate the EI of the selected products by using available methods and tools. The idea of LCA has emerged as the collection and evaluation of the inputs and outputs as well as the potential EI of a product throughout its life cycle [52]. It has been revealed that approximately 95% of energy consumption and emissions occur in the operational phase [53] but as far back as 1998, it was reported, [54] that using optimisation technologies, the effects on life cycle energy and emissions from the operational phase can be moved back to the material production and construction phase. There are several BIM-based tools and systems that have been and are being investigated and developed to confront sustainability concerns across the construction process from, design inception to facilities management and [42] [55] [56] [57] [58]. However, it is warned [59] that although a significant amount of work has been undertaken on the technical interoperability aspects of BIM and sustainable design analysis (SDA), the practice is still fairly new and general practitioners are perplexed by both the amount and complexity of software solutions on the market. Whilst these technologies may aid in attaining the outcomes required by sustainable assessment methods, the mechanistic and linear approach required to achieve credits fails to capture, and may even prevent, the more humanistic and developmental benefits BIM may bring in terms of dialogic stakeholder engagement, common understanding and internalisation of sustainability values that add value to the end user through continuous analysis and discussion of sustainability throughout the design and construction process with relevant stakeholders. [48]. Although BIM and sustainable design have emerged from somewhat different underlying market factors, they share a significant common thread: the success of both endeavours depends heavily on a front loaded, deeply integrated building design philosophy that aims to include all team players from the very beginning of a project, [32]. Many of the philosophies and ideals of BIM used in conjunction with; sustainability, LCA and SDA are mirrored by the tenets and concepts of Lean Construction.

b) BIM and Lean Construction

Lean construction processes have been developed from the processes used in manufacturing and based on the 'Toyota Production' system; improved scheduling of resources and materials, streamlining of construction, just in time deliveries. [60] [61] [62] [63]. Lean could be viewed as a philosophy through which a project may be undertaken. One definition of Lean [64] is it is; 'a way of thinking and delivering value, innovation and growth by doing more with less; less human effort, less equipment, less materials, less time and less space aligning effort closer to meet customers value expectations at the heart of Lean are flexible, motivated team members, continuously solving problems.' This definition is similar to those put forward for sustainability. In short, it aims to balance the shortcomings of the time-cost-quality triangle trade-off paradigm within health and safety legislation. BIM at the design stage can aid in this. Through better coordination and sequencing it allows for offsite fabrication, Just-In-Time (JIT) deliveries, improved scheduling, improved procurement, improved materials management etc. The BIM Handbook [18] also states in its introduction that building information modelling provides a basis for new capabilities in construction and allows for changes in roles and relationships among a project team. It goes on say that when it is implemented appropriately, BIM facilitates a better integrated design and construction process, resulting in better quality buildings costing less with a reduced project timescale. LC [65] has two main goals to serve during the construction process and are;

1. Minimise physical and process waste.

2. Improve the value generation to the client.

BIM is able to provide a foundation and a mechanism for the outcomes that LC is expected to deliver. Eastman et al. [18] (Ch. 9) cited in [66] comment that 'Lean construction techniques require careful coordination between the general contractor and subs to ensure that work can be performed when the appropriate resources are available onsite'. It has been shown that BIM provides an accurate, detailed model of the design and can schedule the materials required for each of the programmed phases and provides a base for improved planning and scheduling of sub-contractors and as stated, can aid in JIT deliveries of people, plant, and materials.' It should also be remembered that these processes in conjunction can aid in the 'value engineering' of a project and lead to an increase in value for money for the client. It should be noted however that LC and BIM are not reliant on one another and can be adopted independently, however there are advantages to running the two simultaneously. It is stated [66], that the individual concepts of LC and BIM have been researched extensively in recent years but there seemed to be much less research that utilised both areas as a collective process. A survey in 2007 [1], illustrates that LC, despite its advantages, ranked lowest on the factors for using BIM and in 2010, [67] looked at the popular tasks for which BIM is used in the USA and LC was not included. This discrepancy in knowledge between these principles needs to be addressed.

III Research Methodology

To address the stated research aim; three tiers of research were sequentially carried out for this paper; an in-depth literature review, two semi structured interviews and a focus group were held with industry professionals. The semi structured format was chosen as a method to elicit as much relevant information as possible, as one question can lead to another and gives the interviewee an opportunity to provide as much information as possible and freely express their thoughts and opinions. Data is analysed using Decision Explorer to create; cognitive maps and output through Central and Domain analytics, allowing unstructured information to be mapped, structured and documented highlighting relationships between clusters in the data.

IV Discussion

There have been many advantages identified through the research to the use of BIM. These were exposed through the literature review and the discussions with industry professionals. It was found that advantages outweighed the disadvantages by a ratio of approximately 3:1. The advantages and disadvantages identified have been amalgamated under the following headings.

a) Economic Advantages

The economic and cost control advantages of using BIM are; many, varied and reach out across all aspects of the project from inception to demolition. [37] [38]. In the design phase BIM can enable the correct choice of design, with the right materials, correct plant etc. Also identified by; [22] [27] [35] [40]. It also aids in the construction process; the research has identified many areas where economic savings and advantages exist. In the construction phase it aids in LC, [18] [65] materials management, increased trades productivity, reductions in project time, early clash and scheduling detections and systems conflicts, it allows designers to provide; floor, space and equipment layouts etc. captures and records handover data allows contractors to provide; equipment make, model, serial, warranty etc., all of which can be used as a digital owners' manual post-handover for use in; asset management, facilities management and the formulation of maintenance plans. [23]. (Interviews A and B, Focus Group)

b) Sustainability Advantages

The use of BIM is increasing as demand for sustainable buildings with minimal environmental impact is increasing, rising energy costs and growing environmental concerns are a catalyst [35]. It can be a vital design tool for sustainability as it allows the comparison designs options and their impact on green building performance. BIM may enable many energy-efficient and sustainable designs, such as passive design concepts, to be addressed early in a project. When the building's size, shape, massing and orientation are developed to perform in partnership with natural elements, requirements for heating, cooling, ventilation and energy requirements can be reduced substantially, [37] [38] and when used in conjunction with LC that sustainable development is achievable. [20] [34] [40] [42]. It is interesting to note that although many of the principles of LC were identified as being advantages of BIM only one of those interviewed (interview A) identified LC in conjunction with BIM.

c) Corporate Advantages

It can be said that all advantages of BIM feedback to corporate level, economic advantages such as reduced project costs, LC, sustainable construction, better working practices, enhanced tendering, all benefit the organization. It was identified in the research that it was felt that overall, BIM made for a more efficient practice and because the operations become more collaborative, open and transparent, lead to better customer service and increased client satisfaction, all of which the organisation could use in its' marketing and promotion. (Interviews A and B, Focus Group)

V LEAN CONSTRUCTION SUBSUMED BY BIM?

During the exploratory meetings and the interview process, those involved admitted to knowledge of the LC process but only one interviewee stated that they used LC practices. Those involved, during the discussion and questioning, could see the relationship between BIM and LC and whilst not adhering to the tenets of Lean Construction could admit to carrying out a form of LC, albeit accidentally. BAM Ireland, in their Sustainability report of 2014, state that they adopted BIM as a "Lean Process" because it increases efficiency in the design and construction procedure and its' advantages in sustainable project delivery but do not mention LC. As stated, LC was not included among popular tasks for which BIM is used in the USA, [67]. A 2007 survey, [1], demonstrates that LC, despite its advantages, ranked lowest on the factors for using BIM. This was furthered in 2009 [66] who state, that the individual concepts of LC and BIM have been researched extensively but there was much less research that utilised both as a collective process. Will the increased use of BIM in all its levels, lead to the demise of LC?

VI CONCLUSIONS

The use of BIM is increasing among design teams as the demand for sustainable projects with minimal environmental impact is increasing, rising energy costs and growing environmental concerns have been cited as reasons. BIM is therefore a vital sustainability design tool as it allows designers to compare designs options and their resultant impact on green building performance. BIM will enable many more energy-efficient and sustainably designed buildings to perform in conjunction with the natural elements, substantially reducing requirements for heating, cooling, ventilation and energy usage. It should also be remembered that the integrated methodology can aid in the 'value engineering' of a project and lead to an increase in value for money for the client. BIM is also capable of providing a foundation for the outcomes that LC is expected to deliver, as the process of BIM provides an accurate, detailed model of the design and can schedule the materials required for each of the programmed phases and delivers a platform for improved planning, scheduling of sub-contractors, manpower plant and materials through JIT deliveries. It achieves this through an integrated methodology to design, construction, and operation. This can enhance; design quality, sustainability, buildability, materials management, reduce waste, reduce maintenance needs and consequently reduce whole-life costs. As many of the principles of BIM and LC are so similar as to be the same, this may lead to LC being subsumed by BIM. The integrated methodology requires a collaborative effort from all the stakeholders, which BIM has been stated to foster and LC require. However, with high rates of litigation in an adversarial industry, things may not be as easy as this and BIM may not be the cure as is hoped, as the nature of the interactions and relationships have not changed, just the way they are carried out. [68] states that, 'technology has simply served to speed up the process of reaching the point at which claims and litigation to create profit margin can be attained'. This research has highlighted that there exists, three times as many advantages for BIM than disadvantages.

a) Recommendations and Implications for Practice

The research demonstrates that the construction industry has taken up the process of BIM but still has a long way to go, despite the obvious advantages. There is a need for better promotion of BIM and the advantages it can bring to a project. It is more than just software to produce 3D models for visualisation. Its' use in materials management, WLC / LCC, sustainability, operations and maintenance, scheduling, Lean Construction, Lean Project Delivery and value management requires further exploration and promotion. BIM can help address the problems associated with implementation and use of Lean

Construction and sustainability, it can aid in their advancement and further research in this area is recommended.

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BIM for Infrastructure on the Bonded and Re-Export Zone at King Abdullah Port, Kingdom of Saudi Arabia

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Abstract – This paper is an honest and practical appraisal of the key lessons learned on a civil infrastructure project; the design of €200m 3,600,000m² (360 Hectare) Bonded and Re-Export Zone (BRZ) in the new King Abdullah Economic City (KAEC) on the west coast of the Kingdom of Saudi Arabia (KSA). GARLAND prepared a masterplan and detailed design of the BRZ on a phased basis. This included a significant bulk earthworks enabling works, new roads, roundabouts, watermains, surface water sewers, swales, ducts, electrical infrastructure, foul sewers and associated pumping stations and other related site development elements including concrete slabs. This paper discusses our use of BIM and technological tools to deliver this extensive project. Given the scale of the project and associated quantities of roads, ducts, sewers, bulk site filling, along with the hundreds of drawings number per client data drop, any inefficiencies in our processes were multiplied. We discuss the lessons we learned and how we applied them throughout the project. We outline how we refined our processes and level of detail required to increase efficiencies and also eliminate waste and non-productive time in our design and detailing. The paper discusses how the client was an influencing factor on our project approach.

Keywords – BIM, civil, infrastructure, Saudi Arabia, King Abdullah Port, Bonded and Re-Export Zone, clash, roads, sewers, watermains, case study

I Background

a) King Abdullah Port (KAP)

King Abdullah Economic City (KAEC) is located on the west coast of the Kingdom of Saudi Arabia (KSA). King Abdullah Economic City contains King Abdullah Port (KAP) which is the newest and first privately owned and operated port in the region, strategically located to offer the optimum gateway to the Gulf Cooperation Council Countries and the Middle East markets and provide a logistically convenient transhipment connection between Asia and Europe. Operational since January 2014, KAP has been planned to accommodate mega vessels in 18m deep berths and currently has a committed capacity of over 3 million TEU (Twenty-foot equivalent unit) containers, with a potential capacity of 20 million TEU at completion.

b) Bonded and Re-Export Zone (BRZ)

The Bonded and Re-Export Zone (BRZ) is a designated securely controlled area directly adjacent and connected to the Port. When completed it will offer land and facilities for storage of imported goods net of duty, streamlined import/export processes, and support services for global logistics and supply chain suppliers as well as localization and light manufacturers supplying markets in KSA, Africa and Middle East, saving time, costs and enhancing cash flows.

This infrastructure project is 3,600,000m² (360 Hectare) in area with an estimated construction value of €200m.

Fig. 1: Rendered Image of the Bonded and Re-Export Zone

c) Our Company and appointment

GARLAND are a consulting civil and structural engineering firm founded in 1937 over 80 years ago which has realised projects in more than 30 countries.

We were appointed initially, in 2014, through our subsidiary company Pivotal International, to carry out a feasibility study to ascertain demand for a facility of this nature. Following this study we were then appointed to prepare a master plan and design guidelines for the BRZ. We are currently completing the detailed design of the infrastructure of this significant development on a phased basis.

The project involves significant bulk earthworks enabling works, new roads and roundabouts, watermains, surface water sewers, swales, ducts, electrical infrastructure, foul sewers and associated pumping stations and other related site development works. The development also incorporates a number of concrete paved sites for the storage of TEU containers and bulk materials by individual site owners.

II Project Information Requirements

Within the project brief, the client for the project, Emaar EC, had a number of design deliverables and information requirements for various project stages. These primarily included different types of 2D drawings and the level of detail required during the various project stages from masterplan to construction drawings.

There was no specific BIM requirement or standard set by the client. However, it was obvious that their required level of detail and information need necessitated the use of BIM processes and tools. Furthermore, given the scale of the project and associated quantities of roads, ducts, sewers, bulk site filling, any approach to the project without the use of BIM tools and processes would not have delivered on both client expectation and programme requirements.

III Existing Process and Tools

a) Pre BIM Projects and Processes

As a company, GARLAND are widely experienced in the delivery of large infrastructure projects. Since 1960 we have been involved in the planning, detailed design, procurement and supervision of construction of Shannon Town and Shannon Freezone, Co. Clare where there are over 50km of concrete surfaced roads on a 500 Hectare site. Similarly, we have been involved in the successful delivery of many other large infrastructure projects including the 180 Hectare Raheen Industrial Estate, in Limerick.

Those aforementioned projects were delivered at a time without the availability of BIM tools and processes. The authors would suggest that these projects were delivered under very different programme requirements, change management environment and to a lesser level of detail. However, it is worth noting that the processes and information prepared by GARLAND for these projects delivered infrastructure that has performed successfully and exceed its design life.

b) Introduction of Infrastructure BIM Tools to GARLAND

As a company we have utilised BIM tools for infrastructure since we first introduced AutoCAD Civil 3D to our organisation circa 2005. Prior to the commencement of the BRZ project, our use of Civil 3D for infrastructure works had primarily been focused on relatively small individual site development schemes or short sections of roads rather than large combined and integrated areas of site development similar in size to the BRZ.

c) Our Comparable Development of BIM on Structural Projects

Our introduction of BIM tools, such as Autodesk Revit, and associated processes to our structural projects and associated design processes occurred circa 2011. Although this was some 6 years after we had started to use BIM on infrastructure projects, we found that we were using BIM extensively on structural projects and that our experience and knowledge in the application of BIM to structural projects grew quickly and surpassed that of our BIM infrastructure expertise.

IV Project Approach

As a company we knew we had the knowledge and experience to deliver large site development and infrastructure projects. We were also confident in our BIM process knowledge and our availability of BIM tools, especially those we had developed over the preceding 7 years on structural projects. We were also keenly aware of what we did not know and that our BIM expertise related to infrastructure projects had not developed as extensively as that related to structural projects.

Our company culture has always furthered the development of both individual skills and company expertise during project delivery. We also recognised that in our BRZ client, we had a partner, who also had vast project experience in delivering projects of that scale and nature.

Armed with all of these facts, we were very keen and very determined to utilise BIM tools and processes to deliver for us and our client on this project. We were also very aware that we would have to develop our infrastructure related BIM skills as the project developed.

One of key actions that senior management within the company wanted to empower on those delivering the project was to always ask, query, seek and find a better way of working on the project. Management were keen to ensure we learned from the lessons that presented and we established the best way of doing things on this project. Management were also keen to impart that we were unlikely to be the first to face these challenges within the industry and that, as we had found our structural BIM learning, someone else is likely to have developed a solution to the required problem. Management therefore encouraged research and solution development to benefit better project outcomes.

V Lessons Learned

a) Data Management

One of the quickest lessons we had to learn on the project was about data management. When compared to the size of the BRZ project, the BIM infrastructure projects we had been working on were quite small. Therefore, we were able to manage the data in single drawing file with some background layouts, such as architectural layouts, as reference files. Given the scale of this project, some 360 hectares, a single drawing and model file was not possible if one was to avoid significant disruption from drawing file errors, drafting program crashes, data loss and prolonged file loading times.

In order to improve our efficiency we carried our research to identify industry best practice. Our research led to an Autodesk publication [1] which provided us with best practice on how to achieve Drawing and Object Relationships. We learned the best practice of separating drawing files into three types: Individual Design Objects (such as existing ground surfaces, alignments, and parcel networks), Base, Linework, and Engineering Drawings and then Production Sheets. Implementing this best practice strategy on our project resulted in lightweight drawing files, prevented unintended changes to referenced files and enabled maximum flexibility and team working as one team member could open a single drawing for editing while other members operated with read-only copies.

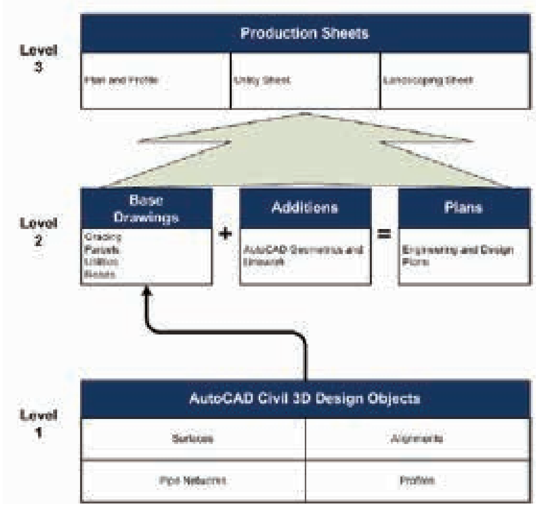

Fig. 2: Three-level project drawing structure [2]

Implementing this strategy of a network of related drawings did result in some confusion and difficultly to managing the multiple drawings files. However, we learned to plan the drawing relationships in advance and prepared diagrams for the project team to reference while working on the project.

Another aspect of this best practice publication that we implemented fully was the working folder structure[3], again to ensure all team members confirmed to a standard methodology for project delivery which now forms part of our ISO 9001:2015 processes.

Our drawing naming convention also assisted with team working as individuals could easily identify different site areas and also types of drawings such as plans, details and section by their container name

b) Lean backgrounds are best

The 320 hectare site layout plan of the BRZ and the surrounding area was present as a drawing background in the vast majority of our drawings.

Fig. 3: BRZ Site Layout

During design and detailing of the project, we recognised a significant load time for our drawing files. Initially, we believed it was our aforementioned poor Civil 3D data management that was the main cause of the delays experienced. However, when delays, drawing size issues and drawing file errors were still apparent after implementing best practice for data management, our attention focused on the common denominator to the drawings concerned, the site layout background.

When investigated, we found the background site layout drawing to be very bloated, oversized and contained errors. One of the key drivers of BIM and lean is the reduction of waste. This is often to be considered to be on site construction waste and carbon from construction of buildings or when in use, however, we believe reduction of waste from design processes to be very worthy of consideration also.

We were able to clean the background drawing which reduced the file size by 25% and also had a significant impact on reducing time required for drawing actions, file loading times and reduction in program crashes. This not only resulted in a benefit to us, but also to those who also use the drawing files such as the client, contractor and other design team members.

c) Deliverable Issuing - There has to be a better way

Emaar EC are developing a new 168,000,000m^2 city, situated on the Red Sea coast, comprising of diverse components including a port, industrial zone, residential projects, commercial offices, educational institutions, and leisure attractions. This involves numerous individual projects including the BRZ. From all of these projects the client has established a number of key requirements when receiving a design deliverables. These included:

1. There had to be an Acrobat Reader (.pdf) file of each individual drawing
2. There had to be a native drawing file (.dwg) of each individual drawing.
3. A single native drawing file containing a number of drawing sheets was not permitted
4. The use of a compressed zip file (etransmit) to issue the native drawing file was not permitted
5. The use of external reference from one drawing file to another was not permitted
6. The native drawing file had to open in multiple editions of AutoCAD and therefore Civil 3D objects had to be compatible to viewing in standard and earlier edition AutoCADs.
7. Each drawing issue had to contain a revision, even if no design content within the drawing changed
8. Each drawing had to contain a stamp referring to its purpose of issue

Our client had developed these requirements from other similar projects and lessons they had learned when the current rules were not in force. Unfortunately for us, complying with their requirements was contrary to everything we were trying to achieve internally which was lightweight files, significant referencing, and reduction of waste by minimising the effort required per drawing.

During the earlier stages of the project, meeting these client requirements was possible as the quantity of drawings was manageable. However as we progressed into the schematic and detailed design of the project, the sheer quantity of the drawings required demonstrated that our original processes would not suffice.

For the detailed design of the project there were hundreds of drawings. We were starting to spend more and more time working for the project in preparing client deliverables instead of working on the design of the project which is where our skilled team could add value.

We would generally have a project issue every Friday which could consists of up to a hundred drawings. If we were to spend 15 minutes preparing 250 drawings for issues that would equal 62.5 person hours or over 1.5 person weeks every week. We simply did not have the resources or the programme duration to do this.

From our structural BIM experience and capability with 3D model authoring software and associated add-ons, we had become very accustomed to batch preparing, editing and issuing of 2D file outputs as required.

Given we had, on earlier stages of this project, developed a routine process for how we needed to convert our working files to client deliverable files, we sought about identifying a technical solution to this mundane and time consuming task. We found a software development company that specialised in construction design software JTB World [4].

JTB World have a number of software products that would batch process a number of the steps required to achieve the required deliverable. Using these programs along with some custom scripting of our processes, which we developed in conjunction with the JTB World, we were able to dramatically reduce the time, and most importantly the human input, required to prepare deliverables for issue to the client. We were able to:

1. Batch change and add items to multiple title blocks without opening drawings
2. Run an automatic process that would change our design files to a single file ready to upload to the common data environment. The process did not affect our original design files.

The automatic process was not flawless and errors in design files would lead to the program stopping. The process also engaged a significant amount of computer resources when operating. Experimentation and development of the script also took a significant time investment. However, we have had a huge benefit from developing this process which has also enabled us to introduce the process on all relevant projects throughout the firm. We also believe there is still scope for further improvements to be made in the scripting and drawing preparation to achieve even better project outcomes.

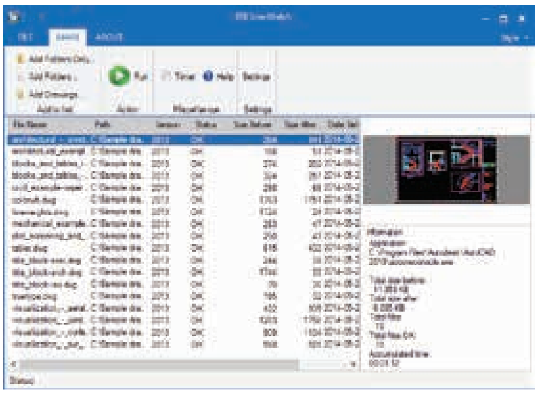

Fig. 4: Batch Drawing File Preparation

d) Cut and Fill – Back to Basics

There is a significant filling requirement on the site to achieve desired finish levels. For example, Phase 1B which has an area of 1,000,000m^2 has a requirement for 1,800,000m^3 of fill with only 12,000m^3 of cut. There will be an average of 1.8m of fill added to the Phase 1B area of the site.

In order to generate accurate quantities of fill and to generate site contours for the enabling works bulk fill, 3D models of the existing site, proposed finished site levels and formation levels of the finished site surfaces were generated and compared.

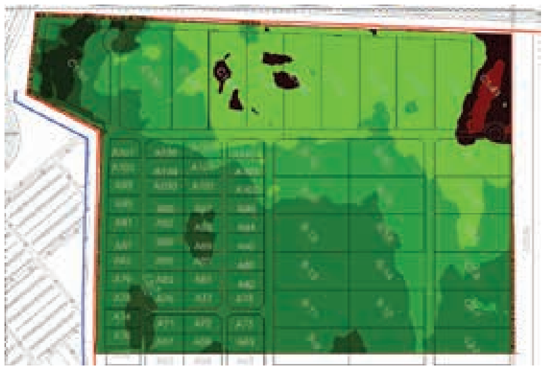

Fig. 5: Phase 1B Cut and Fill Model

We faced a number of challenges when performing the cut and fill analysis for the site. The scale of the different phase areas resulted in huge quantities, which were often difficult to relate to as a result generate a grounding for an expected result.

During checking of our draft earthworks contract site filling contours, it became apparent that some of the contours were not following expected paths.

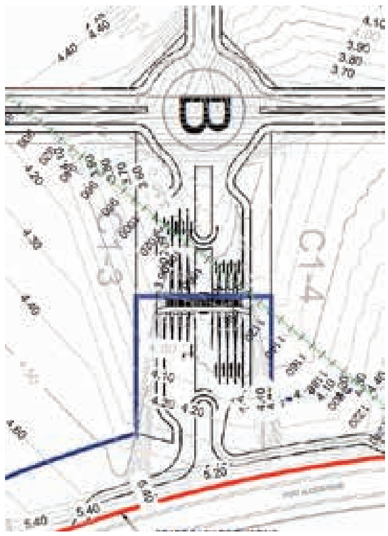

Fig. 6: Draft Phase 1A Site Fill Contours

Upon investigation, we realised that our 3D model of the finished site surfaces and levels contained a huge amount of information and 3D points. There was also some unexpected 3D information present within the data. We established that our draft site fill contours were unintentionally connected to some unintended 3D data points.

In conjunction with a leaner, structured and cleaner data management approach, we simplified the modelling of the 3D surfaces being compared. We reviewed internally within the team and organisation what it was we were trying to achieve and how best and simply we could obtain the desired results with assured accuracy.

Our resulting approach was to simplify our models. Just because the detailed information and model was available, we did not have to use all of the information. We instead created feature lines connected to only select points of the final 3D model. The lesser but targeted points resulted in a 3D model that was more suited to the intended purpose and use of the model and the associated output data.

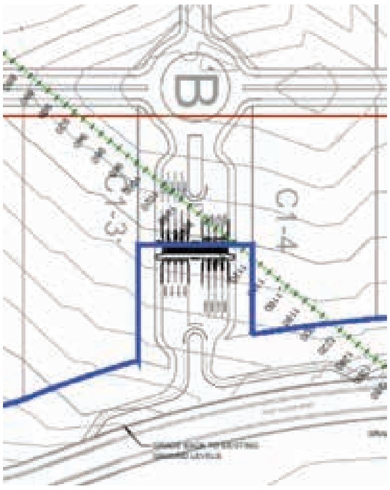

Fig. 7: Final Phase 1 Site Fill Contours

e) Interoperability - Design Programs and Authoring Software

One of the biggest benefits we have realised on the structural side of BIM was the interoperability between our structural analysis software and our 3D authoring software.

We use Microdrainage for our foul and surface water sewer analysis. Similar to our structural analysis software, this design software creates 3D models for analysis purposes. We had always been using these 3D models which are created using an add-on within the AutoCAD environment to run design and simulation. The design program can generate long sections and independent data outputs, which for smaller projects is sufficient.

For change management purposes and to ensure integration and accuracy with the overall 3D model, we wanted to go further on this project. We used the interoperability between Microdrainage and Civil 3D to do work once in either tool and see the outcome in both. Once we manged to make Microdrainage parts list communicate successfully with the Civil 3D parts list we achieved our targeted goal and brought this lesson learned to other projects where the effort required match or exceed the benefit gained.

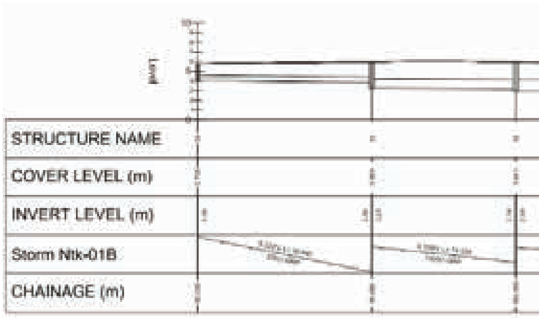

Fig. 8: Sewer Long Section Created using Civil 3D and Microdrainage

e) Clash Avoidance including Watermains

One of the distinct requirements of the client brief was to provide a clash free design. For over 15 years we have been using our foul and surface water analysis tool, Microdrainage, to carry out clash avoidance on sewer networks during the design process. In order to prove to our client that our design for this project avoided clashes, we undertook a number of actions. We modelled the watermain in Civil 3D, a task we would not generally consider necessary for smaller projects.

Using the authored 3D models of the sewers and watermain from AutoCAD 3D, we used Autodesk Navisworks to identify any areas where clashes occurred and modified the design of the relevant network accordingly. Although not a specific deliverable requirement of our contract, we were able to issue a Navisworks 3D file of all three civil networks to the client to demonstrate that our design avoided clashes.

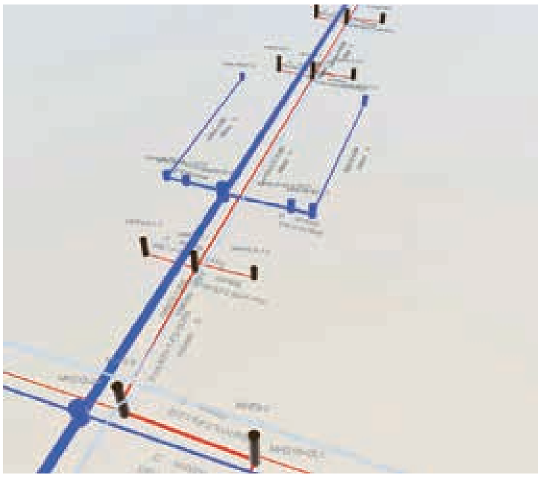

Fig. 9: Extract of Phase 1A 3D Clash Avoidance Model

VI Conclusion

Given the scale of this project, along with the hundreds of drawings required per client data drop, this paper has shown that any efficiencies or wastage in design processes can be multiplied. A 5 minute saving (or increase) in time per drawing has the impact of decreasing (or increasing) the required time to compete a data drop by days and weeks.

This paper has presented a number of lessons we learned during the earlier stages of this project and how we have applied these throughout the development of this project. The paper gives an insight into how we have refined our BIM processes and the level of detail used to increase efficiencies and eliminate waste and non-productive time in our design and detailing. The paper has presented examples such as the cut and fill modelling where an assessment of the required information need can lead to better outcomes.

We presented an example of how we used BIM as a means to design, coordinate and scrutinise and how we utilised an array of tools for clash avoidance.

As is apparent from a number of the lessons we learned on this project, one of the largest factors in driving us to develop solutions was our client. We believe this was achieved by how they influenced us during our interactions with them, how they used the information we provided and finally how their employer requirements, established form their previous project learnings, drove us to develop to meet their expectations.

Just because you can do something does not mean that you should or you need to. This has been one of the most fundamental lessons to come from this project. As a firm we previously delivered large infrastructure projects such as Shannon Town and Free Zone and Raheen Industrial Park without BIM tools and process. As an industry we should not lose sight of the design principles, rules of thumb and strategies employed prior to BIM process and tools. We should ensure we are providing lean and practical project outcomes using all of the best available technologies, process and previous project experiences.

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A Quantitative Investigation into how Building Information Modelling has Affected the Transfer of Information on Construction Projects

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Abstract – A request for information (RFI) on a construction project is a written formal procedure initiated by the contractor seeking additional information or clarification for issues related to design, contract documents and even construction elements. Response times to RFIs and other queries are typical key performance indicators (KPI's) on a construction project. As a result, slow RFI response times are considered to be poor performance metrics which can cause disruption and even delays to the project schedule. Building Information Modelling (BIM) enables collaborative creation and management of information on a construction project and across the project lifecycle. This paper investigates if the transfer of information and collaboration between all project participants improve as a direct result of BIM by examining the number of RFIs submitted and RFI processing efficiency on a BIM level 1 project. The main goal for this paper is to provide a benchmark set of results for analysis on the progression of BIM and the RFI process in the future. Although research has been carried out on the RFI process and its effect on project efficiency, little or no research has specifically evaluated effects on RFI processing efficiency as a direct result of BIM. The quantitative results of this paper found that the implementation of BIM on a construction project reduced the total number of RFIs issued per million euro of award contract. However, average and median response times for single party and multi-party RFIs saw no direct improvements. The poor punctuality and processing efficiency performance of multi-party RFIs, highlight that although there was an overall reduction in the number of RFIs submitted, issues with collaboration and coordination between project stakeholders still exist.

Keywords – BIM, Requests for Information, RFI, Multi-party, Conflict Resolution, Collaboration.

Introduction

The construction industry is highly fragmented, involving data-intensive processes across the entire supply chain [1]. Complex construction projects combined with the pressure to provide value for money and promote sustainability have driven the building industry to adopt Building Information Modelling (BIM) and as a result the implementation of BIM has been steadily changing the transfer of information between project participants within the AEC industry over the last decade [2].

A Request for Information or RFI processing efficiency is considered to be a Key Performance Indicator (KPI) on construction projects. Therefore, slow response times to RFIs can lead to project delays and cost overruns. BIM is said to have improved the transfer of information throughout a construction project and past research has stated that the early multi-disciplinary involvement during the design stages has led to an overall reduction in RFIs [3].

Current literature and findings on the success of BIM's implementation have mostly been developed from the client's perspective and highlight the benefits that can be achieved from its adoption as a whole. According to the 2017 National Building Society's Annual BIM Report [4], BIM adoption rates have increased by an average of 8% each year since 2012. However, Engineers and Contractors only made up 8% of the respondents used for this report. Similarly, only 46% of Engineers in the McGraw Hill Smart Market Report (2014) found BIM to have a positive ROI [5]. These figures highlight that there is a need for research on BIMs impact from a project stakeholders' perspective.

Studies have manly used questionnaires to develop a better understanding of how BIM affects the transfer of information of construction projects but little or no research has been conducted to attain clear quantitative results on the actual impact BIM has on this issue. Therefore, examining data on the total number of RFIs submitted and RFI processing efficiency throughout the project lifecycle of a BIM level 1 project will investigate the impact BIM has on transfer of information between project participants.

This paper examines data from a BIM level 1 construction project to determine if there has been an overall reduction in the total number of RFI submissions. An investigation into the improvements (if any) on BIM related RFI processing efficiency is a core component of this work. Overall, we take a case study approach to develop clear, quantitative data on the effect BIM has on the transfer of information. In particular, between the project stakeholders and the main contractor in the context of a construction project. The approach examines the total number of RFIs submitted, processing efficiency and punctuality of both single and multi-party RFIs. The correspondence files between contractor and project participants from a BIM Level 1 construction project are the input data used to examine the number of RFIs and their respective response times throughout the project.

The remainder of this paper is structured as follows: A brief literature review details out the current definitions of BIM and the RFI process. The current uptake of BIM and barriers to its adaption in Europe will also be addressed. The research methodology and process diagram outlining the research activities used to carry out this study will be addressed in section 3. An introduction the case study, analysis of data sources is defined in section 4. Section 5 outlines the rules and considerations made for the main analysis. Results are drawn in section 6. Discussion and conclusion will be addressed in sections 7 & 8 respectively.

Literature Review

Existing literature indicates that soft gain advantages caused from the implementation of BIM in terms of shared information, coordination and fewer RFIs [6, 3], leading to greater efficiency by means of increased collaboration [7, 4] and the implementation of BIM is expected to be key requirement in the procurement for future private and public works in Ireland [8].

Although researchers have found these advantages, the reality of issues relating to data management and collaboration have been highlighted by others; [8 , 9, 10] the most common being a lack of trust between team members, software issues and the changing roles of project participants in an industry that lags behind other sectors because of its fragmented nature [11].

The examined literature determined the advantages and disadvantages of implementing BIM on construction projects. However, little or no quantitative research has been carried out on the impacts of BIM on the transfer of information between project participants. It is clear that poor RFI processing efficiency is the main critical cause of conflict throughout a construction project [12, 13, 14]. Similarly, response times to RFIs are considered to be KPI's on a construction project. Slow RFI response times lead to schedule and cost overruns increasing the potential for claims [15], [16]. Both Hughes et al (2013) [16] and Hanna et al. (2012) [15] found that two key quantitative metrics to monitor performance in construction projects were:

1. The percentage of RFIs answered within the requested time period and
2. RFIs per million dollars of award contract.

Hughes et al. [16] found that projects between $5M and $50M have an average of 17.2 RFIs per $1 million of construction cost and the median RFI response time for projects with a duration of 1-2 years was 9.4 days. The main metrics used to measure the benefits of BIM implementation are the overall cost, programme duration and cost of changes [17]. Therefore, if this research paper provides results in terms of the quantitative metrics stated both [16] et al. and [15] empirical findings on RFI processing efficiency and RFIs per million euro of award contract.

A wide variety of metrics are used to measure the benefits of BIM implementation, but the overall cost (often used by 50%) and the cost of changes (often used 50.91%) are the most frequently measured aspects of BIM [18]. Therefore, establishing clear, quantitative data on the RFI processing efficiency of a BIM project will determine the benefits of its implementation. The methodology used to investigate this will be addressed in section 2.

Methodology

This section presents an overview of the research methodology undertaken and focuses on producing a detailed quantitative analysis of the improvements, if any, of RFI processing efficiency as a direct result of BIM (Figure 1). The intended outcome of this project is to provide clear results on the reality of BIM's impact on collaboration and project performance by producing a benchmark set of metrics for analysis of the progression of BIM in the future.

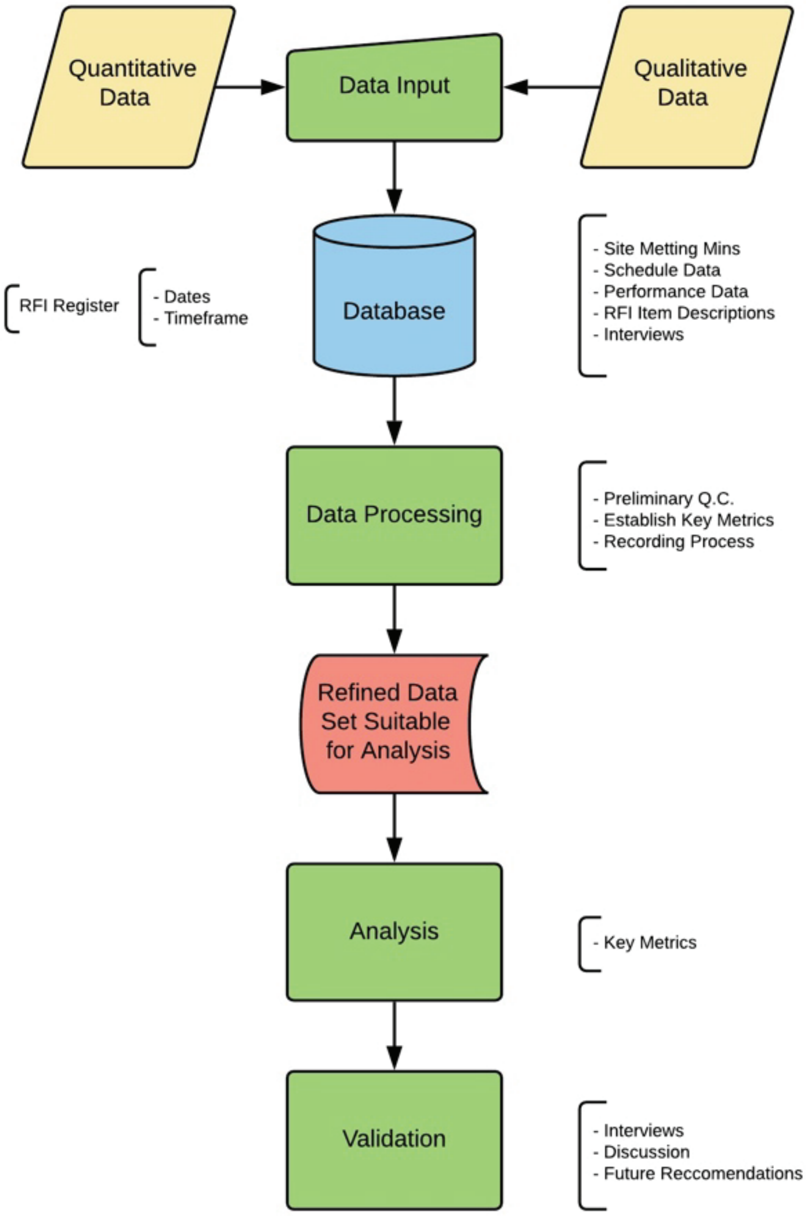


Fig. 1: Methodology for evaluating the effect of BIM on the transfer of information on construction projects

Two of the main advantages of Building information modelling (BIM) are creating and managing information on a construction project across the project lifecycle [4]. Both the transfer of information and collaboration between all project participants are said to have been improved as a direct result of BIM. Therefore, in theory, BIM should positively impact the RFI procedure in three ways:

1. The average response time (in days) for single party RFIs and multi-party RFIs should improve as collaboration and access to information have been enhanced.
2. The percentage of on-time responses for signal party RFIs vs multiple party RFIs should also be equivalent as all project participants have equal access to project's BIM managed model and data via the Common Data Environment (CDE).
3. The number of RFIs issued per million euro of award contract should reduce.

Reviewed RFI literature determined that RFIs are caused due to a lack of detail in the initial design and contract documents issued by the project designers. Response times to RFIs are typical key performance indicators (KPI's) on a construction project. As a result, slow and late response times are considered to be poor performance metrics which can cause disruption and even delays to the project schedule. Both Hanna et al. [15] and Hughes et al. [16] found the procedure considered to be good practice for RFI submittal forms to include:

- Date of Submittal
- Date Response is Required
- Date of Actual Response
- Name of submitter

Therefore, the case study methodology follows this RFI submittal format in order for the average response times, parties responsible and number of late/ on-time RFIs can be calculated. From which, quantitative data on the processing efficiency for single party and multi-party RFIs on a BIM level 1 project can be examined.

Case Study

The case study project was a 3-storey office block in Dublin, Ireland. A BIM managed 3D CAD model was created during the design stages in accordance with the British Standard 1192:2007, 2D drawing deliverables were extracted from model and issued out the main contractor. The project team was made up of 26 different stakeholders. A stakeholder is an individual or organisation that can affect or is affected by the project [19], [20]. In this case, the term stakeholder includes architects, engineers, main contractors and sub-contractors involved in the completion of this project. Table 1 provides an overview of the project. During the construction phase of the case study project, regular site meetings were held between project stakeholders. An online system was used to log RFIs, progress reports and meeting minutes. These documents were shared and updated daily by the main contractor and project stakeholders via a common data environment.

Table 1: Case Study Overview

BIM 1 Project	
Location	Dublin, Ireland
Contract Value	€20m
Building Type	Reinforced Concrete
Area	9700 m^2
Delivery Method	Construction Management

The primary source of data used for this research was taken from the construction documents created throughout all stages of the project's lifecycle. As seen in Table 2, a total of 145 documents were obtained for the findings of this study. The building's 3D model and 2D drawing deliverables were also analysed in order to attain a better understanding of certain RFIs. The literature reviewed in chapter 2 was used as a secondary source of data for this research. We obtained information relating to the RFI procedure format, BIM and collaboration via journals and construction reports. A manual conversion process was needed to transfer this data from PDF electronic documents onto an interactive excel sheet. By doing so, the total response time (in days) and other variables could be calculated.

Table 2: Analysis document list

Project Delivery Issue	**Number of Documents (files)**
Requests for Information	68
Site Meeting Minutes	28
Progress Report	27
Coordination Meeting Minutes	6
BCAR Meeting Minutes	7
Supplementary Documents	10
Total Documents	**145**

This section examines the format of the RFI submittal forms issued by the contractor during the case study project. An important part of the data acquisition for this project was conducting a preliminary quality control on whether the contractor followed the steps considered by some scholars [16, 15] to be best practice when submitting an RFI form.

The RFI Register for the case study project analysed contained all the information suggested in the research methodology section of this paper. The RFI submittal form used by the main contractor during the project contained the following information:

- Item number;
- Attention of;
- Date Requested;
- Date Required;
- Received from;
- Description;
- Form of Response;
- Status and
- Remarks

Similarly, a log containing all RFIs and their status was kept and used as background information for coordination and site meetings. The responsible party/ parties for each RFI was explicitly stated via the "Attention of" field of the RFI submittal form.

Therefore, the specific type of RFI (single party/ multi-party) could be determined.

Scholars [15], [16] found that a key efficiency metric for RFI processing was the number of days for a response to be provided. Therefore, the efficiency of single-party RFIs and multi-party RFIs could be calculated using the data provided.

Rules and Considerations for Analysis

The management and handling of data merit careful consideration in research. The data set used for this paper comprises of both qualitative and quantitative data. Therefore, the rules for its analysis must be applied adequately. Methodological and statistical texts are clear that for ordinal data one should employ the median or mean as the measure of central tendency [21]. However, there are advantages and disadvantages to both forms of statistics. For example, the mean of a data set can be easily biased by adding or removing a few extreme values, however the median remains insensitive [22]. Similarly, the statistical mean represents the full range of a given data set, which can show an honest representation of the central tendency. Both forms will be used in this research paper as they offer a more comprehensive platform from which comparisons can be made. In order to accurately apply the median to a given data set, the assumptions that all measurements are independent and there is no overall systematic error within the sample must be made. If these factors are not considered, the median statistic will lead to the incorrect result [22]. The median and mean statistical forms mentioned above are commonly found in research. However, no measure of central tendency can reveal the whole picture of the examined variable [23]. For example, the median reply time could be the same for both multi-party and single party RFIs even if a large proportion of multi-party RFIs were significantly late. Therefore, in order to effectively establish the processing efficiency for both types of RFIs, a measure of spread for late responses was created which can be seen in Table 3. Using this spread, we categorized the total number of late responses according to the number of days late for each reply. These findings represent the punctuality performance of both single party and multi-party RFIs across the project lifecycle.

Table 3: Late Category Scale

Late Scale	1	2	3	4
Time	1-7 Days	8-14 days	14-30days	30+ days

As illustrated in Table 3, each category is assigned a particular colour and these colours will be coordinated to the punctuality analysis pie charts that form the basis of the Results section. Conducting analysis on the median and average reply times, combined with an investigation into the punctuality performance of single party and multi-party RFIs establishes the metrics as stated by both Hughes et al. and Hanna et al. [16] [15].

Results

Over the total duration of the project a total of 66 RFIs were issued by the contractor, 40 of which were single party RFIs and 26 were multi-party RFIs. 59% of all RFIs were issued during the first 4 months of construction. The total duration of the case study project was 13 months. Hughes et al. [16] analysis in 2013 indicated that projects with a duration between 1 and 2 years had a median reply time of 9.4 days. Multi-party RFIs had a median reply time of 16.5 days versus a median time given of 14 days. Similarly, the median response and reply times for single party RFIs was 15 days and 11 days respectively. These findings suggest that the median time taken to respond to multi-party RFIs was similar to that of the single party RFIs. However, the median reply time for all RFIs was 6 days longer than the results found by Hughes et al. [16], this suggests that even though BIM was implemented, there were no improvements in the processing times for single party and multi-party RFIs.

Figure 2 represents the punctuality of; all RFIs, single-party RFIs and multi-party RFIs, expressed as a percentage throughout the construction project.

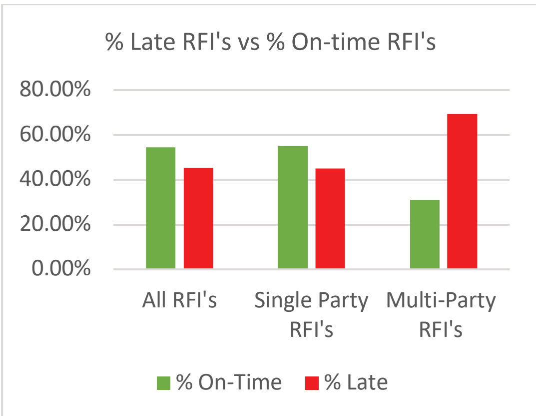
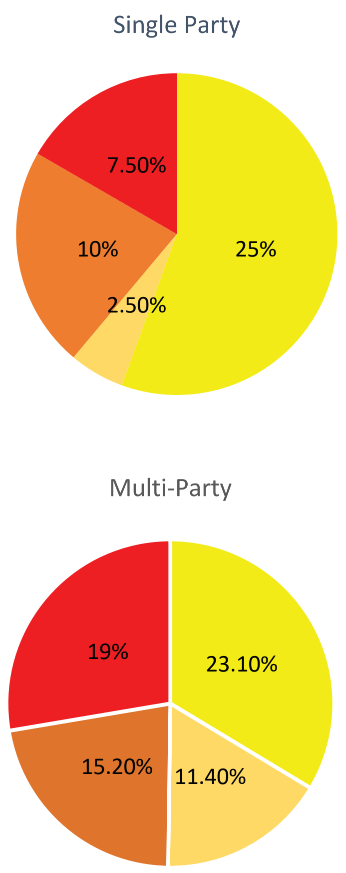


Fig. 2: RFI Punctuality Performance

These results show that 55%, or 22 of the 40 single party RFIs were responded to on-time, while 69%, or 18 of the 26 multi-party RFI responses were late. However, the rules and considerations include a measure of spread for the late RFIs throughout the project. This was achieved by categorizing the 'lateness' in days for all late RFIs. By doing so, the punctuality performance for both single party and multi-party RFIs can be analysed.

Figure 3 represents two pie charts displaying the punctuality performance of single party and multi-party RFIs. As stated previously in Figure 3, 45% of all single party RFIs were late. This resulted in a total of 18 RFIs being responded to outside the given timeframe. From this, 56% were late by 1-7 days and 17% were late by 30 days or more. Figure 3 also concludes that 69% of all multi-party RFIs were late. This resulted in 18 of the 26 multi-party RFIs being responded to outside the given timeframe. A total of 33% of the multi-party RFIs were late by 1-7 days and 28% were late by over 30 days. Figure 3 highlights that 70% of multi-party RFIs and 45% of single party RFIs were late by at least 8 days or more. Therefore, the results suggest that although BIM has been implemented, issues with collaboration are still evident as a result of the poor processing efficiency of multi-party RFIs.



Late Scale	1-7 Days	8-14 days	14-30days	30+ days

Fig. 3: Categories of lateness for multi-party and single-party RFIs

Discussion

Poor processing performance of multi-party RFIs is evident throughout the analysis conducted. Long median reply times coupled with response times of a minimum of 8 days or more for 70% of all multi-party RFIs suggest that issues with collaboration on projects that implement BIM still exist. The increased average reply times for all RFIs in Figure 3 were a result of a number of outliers within the data set that skewed results. These outliers were typically made up of RFIs that were responded to by 30 days or more. One senior engineer observed that:

"In general, it is not uncommon for contractors to abuse the RFI system by submitting large amounts of RFIs, increasing their potential to benefit from claims in terms of finance and schedule extensions. This issue in general can increase the number of RFIs submitted and in turn, increase the number of late responses."

Hughes et al. (2013), found that this issue is so prominent that some claim seminars for contractors include sessions on how to profit through the use of RFIs. A common argument for contractors in cases like this are that large proportion of RFIs were responded to outside the given timeframe, therefore a claim or schedule extension is adequate even if the information was readily available in the original design and specification documents. Similarly, unapproved change orders can directly result from contractors submitting excessive numbers of RFIs. The management of RFI data throughout a construction project merits careful consideration for all project participants.

The case study project saw improvements in terms of the total number of RFIs issued per million euro of the award contract; 3.3 RFIs were issued per million euro of award contract versus 17.2 found by Hughes et al. in 2013 [16]. BIM and early stage contractor involvement were important factors:

"The total number of RFIs issued throughout a project have definitely reduced as a direct result of BIM. Access to information via the CDE has also reduced the overall time spent on re-works and responding to specific RFIs."

However, the study conducted by Hughes et al (2013), contained data from Europe for the RFI median reply times and number of RFI's that received no response. The average number of RFI's issued per million dollars was taken from the global dataset. Therefore, the results for the BIM level 1 project were not strictly comparable to these figures. However, the qualitative results found from the semi-structured interviews with project participants confirmed that there has been a noticeable reduction in RFIs as a direct result of the implementation of BIM.

Conclusions

This study offers an empirical examination of the role BIM has on the transfer of information throughout a BIM level 1 construction project. The overall aim of this paper was to provide a benchmark set of results for analysis on the progression of BIM and its impact on the RFI process in the future. The results found in this paper provide clear quantitative evidence confirming an overall reduction in the total number of RFIs issued on a BIM level 1 project. The main barrier found to implementing BIM into the construction industry was its return on investment (ROI). The results of this paper conclude that if implemented correctly, BIM will improve the transfer of information and reduce time spent responding to RFIs.

The findings determined that issues with collaboration and coordination between project stakeholders still exist. Improving collaboration in construction still requires the key fundamentals of effective communication and coordination between team members to be established during the early stages of a project. The transfer of information and collaboration are set to shift as the public and private sectors move towards BIM level 2 in Ireland. PAS 1192:2 introduced the roles and responsibilities of an Information Manager on BIM level 2 projects. If this role is competently adapted by project stakeholders, improvements to the RFI process and collaboration should prevail. The recent introduction of a new ISO 19650 series in 2018 has incorporated both BS19920 and PAS 1192:2 documents to offer an international standard of good practice for the construction industry.

The main future recommendation of this paper is for project participants to include metadata specifying RFI categories, cost, and schedule implications within the initial contract documents in future BIM level 2 projects. As a result of this, the main contractor would be legally obliged to include this information for each RFI submission. The standards mentioned above, and semi-structured interviews with industry professionals were used to make this recommendation.

Acknowledgements

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The impact of the digital twin on construction contract procurement and disputes – Lessons from 10 years of BIM in the US Government Services Agency

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Abstract – This research is focused on the impact of BIM on construction contract procurement and related disputes. The research uses published US GSA and CBCA data to discern if BIM has had an effect on the nature or quantity of construction disputes. It seeks to find evidence of reduced or improved dispute outcomes by comparing CBCA appeals in 2007 (prior to implementation of Virtual Design and Construction as a contracted requirement by the GSA) and 2017. Differences are found that indicate 3D BIM technology has positively avoided certain types of disputes. However, there are further contractual risks that may be associated with BIM and that may require additional skill and knowledge for construction contract procurement specialists and construction contract practitioners to effectively manage them in the future.

Keywords – BIM, Construction Dispute, Contract Risk.

I Construction Disputes & BIM

"The truly timeless motto 'Prevention is better than cure' is always applicable in dispute resolution. One should understand the nature of the dispute cycle and realize how to break this cycle by taking measures to prevent or address potential disputes from a project's outset."[1]

The application of appropriate technology can mitigate some of the underlying root causes and pathogens that lead to disputes. In particular, appropriate digitization of project design, survey and documentation of existing conditions can mitigate those disputes relating to contract design documentation. Further, the actual process of producing detailed 3D digital designs will foster teamwork, potentially breaking down us and them mentality and forcing project teams to find new practical ways of working with each other through alliance and IPD (Integrated Project Delivery) contracting concepts. "the use of an alliance model encourages cooperative relationships instead of a legalistic approach. Alliance contracting is typically designed to align parties' interests, avoid a blame culture, accept collective responsibility for risk, and avoid win–lose scenarios"[1]. However, other pathogens will remain leading to disputes when events conspire to bring them to the surface. Technology is not a panacea but can be a step in the right direction. 3D design is one facet of BIM. "Expanding the BIM application to dispute resolution or prevention will be a new trend in engineering and construction. Nowadays, BIM represents one of the most promising developments in engineering and construction. It signifies a new way of doing business for the industry, changing the approach to designing, pricing, constructing, and maintaining buildings"[1].

"BIM application requires a collaborative working environment to support effective knowledge and information flow among contracting parties. The concept of integrated project delivery (IPD) is expected to inspire the global engineering and construction market to develop a proper framework for regulating BIM application, to promote collaboration, and to prevent disputes associated with this application"[1]. However, just as there is no single approach to contracting, there is no single approach to BIM implementation or the rules or agreement that should govern it. Despite the literature expounding the many advantages of BIM[2], there is not a consensus as to what it is or even if it is necessary at all. The existing fragmented nature of the AEC industry in many jurisdictions with differing laws and governmental approaches means that it will be a considerable time before a proper framework for regulating BIM application is actually a reality. There will be islands of quality BIM application but no more for the foreseeable time to come.

So, the question remains as to whether BIM has had a positive impact on dispute mitigation or not?

II BIM Legal & Contractual Risks

There are many articles pointing out the potential legal issues that may arise through digitization of design and construction process, however the actual materialization of these risks has to date been almost non-existent[3]. This is either because BIM is working or because it is not being implemented[4] widely enough for the disputes that Olatunji argues are inevitable to percolate to the public view. It is also correctly held that just because BIM related disputes are not reported it does not mean that "the vulnerability of BIM projects to disputes has not been vacated"[5].

Olatunji has argued that "the interdependencies between BIM deliverables and project outcomes is such that a considerably small dispute trigger could enable disproportionate outcomes"[4]. BIM is a tool just as a chainsaw is a tool, when used properly it provides substantial cost savings and efficiency but when it goes wrong it can go horribly wrong. Evidence of such instances have not however been seen in the public domain as yet but contract drafters and project procurement professionals must ensure new legal risks and operating challenges introduced by BIM are mitigated.

III Form of Contract

The UK forms, such as NEC 3 and JCT, utilize standardized CIC Protocol[6] and specific BIM elements are added as part of the technical scope[3]. None of the Irish Forms of Contract include for BIM, instead the same practice as in England has been adopted for those forms, wherein BIM elements are added as part of technical scope possibly including standardized CIC Protocol from the UK or other templated documents.

Some US forms of contract have specific BIM addendums most notably ConsensusDocs® 301 BIM Addendum[7] and AIA E203-2013 BIM and Digital Data Exhibit[8]. USACE and GSA have bespoke contract documents and standards which include specific CAD and BIM Standards[9].

Alwash[5] and many other commentators argue that lack of BIM specific contract forms is an inhibitor to adoption and that "development of a BIM contract instrument is an invaluable step"[5], without which there will just be a continuation of the adversarial approach (of course now potentially further complicated by uncontracted BIM).

IV Hypothesis

Will the digitization of the construction processes and the resulting production of a digital twin to the physical building change the qualitative nature or quantum of construction related disputes? It is often claimed that BIM will reduce construction dispute. My hypothesis is that the nature and quantum of construction disputes will change as a result of BIM implementation.

The nature will change because disputes concerning coordination and sequencing of works will become fewer as BIM will at a minimum largely eliminate problems of space management and when implemented properly will eliminate work sequencing issues. However, there may be new areas of dispute concerned with ownership of model; information interoperability or quality; or design responsibility. Although certain types of claim should become rare, they will not disappear and poor implementations of technology could worsen an underlying bad situation for example were field work proceeds ahead of detail design.

The quantum will change as proper implementation of BIM will greatly reduce the incidence of late changes. There will continue to be changes and uncertainty but these will be played out during the detail modelling phase and less so during construction when productivity of the project is severely impacted due to the high burn rate of physical construction.

This hypothesis is supported by the literature[2], even though adoption of BIM in industry has been slower than anticipated[10]. However apart from anecdotal information from pilot projects[3, p. 9], which are incentivized to be successes and are therefore not neutral studies, there appears to be no data to hand which can prove or disprove such an hypothesis. There is an alternate argument that "It is illogical to measure the social value (collaboration) of BIM using adversarial instruments"[5], but dispute avoidance or mitigation must be a social value of itself and therefore if it can be shown that BIM has positively changed adversarial incidents this must be a logical validation of the hypothesis proposed.

V Selected Data Source

With gratitude to my colleagues, Dr. Bill East and Dr. Shawn O'Keeffe, I was pointed to the US federal governments approach to dispute resolution. With thanks to Dr. Bill East, in particular, I was able to identify both Armed Services Board[11] of Contract Appeals and the Civilian Contract Board[12] of Appeals. Both boards of appeal operate similarly. Contracting Officer decisions can be appealed to the appropriate board signifying a contract dispute exists. This dispute is either negotiated or amicably brought to a resolution, in which case the board dismisses the appeal, usually with prejudice thereby rendering the solution arrived at enforceable. Where an appeal cannot be disposed of amicably or where there is doubt as to the boards jurisdiction the board provides a decision. The boards are creatures of statute and as such they are obliged to publish their decisions and dismissals.

Having randomly reviewed the type of appeals that each board dealt with, I selected the Civilian Board of Contract Appeals (CBCA) as an appropriate data set to use as a basis for investigation into the hypothesis. The Civilian Board was broader in scope having less specifically military content and more content that would be akin to the OPW in Ireland, albeit on a much much smaller scale. I contacted the Chief Counsel of the CBCA to ascertain if there were any reports compiled by them in order to shorten my research. Unfortunately, I was informed that “the Board does not maintain statistics or reports of the sort you are seeking”.

VI GSA and BIM

The GSA is a US Federal Government Agency, established in 1949, responsible for government real estate acquisition, disposal and management as well as procurement of services and equipment for government use. GSA services include the provision of ‘non-tactical’ services for the military, in addition to buildings for civil government function such as: schools, court houses, embassies, museums and office space. According to 2016 annual reports, GSA manages assets valued at $40 Bn. and annually spends in the region of $23 Bn., of which approximately $1.1 Bn. is spend on land and buildings i.e construction. A further $1.7 Bn. is spent annually on Operations and Maintenance. Efficiency and effectiveness of services is paramount. The GSA Office of the Chief Architect implemented BIM to avoid construction cost overruns in excess of legislatively authorized maximum contingency funds. Such overruns require GSA to individually justify legislation to increase the budgets for GSA projects. The GSA has required 3D coordination, which is the most basic component of BIM, to be used since November 2006[13, p. 4]. The GSA invested in a program of 3D and 4D visualization working towards BIM. In 2007 the GSA also required open standards based information to be provided in design models[14]. As well as sponsoring their own programmes and support standards, GSA was involved in setting standards through NBIMS[15]. Notably, the US Army Corps of Engineers was a direct sponsor of NBIMS[16].

VII Methodology

The CBCA has appeals emanating from contracts prior to 2007 implementation of 3D-VDC as well as appeals up to the current time. I researched in detail the appeals in 2007 setting that as a base-line and then again the appeals in 2017 to see if there was a perceptible difference in nature of appeal subject matter as a result of the implementation of a 3d-VDC mandate.

Analysis of 191 Appeals form 2007 took some 22 hours of effort and yielded 77 Decisions to be classified further.

The Boards throughput for both years is approximately 50 Appeals per quarter and is largely unchanged between 2007 and 2017 as can be seen in Fig.1

Date	Decision	Dismissal	Grand Total
2007	**77**	**114**	**191**
Qtr1	25	26	51
Qtr2	19	33	52
Qtr3	11	22	33
Qtr4	22	33	55
2017	**73**	**78**	**151**
Qtr1	30	26	56
Qtr2	20	23	43
Qtr3	23	27	50
Qtr4		2	2
Grand Total	**150**	**192**	**342**

Fig. 1: CBCA throughput

Construction accounts for 55% of Decisions in 2007 but reduced to 45% in 2017 in Fig 2 below

Date	Construction	Leasing	Services	Grand Total
2007	**42**	**8**	**27**	**77**
Qtr1	14	2	9	25
Qtr2	8	3	8	19
Qtr3	5	1	5	11
Qtr4	15	2	5	22
2017	**29**	**11**	**33**	**73**
Qtr1	13	5	12	30
Qtr2	7	2	11	20
Qtr3	9	4	10	23
Grand Total	**71**	**19**	**60**	**150**

Fig. 2: CBCA throughput by type

Construction dispute causations are shown in Fig 3 below.

Year	Changes	Delays	Differing Site Conditions	Not Stated	Termination	Grand Total
2007	15	6	7	5	9	42
2017	8	6	4	8	3	29
Grand Total	**23**	**12**	**11**	**13**	**12**	**71**

Fig. 3: Construction dispute causation

Researching the detail of the Appeals it was possible to identify a number in each year where BIM should have avoided or prevented the disputes from happening. Per Fig 4 a total of 11 were identified.

Year	Changes	Delays	Differing Site Conditions	Termination	Grand Total
2007	4	1	1	2	8
2017	1	2			3
Grand Total	**5**	**3**	**1**	**2**	**11**

Fig. 4: Construction Disputes with BIM impact

There is a discernible difference between 2007 and 2017, notwithstanding that all data for Q4 included in 2007 and not in 2017.

There are 8 appeals identified in 2007 where proper use of BIM should have avoided the dispute completely or led to a resolution prior to appeal.

In 2017, there were 3 appeals, where on the face of it BIM may have avoided the dispute deal with either 4D - scheduling and sequencing; or 5D – quantity take-off and costs.

Decision Date	Case Number	Appellant	Judge	Claim Category	Outcome	Notes
12-Dec-07	***CBCA 870***	Cal, Inc.	Hyatt	Termination	Government	Work Quality and As Drawings at issue
10-Dec-07	***CBCA 439***	Acquest Government Holdings U.S. Geological, LLC	Gilmore	Changes	Mixed	Design Specification a Intent Unclear
07-Nov-07	***CBCA 413***	Acquest Government Holdings, Opp, LLC	Gilmore	Delays	Mixed	Subcontractor claims available
16-Oct-07	***CBCA 582***	Charles Engineering Co.	Sheridan	Changes	Mixed	Defective Work vs Ad Work - Ultimately Bui Performance
01-Aug-07	***CBCA 402-R***	Mitchell Enterprises, Ltd.	Daniels	Differing Site Conditions	Government	GSA's Design provide insufficient interstitia
30-May-07	***CBCA 402***	Mitchell Enterprises, Ltd.	Daniels	Changes	Government	LDI - as subcontracto Mitchell Defective Drawing 98 and Failure by GC to - Interstitial space. Fo contract states servic diagrammatic in natu Argument about qty offsets from take-offs
09-May-07	***CBCA 439***	Acquest Government Holdings U.S. Geological, LLC	Gilmore	Termination	Mixed	950K Argument over design and design int performance specific
30-Jan-07	***CBCA 389, 589, 590***	AMEC Construction Management	Daniels	Changes	Mixed	$6.7M award is allow offset by GSA

Fig. 5: 2007 Disputes that BIM may have prevented

The specifics of the 8 appeals identified in 2007 are: Six of the appeals concern 3D – design model geometry and visualization. In turn these are:

CBCA 439 – Contracting on an incomplete design leading to a dispute about interpretation and performance. Where BIM design methodology is applied this should not have arisen at all, as detail design would be completed by team prior to any build.

CBCA 402 – Space coordination failure – the owners design or changes to same would not fit yet the Contractor had taken on the responsibility to coordinate. Again where a BIM design methodology applied this should not have arisen at all. Problems would have been identified and resolved before build so cost risk would be design time only.

CBCA 402-R – same issue as CBCA 402

CBCA 413 – same issue as CBCA 402 but on a different project with different participates. This issue would not go to dispute were a BIM design methodology used and would have been instead resolved in the model prior to the commitment of real cost or risk to program/schedule time.

CBCA 439 – the republished decision of 10th Dec 2007.

CBCA 870 – Issues of work quality notwithstanding the issue of as built drawings should not arise where proper BIM design and construction methodology is followed. What is modelled is built so variation to the model is strictly controlled and model is updated in order to ensure space management is successful. Traditional build methods may involve a detail as built being prepared as the actual installation will only follow the design intent, often quite loosely. In BIM what is modelled is what is built otherwise the control of space and sequence afforded by BIM is lost.

Of the remaining two appeals identified:

CBCA 582 – concerned a dispute about the delivered building performance. Digitized design using BIM techniques and digital modelling of expected outcomes ensures better communication of the requirements and better understanding of the expected results thereby avoiding such disputes. This requires effort and resources by competent design teams working hand in hand with the building user. Lowest design consultant is unlikely to achieve this.

CBCA 389, 589, 590 – although the appeal instant is about a legal point concerning rights to offset, the underlying project was the renovation of the Interstate Commerce Commission

and Connecting Wing Buildings in Washington, D.C which an earlier appeal found against the Government in the amount of $6.7 M. Little detail is available on the project. The appellant was highly claims orientated. This project was undertaken when many modern digitization methods were in their infancy so it is reasonable to postulate that application of BIM and digitized surveying methods should have greatly ameliorated issues.

Decision Date	Case Number	Appellant	Judge	Claim Category	Outcome	Notes
22-Aug-17	***CBCA 5800***	CTA I, LLC	Chadwick	Delays	Mixed	Probably Constructive Acceleration and Productivity loss mixed
05-Jul-17	***CBCA 5760***	SFM Constructors, Inc.	Somers	Delays	Appellant	Failed to manage contractors sequencing
09-Jan-17	***CBCA 5240***	Bluegrass Contracting Corporation	Somers	Changes	Government	Dispute over Method of Measurement

Fig. 6: 2017 Appeals where BIM should have resolved of the face of it.

The specifics of the 3 selected 2017 appeals show they likely fall outside of BIM. Within the 4D related appeals (CBCA 5800 and CBCA 5760), it is quite likely that these are outside the control of BIM and are really related to allegations of Contracting Authorities' failure to provide timely decisions. The single 5D relate appeal (CBCA 5240) is in reality an argument of the price per unit rather than the quantities per se, so BIM is likely to be of little help there. In fact, it is quite likely that quantities on this work were established based on BIM.

V Conclusion

The most striking comparison between 2017 and 2007 is that there are no 3D related disputes apparent from the 2017 appeals whereas in 2007 there were 6 and possible 7 when AMEC included.

In percentage terms that is 6 of 42 i.e. 14% to 17% of Construction Appeals Decisions.

As per Zack's assumptions[17], it is reasonable to expect that appeals are just the visible part of a pyramidal iceberg of disputes. If an equivalent 14% reduction occurs through the pyramidal iceberg this is a very substantial justification in favour of 3D Coordination and BIM policy adopted by GSA and USACE since 2007.

The second most striking comparison is that there are no new discernible basis of appeals. By 2017 the 3D/BIM policy had been in place for 10 years. One would expect that if there was weaknesses or causation for dispute within this policy that it would lead to appeals. None were found in the 2017 data set.

However, the research conducted here is far from conclusive. Due to resource constraints in particular, it is based on 7 quarters of Appeals over just 2 years (2007 and 2017) reviewing 341 appeals yielded just 11 construction appeal decisions where there was enough detail provided for a single reviewer to access if BIM methodologies should or would have had a positive impact. There is no clear commercial benefit analysis that can be completed with the data available. By just being able to select 2 years there is no view of impact of annual activity levels. For example, the years preceding 2017 may have seen very low levels of project activity leading to no disputes being brought to appeal that would have been avoided by using 3D visualization and coordination. That said it is noteworthy that the boards activity has a constant beat rate of 47 to 49 appeals per quarter. When research data points are viewed in conjunction with the overwhelmingly positive literature concerning the benefits of BIM, it is most likely that the implementation of a contractual obligation to use 3D visualization and coordination along with BIM design processes has indeed effectively eliminated that type of dispute.

The research could be improved by using a team of subject matter experts to review relevant construction decision appeals.

It is to be expected that similar results would be found in the British Isles if similar 3D coordination and BIM design processes were contractually imposed. Although there are differences between British Isles and US Construction Law such as the Spearin Principle, Global Claims and Constructive Acceleration those differences are not such as to void the transposition of the results.

This research into the impact of the digital twin on construction disputes has found that some types of disputes may be avoided but that there are no new types of dispute as a result of BIM, as yet. Research into CBCA decisions of 2007 and 2017 strongly indicates that BIM is impacting the nature and type of disputes and may even completely avoid disputes involving spatial geometric coordination which used to be commonplace prior to BIM, accounting for 14% to 18% of CBCA decisions in 2007. This same research has not shown an emergence of new types of disputes brought about by the introduction of BIM, although the literature is replete with the possibility of such disputes. The research is however far from conclusive as it is only identifies a relatively small number of decisions of the total in each of the years examined that could have been impacted the digital twin.

Due to the private nature of arbitrations and the lack of reporting around arbitrations or adjudications it is difficult, if not impossible, to elucidate solid facts regarding the real impact of the digital twin on construction disputes, however the indications are that it is overwhelmingly positive. For the arbitrator the inevitability of construction disputes remains. The digital twin poses new questions for the arbitrator to resolve as well as new forms of evidence and new standards that should be applied. The arbitrator will be required to resolve new issues in new ways as well as old issues resolved in new ways using BIM and related technologies. In time new forms of disputes are to be expected as a result of BIM but they are not evident as yet.

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CitA BIM Gathering **Proceedings**

BIM Education and Training

Improving the Sustainability of the Built Environment by Training its Workforce in More Efficient and Greener Ways of Designing and Constructing Through the Horizon2020 BIMcert Project

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Abstract−The construction industry consumes up to 50% of mineral resources excavated from nature, generates about 33% of CO^2 present in the atmosphere and is responsible for 40% of total global energy through both construction and operation of buildings. The realisation that current pervasive construction practices now face globalization, sustainability, and environmental concerns, as well as ever-changing legislation requirements and new skills needed for the information age has resulted in technologies such as Building Information Modelling (BIM) becoming a key enabler in navigating these barriers. To assist in overcoming these barriers, a number of funding initiatives have been put in place through Horizon 2020 with a focus on BIM, due to it having the potential to rapidly produce energy outputs that enable design teams to analyse and compare the most cost-effective, energy-efficient options. One of these initiatives, the BIMcert project, aims to educate all areas of the supply chain in the use of BIM, to achieve better energy efficiency during the design, construction and ongoing maintenance of an asset. The goal is to develop more efficient and relevant training programme materials that integrate concepts of sustainability and renewables with practical application and integration with technology. The first stage of this project involved a

detailed and exhaustive process that was used to establish the proposed curriculum, methodologies, concepts, and pilot training material. This paper will explore stage 2 of the BIMcert Project were a series of workshops across the consortium's jurisdictions were used for the rigorous evaluation of pilot training material. The paper will also discuss how the developed training material has assisted in improving the sustainability of the built environment by training its workforce in more efficient and greener ways of designing and constructing through the use of BIM processes.

Keywords– Building Information Modelling, Sustainability, Education, Horizon 2020

I INTRODUCTION

The construction sector is now responsible for one-third of global carbon emissions, one-third of global resource consumption, 40% of the world's energy consumption, 40% of global waste generated and 25% of the world's total water consumption [1]. Increasing energy efficiency and reducing energy consumption are some of the leading research objectives in the Architecture, Engineering and Construction (AEC) industry and have been backed by international strategies, such as the 2020 Climate & Energy Package, which aims for a 20% increase in energy efficiency and a 20% reduction in CO2 emissions, based on a 1990 report [2]. Reaching these figures are made more difficult as a result of clients, consultants, and contractors not willing to change their attitudes and culture by exploring new territories and adopting new ideas and practices [3]. This is made more difficult as the relationships required for the delivery of the constructed product among main contractors and subcontractors are often weak and difficult to manage [4]. The construction supply chain has a reputation for low-trust and adversarial trading relations between supply chain stakeholders [1]. This leads to typical examples of on-site problems such as a lack of information sharing, poor communication between project actors, as well as project members not always sharing the same understanding of the construction project process [5]. If energy targets are to be met then key supply chain stakeholders, namely, the developers, architects, consultants, contractors, and suppliers must harmonize their conflicting interests and coherently implement green practices with each other [1].

In recent years, to try to harmonise the construction sector and offer more rewarding methods of doing business, Building Information Modelling (BIM) has become prevalent. BIM is a collaborative process in which all parties involved in a project use three-dimensional design applications. BIM is now seen as the centrepiece of the industry's digital transformation [6]. Furthermore, BIM can be used to model buildings and sequentially perform multiple analysis, enabling energy performance predictions that can be applied to compare design alternatives, allowing for an improved final decision [2]. BIM-based energy modelling provides several benefits including more accurate and complete energy performance analysis in early design stages, improved lifecycle cost analysis, and more opportunities for monitoring actual building performance during the operation phase [7]. With a rapidly changing climate and global energy crises, the ability to use BIM tools to obtain architectural designs that offer environmental effectiveness has become a leading issue in the contemporary architectural and construction industries [8].

However, if BIM for energy analysis is to be adopted within a project, the developer / client is vital for creating green supply chains, as their green building requirements will play a pivotal role in the green behaviour of other downstream supply chain stakeholders [1]. Energy problems tend to happen in the local construction sector mainly because of inefficient use of energy and lack of skills among construction industry participants [3]. The World Economic Report states that a lack of employees with sufficient BIM skills within the industry is delaying BIM adoption. This is leaving organisations with three options for increasing their BIM talent pool: hiring new talent with the required skills; upskilling the existing workforce; and simplifying BIM technology and processes to reduce required skills. The report stresses that education must be reformed to provide prospective employees with necessary BIM skills, as well as the interdisciplinary skills needed for BIM collaboration [6]. To assist in overcoming these barriers, the Horizon 2020 BIMcert project will educate all areas of the supply chain in the use of BIM, to achieve better energy efficiency during the design, construction and ongoing maintenance of an asset [9].

II BIMCERT BACKGROUND

Horizon 2020 is the biggest EU research and innovation programme ever with nearly €80 billion of funding available over seven years (2014 to 2020). An initial funding call, as part of this programme, was made available with a focus on supporting innovation through research by way of demonstration of more energy-efficient technologies and solutions. The BIMcert consortium, consisting of industry and academia who are experts in providing BIM solutions, skills and training for the construction industry, backed up by a Technical Advisory Board consisting of stakeholders and external experts, responded to the call. The consortium put forward a proposal to enable the development of a method, materials and micro accreditation for upskilling across the construction supply chain to allow BIM techniques and technologies to be utilised to address energy efficiency requirements.

BIMcert's goal is to develop more efficient and relevant training programme materials that integrate concepts of sustainability and renewables with practical application and integration with technology, as based on real-life industry needs and limitations. The BIMcert consortium consisting of members from Northern Ireland (Belfast Metropolitan College and Construction Industry Training Board (CITB)), Republic of Ireland (Technological University (TU) Dublin and Future Analytics Consulting), Portugal (CERIS/Instituto Superior Técnico), Macedonia (Institute for Research in Environment, Civil Engineering and Energy (IECE)), and Croatia (Energy Institute Hrvoje Pozar (EIHP)) established five core objectives consisting of:

1. To **improve the sustainability** of the built environment by training its workforce in more efficient and greener ways of designing and constructing through the use of BIM processes, better materials, products, and energy sources.
2. To engage with the **entire construction sector supply chain** via BIM to develop more extensive European links and to encourage a system of peer support across states of varying maturity concerning the delivery of more energy efficient new and renovated buildings.
3. To encourage **greater workforce mobility**, continuous upskilling, and better employability for all levels of an employee in the construction sector.
4. To **create clear pathways of development for individuals and SMEs to upskill** from any starting point of knowledge to any required level of the individual or collaborative expertise in support of sustainable energy efficient construction.
5. To **develop a pan-European framework** for recognition and accreditation of BIMcert's micro accredited learning modules that will combine to build towards fully standardised skills recognition linking within existing national and European initiatives and frameworks of accredited courses and awards.

The consortium established a series of work packages which are to be conducted in five stages:

- **STAGE 1** – **State of the Art:** an open approach to gather state of the art information through direct engagement with project stakeholders across Europe to ensure that the skills gaps identified by SMEs about the implementation of BIM technologies and methods in support of improved energy efficiency in the construction sector are correct.
- **STAGE 2** - **Development:** development of the BIMcert platform, which will provide information about the project, share BIMcert outputs, and support stakeholders' communication and collaboration.
- **STAGE 3** - **Testing:** the rigorous evaluation of the curriculum, the learning materials, and the proposed platform.
- **STAGE 4** - **Accreditation:** accreditation of the proposed BIMCert training units and courses.
- **STAGE 5** - **Exploitation and Dissemination:** the exploitation and dissemination of the project through a broad-ranging outreach campaign.

The work stages run in parallel and are all critical to each other's success. The paper by McAuley et al. (2019) focused on stage 1 which will be briefly discussed in the next section to provide context to the reader on how the pilot materials were created [9]. This paper will focus on stage 3 with stage 2, 4, and 5 outside of scope, however, references will be made to them throughout.

a) Stage 1 Results

The first stage of this project involved a detailed and exhaustive process comprising of a pan-European wide survey to ascertain the current level of BIM maturity, knowledge, and understanding within built environment practitioners and academia. The results from the survey were cross-referenced with five workshops that were held within the project stakeholders' jurisdictions. The results highlighted that all respondents recognised that BIM training is required at all levels within their organisations with a necessity to raise awareness of BIM as a sophisticated sustainable, supportive software, not only for modelling and visualisation tools but furthermore by developing training modules to facilitate the trend. The results from the survey and workshops were used to establish the basis of what training courses should be designed that best-matched industry needs.

A state-of-the-art literature review of the current global status of BIM with regards to education and what pedagogical methodologies are being applied to deliver these courses was performed in parallel. The survey and workshop findings were aligned with the results from the state-of-the-art literature review where it was found that the most suitable pedagogical approach would involve a scaffolded learning environment guided by a series of instructor-led live lectures. This could be complemented through problem-based learning, design for disassembly, and guided self-learning, which would create an active learning environment. Different teaching approaches comprised of narrative videos and live lectures with a focus on the student engaged in self-guided learning through problem-based learning before they advance.

The initial findings for the suggested training courses and methodologies were tested through a series of reality check workshops. The outcomes from the reality check workshops resulted in the establishment of the final training descriptors, including learning outcomes, suggested syllabi, methodologies and delivery details.

The consortium members decided that the best way forward was to break the development of the curriculum into three strides. Figure 1 identifies the units and courses that best reflect the needs of the industry from the consultation process. The learner initially accesses the BIMcert portal and will be presented with one of two options. If the learner selects Option A, then they must take the BIM Ready training unit plus online assessment. If the learner has prior knowledge of BIM they can choose Option B which will enable them to take the online assessment without enrolling in the training unit. Successful completion of the assessment in either case grants access to Stride 2. This entry unit is critical to ensuring that all learners have a basic understanding of BIM before they select their next unit within Stride 2. The BIM Ready unit is also vital here as it will serve as a diagnostic tool to assist the leaner in the selection of the next unit.

It was agreed to break Stride 2 into three separate sections. Within Stride 2A, the learner can select many standalone units that will introduce them to BIM principles, digital skills, and modelling techniques. The following training units have been developed, as part of Stride 2A in response to the survey and workshops findings.

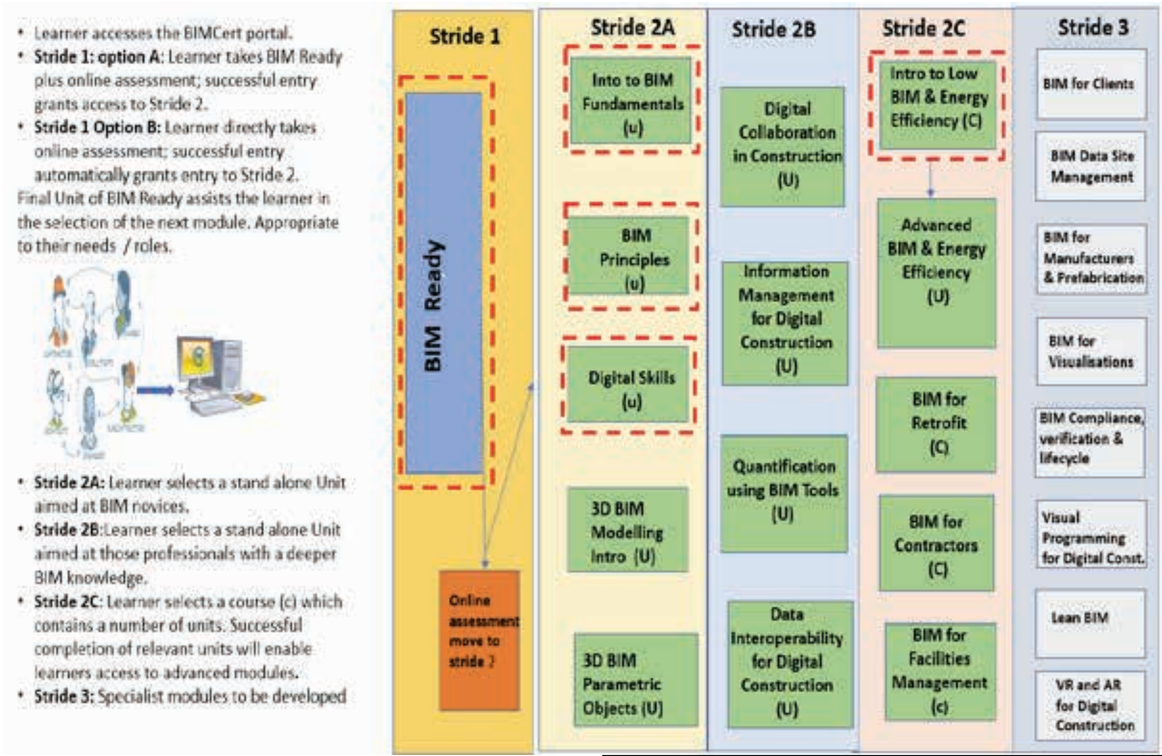
- **Introduction to BIM Fundamentals:** This training unit will enable the learner to develop a fundamental understanding of the information communication technology (ICT) skills required for working within digital construction.
- **Introduction to BIM Principles:** This training unit will allow the learner to develop a fundamental understanding of BIM and associated workflows.
- **Digital Skills:** This training unit will enable the learner to develop a fundamental understanding of the use of digital skills for construction sites.
- **3D BIM Modelling**: This training unit will allow the learner to develop the fundamental skills for three dimensional (3D) BIM using industry standard software for their particular profession.
- **3D BIM (Parametric) Objects:** This training unit will enable the learner to develop the fundamental skills to create BIM objects using industry standard software.

Stride 2B represents units aimed at those more experienced BIM users who wish to advance their knowledge in BIM, e.g., interoperability, collaboration processes, etc. While learning outcomes are developed for these training units, it is not the intention of the BIMcert consortium to develop them any further during this iteration of the Horizon 2020 project. Stride 2C offers learners the choice of one or more courses, which consists of a series of units. Each unit within a course represents a specific learning outcome (LO). This LO / unit will be offered as an individual micro size training option, to ensure that the BIMcert can attract learners who require specific areas of knowledge but do not have the time to complete a standard unit (Stride 2A and 2B) consisting of a series of LOs. After completion of all units associated with the course, the learner will receive a higher award. The learner can take advanced units once they finish the relevant Stride 2C course units, i.e., Advanced BIM & Energy Efficiency. As with Stride 2B, it is not the intention of the consortium to develop all of the courses in this stride. Stride 3 represents a more discipline-focused stride that represents current specialisations of BIM usage, tools, and concepts. The range of units can be expanded or adjusted in the next stage of the BIMcert project in response to market needs.

III METHODOLOGY

A total of five trial workshops were held across the partner jurisdictions. The workshops were hosted both within the partner city bases and online. A variety of material from a selection of LOs from the BIM Ready (Stride 1), BIM Fundamentals (Stride 2A), BIM Principles (Stride 2A), Digital Skills (Stride 2A), and Introduction to Low Energy Building Construction Course (Stride 2C) was developed for testing. The BIMcert consortium selected these particular learning units because these have the potential to impact significant numbers of construction site workers across Europe rapidly.
Figure 1 BIMcert Learning Pathways

In addition, the material could be delivered through instructor-led live lectures which would enable the opportunity for the lecturer/trainer to engage with the class. It was also the intention to develop material that could be used for guided self learning, to gain an insight into how potential users would interact with



this material. The workshops targeted both novice and groups of people *au fait* with BIM from designers and architects to contractors and engineers, as well as policy makers and professional associations (chambers) of engineers and industry. The overarching purpose of the workshops was to establish if the pilot material was adequate to meet the needs of the industry.

IV DEVELOPMENT

A total of 132 physical and 8 online attendees across the five cities participated in the testing of the pilot material. The following section will provide a review of the developed pilot material, workshop structure, and results.

a) Pilot Material

As discussed previously, it was agreed as part of Stage 1 that a selection of material was to be developed from the chosen training units. As each training unit had a series of LOs, it was deliberated amongst the consortium which ones would create the most significant impact during the trials. Table 1-5 details the LOs selected for further development.

LO	Description
An introductory self-study tool covering subjects such as: what is BIM, BIM process, BIM maturity levels, BIM terms, benefits & barriers, etc.	A free self-study and knowledge diagnosis tool to introduce you to BIM and/or provide assessment and recognition of prior knowledge, while getting on track to be ready for BIMcert upskilling and using BIM within your professional role.

Table 1 BIM Ready (Developed by Belfast Metropolitan)

LO	Description
Define what BIM is and explain key terminology	Instructor-led live lecture presentation at all workshops. Presentation material to explain the basic principles of BIM and summarise the common terminology associated with BIM.
List the benefits & value of a BIM workflow	Instructor-led live lecture presentation at all workshops. Presentation material to summarise and list the overall benefits of BIM, particularly concerning specific roles in the construction industry and energy management.

Table 2: BIM Fundamentals training materials (Developed by Belfast Metropolitan)

LO	Description
Explain the context and essentials of BIM.	Instructor led live lecture presentation at all workshops. Presentation material to explain key terms and definitions within BIM, summarise BIM maturity levels, explain the impact of BIM maturity Level 2 requirements for project delivery.

Illustrate the benefits of BIM to the construction sector.	Instructor led live lecture presentation at all workshops. Presentation material to articulate the benefits of BIM to the construction sector.

Table 3: BIM Principles training materials (Developed by TU Dublin)

LO	Description
Describe the use of digital skills and devices in construction.	Online guided self-learning training materials demonstrating how to analyse the use of digital skills and devices in construction.
Define how to use digital skills and devices to access digital information.	Online guided self-learning training materials demonstrating how to access BIM models and information.

Table 4: Digital Skills Training materials (Developed by TU Dublin)

LO	Description
Outline the key principles of system thinking.	Instructor led live lecture presentation at all workshops. Presentation material to demonstrate the key principles of system thinking.
Illustrate how BIM can be utilised in low energy building construction.	Live demonstration of software and plug-in(s) to show energy assessment/simulation to address how BIM tools can reduce energy loss

Table 5: Intro to Low Energy Building Construction Training materials (Developed by the Institute for Research in Environment, Civil Engineering and Energy)

It was agreed to host the pilot material on the BIMcert webpage (https://energyBIMcert.eu) where attendees were expected to complete an evaluation form to provide feedback on the training material. The final established material is to be hosted on the BIMcert Platform to be developed by IST of the Universidade de Lisboa for the final stage of trials in October.

b) Workshop Structure

The workshops took place from January to April 2019 within the five key stakeholder jurisdictions and were led by FAC. They were conducted in English with translation support from consortium partners IST (Lisbon), IECE (Skopje) and EIHP (Zagreb) where needed. The agenda for the workshop covered the following in all five test sites:

- Demonstrate a sample of the training materials.
- Simulate a live version of how to access materials online.
- Simulate BIMcert live webinars, including a live session with a tutor.
- Facilitate Q&A sessions with demonstrators.

All participants had access to sample materials before during and after the trial, to enable them to experiment, use and most importantly give their feedback to facilitate improvement. Each of the workshops broadly followed the following agenda:

1. The workshop was opened by FAC who provided instructions on how to access the materials, as well as discussing the curriculum development and learning pathways.

2. As the BIM Fundamentals and BIM Principles were covering topics that were of similar context Belfast Metropolitan and TU Dublin worked in unison to ensure presentations and materials did not duplicate each other. The BIM Fundemetals LOs delivered by Belfast Metropolitan consisted of two separate presentations which focused on;
   1) define the context and essentials of BIM and explain key terminology; and
   2) list the benefits and value of a BIM workflow.

   The software Kahoot (https://kahoot.it/) was used at the end of this presentation to enable an online interactive assessment component to the workshops and thereby integrating gamification aspect to the trialling process.

3. The BIM Principles LOs delivered by TU Dublin consisted of two separate presentations which focused on;
   1) explaining the impact of BIM matury Level 2 requirements for project delivery; and
   2) illustrating the benefits of BIM to the construction sector.

   TU Dublin also created self-guided learning material for the Digital Skills LOs for;
   1) demonstrate ICT file management; and
   2) demonstrate the use of digital design review tools to access and evaluate a BIM model.

4. The Introduction to Low Energy Building Construction LOs delivered by IECE consisted of a presentation which focused on outlining the key principles of system thinking. The second LO was delivered through a pre-recorded instructional video to illustrate how BIM can be utilised in low energy building construction.

5. Belfast Metropolitan demonstrated the introductory self-study BIM Ready.

6. The remaining time was left open for discussion and feedback from the audience.

Evaluation questionnaires were used to gather feedback from end-users about their experiences, as well as documented feedback from the audience at the end of the workshop. FAC and CITB were responsible for collating this data, and this section of the paper draws from the findings of their report.

While the delivered material was in general well received, some specific comments were recorded from each workshop. The key findings from the Macedonia workshop indicated that there should be a correlation with relevant national standards for construction and energy efficiency, that could be a basis for the adoption of BIM. The training materials that were presented were found appropriate and understandable. However, it was suggested to split them into smaller learning units. Some of the attendees recommended enriching the learning content with more information on BIM in energy efficiency by presenting on a prototype case study. In Croatia, the attendees requested more information on real case studies, BIM objects, libraries, and for a focus on how to extract data from BIM models with more interaction between the lecturers. In Ireland, where BIM is at a more advanced maturity, key comments included the need for more practical application within the materials. Other suggestions were to reduce the learning scope/content to make it more attractive to blue collar workers/skilled trades people. In Portugal, there was a request for material that focused on ISO 19650, case studies and in general more information on certification pathways, as well as the use of interactive tools such as Kahoot or other interactive mediums via the BIMcert Platform. Finally, the UK workshop found that the material should be more practical in terms of how exactly BIM will improve the workflow, reduce text on slides, and explore how BIMcert can be used for Continuous Professional Development (CPD) points.

In summary, the results from the workshop found that awareness has raised since the last round of workshops conducted in stage 1, which was partially due to BIMcert but reported skill level remains comparably static. Contractors still reported being reluctant. The attendees requested better use of case studies to be included in models and tools to exemplify real-life applications of BIM. Stage 1 results found that there was a reluctance to engage with IT as a medium for learning which emerged again at this testing stage. However, the demonstrations of how this IT works and will be integrated into the curriculum has allayed some fears. It was found that the BIM supply chain is still congested, which is a significant factor in preventing uptake and upskilling. Overall, BIMcert is seen as a positive and viable enabler/facilitator of BIM upskilling if mapped to certification and standards clearly.

d) Parallel Work packages

While the workshops were being hosted, there was a series of other work packages working in parallel. This included the IST and iNESC-ID Lisboa, who are responsible for the final BIMcert platform. The platform is being designed in tandem with the material to ensure that users can access the training units and have clarity on their learning pathways. The platform will operationalise gamification theory and application to ensure that users have an interactive and unique BIM training experience. EIHP were also promoting the workshop through social media, as well as using a number of dissemination channels to boost the project's profile and communicate its capability continuously. FAC and TU Dublin worked with EIHP and the full consortium to produce a project video, which can be accessed here:

https://youtu.be/gs6lqXZiaH4

A work package has also been dedicated to seeking accreditation for training units before the final set of trials in October. Accreditation work was ongoing during the workshops, spearheaded by Belfast Metropolitan with input from all project partners. IECE were also establishing metrics to demonstrate how the project could validate its training targets. These parallel work packages are outside the scope of this paper but will be explored in future reports, conference and journal papers released by the consortium.

V Conclusions

BIMcert demonstrates a focused response to assist in upskilling the supply chain by offering just in time training that has been adapted into micro size training units. This will ensure that users have a wide selection of training options that will be accredited before the final release on the BIMcert platform. By building on these training units, it will offer supply chain members the opportunity to demonstrate to potential employers that they have fundamental capabilities to work within a digitally focused environment. Further to this, they will also be educated within sustainability and energy focused construction, as all the proposed training units will have LOs within them to demonstrate/explain how BIM can be used in this context. It is predicted that the BIMcert consortium will upskill 1,000 people by the end of the project (January 2020). This significant training key performance indicator demonstrates the confidence and expected impact the project intends to make in its first cycle.

VI NEXT STEP

The next set of trials will begin in October and will test both the refined material and BIMcert Platform. The project is to be completed by January 2020 and will be celebrated with a conference to be held in Belfast. Our ambition is to catalyse a shift to a more energy-efficient construction sector, reduce the effects of the sector on climate change and provide upskilling pathways to workers that have previously not had access to digital training platforms.

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The BIM-Futures Toolkit: Designing, developing and piloting a professional development capacity framework for academic staff involved in BIM-related education.

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Abstract

In November 2017, the Irish Government set out their strategy for the increased use of Building Information Modelling (BIM) in the design, construction and operation of public works projects that are funded through the public capital programme on a phased basis over the next four years. The subsequent publication of the Roadmap to Digital Transition for Ireland's Construction Industry 2018-2021 clearly identified training and education as key priorities in the development of core competences to enable this transition towards a more collaborative working environment. It identified an urgent need for a consistent, seamless and coherent digital experience for students in Irish education and industry to help grow capacity and maturity in the use of BIM and other innovative techniques. Key to this will be ongoing professional development and upskilling of higher education staff across all built environment disciplines. This paper will present findings from a review of BIM competency-related literature that will inform the development of capacity-building framework for higher education academic staff and students. In addition, a gap analysis of Level 8 programmes in the Department of Building and Civil Engineering in GMIT will be presented to identify opportunities to embed BIM within existing structures in the first instance leading to an evaluation of interdisciplinary learning options with BIM employed as a pedagogical methodology.

Keywords - BIM, Capacity, Competency, CPD, Framework, Higher Education

I INTRODUCTION

The World Economic Forum has identified the need for industry as a whole to drive the transformation that will initiate a mindset 'breakthrough' in relation to: technology, materials and tools; processes and operations; strategy and business model innovation; people, organization and culture; industry collaboration; joint industry marketing; regulation and policies and public procurement [1]. Building Information Modelling (BIM) is identified not only as a key enabler for collaboration and efficiency but also as a facilitator to utilize other exciting technological applications i.e. 3D printing, robotics, augmented and virtual realities etc. The higher education sector has a responsibility to respond to these current industry trends while also exploring possible futures i.e. consider Balfour Beatty's 2050 vision statement [2], which predicts that '*the construction site of 2050 will be human-free. Robots will work in teams to build complex structures using dynamic new materials. Elements of the build will self-assemble. Drones flying overhead will scan the site constantly, inspecting the work and using the data collected to predict and solve problems before they arise, sending instructions to robotic cranes and diggers and automated builders with no need for human involvement. The role of the human overseer will be to remotely manage multiple projects simultaneously, accessing 3D and 4D visuals and data from the on-site machines, ensuring the build is proceeding to specification. The very few people accessing the site itself will wear robotically enhanced exoskeletons and will use neural-control technology to move and control machinery and other robots on site.*'

This challenge is further accentuated by the ongoing talent shortage in the sector, which has been influenced by a failure to innovate, competition from other industries, conservative work cultures and ongoing image difficulties [3]. This hesitation to fully embrace change and innovation has seen productivity stagnate and even decrease over the past 50 years [4]. However, there is evidence to suggest that the recent evolution of digital technologies and applications has begun to facilitate a move towards a more efficient, productive and collaborative way of working.

In November 2017, the Irish Government

recommended the use of BIM in the design, construction and operation of public buildings over the next four years. The subsequent publication of the 'Roadmap to Digital Transition for Ireland's Construction Industry 2018-2021' clearly identified training and education as key priorities in the development of core competences to enable this transition towards a more collaborative working environment [5]. The report identified an urgent need for '*a consistent, seamless and coherent digital experience for students in Irish education and industry to help grow industry capacity and maturity in the use of BIM and other innovative techniques*.'

The most recent survey of UK BIM stakeholders found that overall trends of BIM awareness and adoption have grown from 10% in 2011 to around 70% in 2019 [6]. Interestingly, a stagnation in adoption was identified, which may be tied in with the current uncertainty around who is responsible for the UK BIM roll-out i.e. within central and local government. It was estimated that adoption rates for the full implementation of BIM[1] was closer to 40% in the UK. This suggests that a two-speed industry has emerged, the 'BIM engaged' and 'BIM laggards', since the implementation of the 2016 UK BIM mandate. This trend is also evident in Ireland, where adoption rates are broadly similar, but with variation according to practice size i.e. smaller practices (those employing 15 persons or less) are significantly less likely to have adopted BIM. In addition, BIM is less likely to be used on smaller works i.e. one-off new houses, extensions, conversions, or alteration-type projects [6].

In both the UK and Ireland, significant barriers to BIM adoption remain. In Ireland, the main barriers are a lack of in-house expertise, no client demand, a lack of training and no time to get up to speed. These challenges are not unique to Ireland's construction sector but seem to be more prevalent [7]. These findings also reflect the ongoing challenges in the UK higher education sector where overall levels of BIM maturity awareness have found to be low, demonstrated by a clear lack of interest in incorporating BIM into the curriculum and surprisingly low levels of engagement with industry [7]. In Ireland, higher education institutes have worked in silos [8-14) to provide BIM educational opportunities at different levels of engagement i.e. active, aware, infused and embedded [15] and scale i.e. undergraduate and postgraduate. There is a clear need for a coherent and coordinated national BIM educational framework that will address current and future industry needs. This paper will outline some initial work carried out in phase 1 of a project entitled 'BIM Futures', which is funded by the National Forum for the Enhancement of Teaching and Learning and aims to design and pilot a professional development capacity framework for GMIT academic staff involved in BIM-related education. This will address a significant identified gap in the field of BIM research where recent global reviews have identified: mobile and cloud computing; laser scanning; augmented reality; ontology; safety rule and code checking; semantic interoperability and automated generation; development of BIM tools; the study of BIM adoption worldwide; energy simulation and BIM-based information as the current hot topics [16, 17]. Santos et al. [17] found that the study of BIM at an academic level was limited with a significant gap in relation BIM implementation at the academic level.

2 METHODS AND MATERIALS

The BIM Futures project will include the following general phases of work:

- A literature review and trend analysis of BIM-related academic and industry publications with a special focus on BIM skills, knowledge, competences and industry needs.
- A curriculum mapping of existing programmes in the Department of Building and Civil Engineering in GMIT to identify levels of BIM engagement.
- Design of a draft BIM competency framework to stimulate feedback and discussion.
- Piloting of a BIM competency framework informed by extensive industry and academic engagement i.e. questionnaire surveys, interviews and focus groups.
- Curation, co-design and development of BIM learning resources aligned to identified engagement hierarchy within the BIM competency framework i.e. roles/disciplines, programmes, modules etc.
- Co-design and piloting of a digital badge micro-accreditation framework working in collaboration with industry, students and academic staff.

This paper will outline an analysis of BIM competency-related literature to date to inform the design of a draft framework, which can be used to identify gaps and opportunities in the current undergraduate offerings in the Department of Building and Civil Engineering in GMIT. The initial curriculum mapping exercise involved a simple prioritized word search of all programme documentation using the following six search terms: 'BIM', 'CAD', 'Revit', 'digital', 'information technology' and 'collaboration'. This identified where BIM (and the related terms) were situated in relation to the learning outcomes, and

[1] In this case, the full implementation of BIM can be defined as the strict adherence to the BIM standards i.e. PAS 1192 series and subsequently ISO 19650 series.

curriculum content. Phase 2 of this element will involve extensive engagement through a questionnaire survey and follow-up interviews with academic staff in GMIT to provide a more granular analysis of current BIM learning opportunities i.e. assessment strategies, pedagogical approaches and the identification of BIM leaders in each discipline.

The initial review of BIM competency literature was carried out using a pragmatic structured approach focusing on known academic and industry resources from previous research [18, 19] i.e. UK BIM Academic Forum's Learning Outcomes Framework, the BIM Excellence (BIM_e) and the Scottish Futures Trust BIM Competency Framework projects etc., before undertaking a literature review of publications available in the GMIT library databases. To improve the search results, phrased, nested and truncated search techniques employing simple Boolean logic were used to identify peer-reviewed BIM competency, knowledge and skills publications. Phase 2 of this element will involve extensive engagement with industry practitioners to inform the alignment of industry needs with graduate and academic staff competences.

The BIM-Futures project will also provide a framework to deliver on the commitments made as part of our Disciplinary Excellence in Learning, Teaching and Assessment (DELTA) award, which was the inaugural engineering winner presented to the GMIT BIM team by the National Forum for the Enhancement of Teaching and Learning in March 2018. This included a three-year plan of work focusing on strategy and capacity building; design of learning; teaching and learning practice; assessment as of/for/as learning; and evidence-based informed approaches. The BIM-Futures output of designing, developing and piloting a competency-based assessment tool that will link to formal and informal learning opportunities as outlined in the national professional development framework will enable GMIT to embed BIM and digital literacy as a core pedagogical methodology across all programmes in the Department of Building and Civil Engineering and School of Engineering.

3 REVIEW OF BIM COMPETENCY-RELATED RESEARCH

The higher education sector has a vital role to play in supporting the construction industry to move towards a collaborative and digitally enabled working environment in the future. A significant amount of studies explored the impact of BIM on different learning environments [20-25] including the development of innovative pedagogical approaches [26, 27]. To coordinate these efforts, several attempts have also been made to develop national BIM educational frameworks [15, 25, 28-31]. A key aspect of this work has been to identify what a learner should know, understand and be able to demonstrate on completion of a BIM programme and/or module. Since 1999[2], one of the key developments in higher education has been the use of learning outcomes to provide greater clarity in the description of qualifications. A 'learning outcome' can be defined as a 'statement of what the learner is expected to be able to do on successful completion of a module or programme in order to demonstrate their knowledge, understandings, skills and/or competences' [32]. In 2015, the UK BIM Academic Forum (BAF) published a learning outcomes framework to provide consistent information on Level 2 BIM for interested stakeholders based on 32 subject areas. Concerns have been raised about the currency of this framework due to the lack of its comprehensive adoption (despite widespread awareness) across the higher education sector[3] [33]. BuildingSMART is aiming to address these concerns by establishing a learning outcomes framework that will consist of two levels (core and practitioner, either role- or activity-based) for a professional certificate programme currently under development.

Interestingly, BIM educational initiatives have also focused more specifically on competences rather than the broader scope of learning outcomes. Competency as a term includes concepts of knowledge, skills, abilities, behaviours and successful performance [33]. However, there is lack of understanding and consistency in relation to the terms 'competence', 'competency' and 'competent' within the construction sector. This may be due to the many interpretations of competency i.e. as an individual, team, project, role, task, process, practice etc. [34]. Despite these challenges, there has been a significant amount of work done to date exploring BIM-related competency development and management. Succar [35-41] has carried out extensive work on the development of conceptual constructs (classifications, taxonomies, models, an ontology and a framework) to build a knowledge structure for the BIM domain, which has informed the introduction of a set of tools and workflows that facilitate BIM assessment, learning and performance improvement. The resulting BIM_e initiative[4] aims to develop: a modular language for digital transformation; generate reliable industry-wide competency benchmarks; identify competency gaps; develop competency-based learning resources; facilitate the exchange of knowledge and experience between academia and industry; and developing free-to-use tools and

[2] Bologna Agreement 1999.
[3] Despite these concerns, it is a useful tool to assess curriculum content as outlined in Section 4.
[4] https://bimexcellence.org/

templates to simplify decision-making processes. Other related research has explored the changing roles of clients, architects and contractors [42]; the competences of BIM specialists [43, 44]; the comparative skills of project managers and BIM specialists [45]; and the professional development of BIM actors [46]. Building on this excellent work, the Scottish Futures Trust are currently working to establish a standardized up-to-date BIM competency framework to identify the knowledge requirements or learning development needs of those who are involved in using BIM [47]. The longer-term aim of this initiative is to develop an easy-to-navigate BIM competency framework to support industry and academia to align curricula, training and upskilling to a recognized standard of performance, knowledge and skills. This mirrors the main aim of the BIM Futures project, which is currently exploring how industry needs, graduate and academic staff competences can be mapped and aligned to provide a coherent capacity-building framework for all stakeholders. Succar and Sher [41] have identified the need for the standardization of training and education in BIM to increase consistency, quality and support greater collaboration between education providers. Key to this, will be the ability of individuals to assess their own competence, which can be viewed as currency in the labour market and identify opportunities for personal development.

The first step in developing a framework for GMIT academic staff is to identify current BIM integration by carrying out a curriculum mapping exercise.

4 CURRICULUM MAPPING EXERCISE

One of the main aims of the BIM Futures project is to support higher education academics to assess their competency and highlight possible areas of improvement and/or need. Specifically, this would support academic staff who were setting up a course or updating an existing one. The first step in this process is to map the current curriculum, which identified that three main levels of BIM curriculum content integration exists within the Department of Building and Civil Engineering in GMIT: a stand-alone BIM programme, a stand-alone discipline-specific module or an embedded topic within a stand-alone discipline-specific module (Table 4.1). This can be further categorized into technology, process and people. The B.Sc. in Architectural Technology[5] demonstrates the most consistent BIM curriculum across the four years with one dedicated technology/software-focused module[6] (each worth 10 credits) in each year. Additionally, BIM topics are included in the following Year 4 modules: use BIM analytical software for daylighting design strategies in the 'Innovative in Architectural Technologies' module and BIM legal issues in the 'Professional Practice: Contract and Procurement' module. The B.Sc. in Civil Engineering has dedicated technology/software mandatory modules in Years 1, 2 and 4 (each worth 5 credits), while lifecycle analysis and BIM is included as a topic in the 'Environmental and Energy Sustainability' module in Year 4. The B.Sc. in Quantity Surveying and Construction Economics has a technology/software focus[7] in Years 1 and 2 with dedicated 'BIM for Surveyors 1 and 2' modules that specifically focus on introducing BIM and onscreen measurement applications (Buildsoft, CostX and Autodesk Quantity Take-Off). Additionally, BIM appears as a topic under the communications management element of the Year 4 'Construction Project Management' module. The B.Sc. in Construction Management has a less consistent approach with CAD/BIM modules (each worth 5 credits) in Years 1 and 2. An elective 5-credit module, 'BIM for Construction' is also available in Year 2, which expands on the technological/software applications while also introducing the process. In Year 4, the Project Management module (10 credits) does include collaborative BIM approaches as a topic.

In 2012, the Department of Building and Civil Engineering were successful in applying for Springboard funding to deliver a year-long certificate in BIM to 19 participants. During this time, BIM-related research also commenced in the form of a two-year collaborative project with a local SME building contractor (Carey Building Contractors) to explore the application of BIM on small-scale construction projects. Building on this work, the Department was approached by RPS in 2013 to explore opportunities to develop flexible industry-focused training in BIM.

[5] All undergraduate programmes referred to are Level 8.
[6] All modules are mandatory unless otherwise stated.
[7] This also provides an introduction to the BIM process.

Table 4.1 Curriculum mapping of GMIT Department of Building and Civil Engineering undergraduate courses as detailed in the programme documentation

Programme	Year 1	Year 2	Year 3	Year 4
Architectural Technology	CAD 1 (M) (10 credits)	CAD 2/BIM (M) (10 credits)	CAD 3/BIM (M) (10 credits)	BIM Architecture (M) (10 credits)
Quantity Surveying	BIM for Surveyors 1 (M) (10 credits)	BIM for Surveyors 2 (M) (10 credits)		
Civil Engineering	CAD 1 (M) (5 credits)	CAD 2/BIM (M) 5 credits		Environmental/Energy Sustainability (M) (5 credits)
Construction Management	CAD/BIM 1 (M) (5 credits)	CAD/BIM 2 (M) (5 credits) BIM for Const. (E) (5 credits)		Project Management (M) (10 credits)
BIM (PT)	BIM VF (M) (10 credits) BIM Collaboration (M) (10 credits)	BIM Research (M) (30 credits) BIM Architecture (E) (10 credits) BIM Structure (E) (10 credits) BIM Infrastructure (E) (10 credits) BIM MEP (E) (10 credits)		

Green denotes BIM-related modules while orange identifies partial BIM integrated i.e. by topic.
M = Mandatory, E = Elective

Table 4.2 Curriculum mapping exercise using the UK BAF Learning Outcomes Framework

UK BAF Learning Outcomes	AT	QS	CE	CM	BIM
Understand what BIM is, the contextual requirement for BIM Level 2 and its connection to the Government Construction Strategy and Industrial Strategy 2025; including an understanding of:					
Background and the need for collaborative working (removing waste, errors and poor quality/in-complete information).					
The value of whole life and whole estate approach rather than capital-led and single asset.					
The concept of Soft Landings/Government Soft Landings (GSL).					
Roles and responsibilities of the supply chain members and clients as part of BIM Level 2 delivery (cultural/behavioural).					
External context for BIM, global, national, standards and support communities.					
Core and extended suite of standards, documents and deliverables describing BIM Level 2.					
Barriers to successful adoption of BIM Level 2 and how to create the conditions for success.					
The value of high-quality data and the principles of data management.					
The key vulnerability issues and nature of controls required to enable the trustworthiness and security of digitally built assets.					
Understand the implications and value proposition of BIM within your organisation; including an understanding of:					
Implementation implications for the introduction of BIM Level 2 on your organisation and supply chain (e.g. training, management processes and systems).					
Organisational change management considerations in context of the introduction of BIM Level 2.					
Assessment of capability of your organisation and your supply chain (e.g. standard methods of assessment PAS91 Table 8).					
Technical, technology and interoperability requirements of Level 2 BIM (Information Management/CDE, model-based design and analysis).					
The importance of Level 2 BIM as a driver for business process review and improvement.					
Legal and commercial implementation implications for the introduction of BIM Level 2 on your organisation and supply chain (e.g. commercial stakeholders).					
The value, benefits and investment associated with BIM Level 2.					
How BIM supports the relationship between design, construction and facilities/asset management.					

The potential security threats to built and information assets, and the need for the development of an appropriate and proportionate security risk management approach.					
Understand the requirement for the management and exchange of information between supply chain members and clients as described in the 1192 suite of standards and PAS55/ISO 55000; including an understanding of:					
The purposes for information in the capital and asset phase.					
Requirements for the exchange of information between supply chain members in a collaborative manner as described in PAS1192-2: 2013 and PAS1192.3: 2014 and provided in conjunction with BS1192:2007					
Roles and responsibilities of the supply chain members and clients of BIM Level 2 and the implications on Scopes of Services.					
BIM Plain Language Questions, Employers Information Requirements (EIR), Organisation Information Requirements, Asset Information Requirements and the exchange of information between supply chain and client in a collaborative manner in context of PAS1192.2: 2013 and PAS1192.3:2014.					
BIM Execution Plan (BEP) in context of PAS1192.2:2013 - the related concepts, purpose and implementation principles.					
Digital delivery of information between supply chain members and with clients in context of BS1192-4:2014 (COBie), Digital Plan or Work (DPoW) and classification systems.					
The concept, purpose and implementation principles of Project Information Models (PIM) and Asset Information Models (AIM) and the relationship and interchange between them.					
A Common Data Environment (CDE) as described in the 1192 suite of standards.					
The implications of Level 2 BIM in relation to project team working methods as described in BS1192 :2007.					
The way in which Level 2 BIM can be adopted to benefit decision-making for design management.					
Technologies/methods for creating, using and maintaining structured information.					
Contractual interventions required to support BIM Level 2 and the implications on exiting forms of contract.					
Ownership of information and related issues of IP and copyright, insurances and potential liabilities.					
Requirements for security-minded policies, processes and procedures which address specific security threats or combinations of threats in a consistent and holistic manner.					

Green denotes curriculum content address learning outcome requirement.

This resulted in the development of a two-year part-time stand-alone Level 8 Higher Diploma in Engineering in BIM, which consists of the following modules: BIM Virtual Modelling Fundamentals (Mandatory (M)); BIM Collaboration (M); BIM Research Project (M); BIM Architecture (Elective (E)); BIM Structure (E); BIM Infrastructure (E); and BIM Mechanical, Electrical and Plumbing (E). This programme was initially piloted with RPS staff over a two-year period before been offered industry-wide in 2015. It is currently been delivered to 50 industry stakeholders in a blended format (75% online and 25% face-to-face) supported by Springboard funding. The has won several national awards including the DELTA award from the National Forum for the Enhancement of Teaching and Learning in March 2018 and has supported RPS directly in achieving the 'BIM Level 2 Business Systems' certification by BRE Global in 2015[8] with successful re-accreditation in 2018[9]. RPS have also recently been awarded the full 3-year Continuous Professional Development (CPD) Award from Engineers Ireland. This is the first time RPS have been awarded the full three-year term (previously only achieved 1-year terms) in recognition of achieving the highest level, Band C - Transformational Status. In their final report and recommendations Engineers Ireland stated '*the company has focused on CPD to leverage expertise and deliver professional integrated services to its clients. RPS is an early pioneer in adopting and recognizing the importance of BIM and are well poised to maximize its usefulness overall.*'

This simple curriculum mapping exercise clearly identified a myopic focus on the software/technology side with curriculum gaps related to BIM processes, people and policy. To address this, the principal author piloted the BRE

[8] The RPS Galway Office was awarded BIM Level 2 Business Systems Certification by BRE Global in November 2015.

[9] This accreditation was extended to the RPS Dublin and Cork offices in May 2018 following a successful audit process.

BIM Approved Graduate (AG) course[10] on the 'Integrated Project' and the 'Resource Efficiency Strategies for the Construction Sector' modules in Year 4 (January to April 2019) of the B.Sc. in Quantity Surveying and Construction Economics and Construction Management programmes respectively. The BRE BIM AG[11] is an online course that provides a detailed introduction to the BIM process, with the following online learning units: BIM definition and terminology; standards, methods and procedures; advantages of information management; the role of a BIM manager; the information delivery cycle; employer's information requirements (EIRs); pre-contract BIM execution plans; post-contract BIM execution plans; production of information; exchange of information and interoperability; and asset information models. A blended learning approach was undertaken, with students completing weekly online units, supported by facilitated face-to-face workshops during class contact hours. This offered the students an opportunity to gain an extra professional qualification, as well as fast-tracking them towards BRE Global individual certification as a 'BIM Informed Professional' or 'BIM Certified Practitioners'[12], depending on the student's subsequent industry experience after graduation. The integration and facilitation of the BRE BIM AG course did address some of the gaps in the curriculum but in a stand-alone format as an embedded topic in two existing modules. For example, analyzing the current curriculum using the UK BAF learning outcomes framework does illustrate the image of the BRE course but it can give a false impression of the level of embeddedness across all the undergraduate courses (Table 4.2). For example, closer analysis identifies that dedicated CAD/BIM modules represent just 0.16%, 0.08% and 0.04% of the credit weighting available for the four undergraduate programmes[13]. Additionally, it should also be noted that the integration of the BRE BIM AG course was undertaken by a small number of academic staff (n3). Therefore, this would suggest that there is a significant opportunity to embed BIM more thoroughly and holistically across all offerings in the Department. This will require innovative and authentic engagement with staff to encourage them to move beyond their own disciplinary silos. This is very apparent when you review the programme learning outcomes as it becomes quickly apparent that only the B.Sc. in Architectural Technology refers to BIM specifically under their 'Knowledge Kind' and 'Know-How and Skill' strands. All the other programmes refer to the more general term 'Information Technology' when outlining their learning outcomes as part of their 'Knowledge Breadth', 'Knowledge Kind', 'Know-How and Skill' and 'Know-How and Skill Selectivity' strands.

5 The Design of a Draft BIM Competency Framework for Academic Staff

The aim of the BIM Futures project is to develop a capacity-building continuous professional development BIM framework for academic staff in GMIT. This will include a generic individual competency assessment linked to the four undergraduate programmes and their associated modules. The development of this framework involves a reverse engineering process working back from industry needs to graduate and academic staff competency requirements. A key challenge in this is expressed by Wu and Issa [48] who suggest that 'BIM' education is considered a solution to accelerate the BIM learning curve, thus providing companies with readymade BIM experts when students graduate.' The UK BAF [15] also recognise that 'the increasing volume of output and information relating to BIM in industry and academia will lead to an additional challenge for the HEIs and the need for greater communication and collaboration between academics needs to be recognised.' When considering the structure of the framework, there are several decisions to make in relation to filters i.e. by role, activity, project phase, competency, learning outcome, programme, module etc. The initial draft structure of the BIM Future framework will set about identifying key industry BIM competences aligned to existing and new professional roles that will inform the development of a set of core and discipline-specific competences for academic staff (Figure 5.1). This approach will then utilise the existing undergraduate structure within the Department of Building and Civil Engineering to map industry needs to learning resources that will be aligned to specific modules and programmes. This will enable academic staff to access learning resources through their disciplines and modules (Figure 5.2), providing (in theory) a simple engagement tool. The structure will also incorporate the concept of T-shaped competences, with core competences for all academic staff forming the horizontal bar of the 'T' and the vertical bar representing the

[10] This was also piloted on the BIM Collaboration module on the Higher Diploma in Engineering in BIM by two co-authors, Mark Costello (RPS) and Gerard Nicholson (GMIT).

[11] The GMIT is licensed by the BRE to deliver this programme.

[12] Students needed to achieve a total grade of 70% to be put on the individual certification route.

[13] This does not include BIM topics within other modules as they are a very small percentage or the BRE BIM AG course. During the BRE BIM AG course pilot, it represented 50% of the 'Integrated Project' module and 25% of the 'Resource Efficiency Strategies for the Construction Sector' module.

competences that are specific to each role in a project team [47]. To further support engagement, a micro-credential digital badge will be developed to provide a recognition framework for academic staff who participate. This will be based on 4 levels of competence ranging from basic, intermediate, advanced to expert [40]. The criteria is currently under review but examples of engagement required for each level may include: 'basic', which would require attendance at BIM events and workshops provided throughout the academic year; 'intermediate', which would entail academic staff using the learning resources provided in their modules including student feedback and critical reflection; 'advanced', which would require academic staff to further adapt and develop the learning resources provided, embed into their modules and present their findings; and 'expert' would demonstrate that staff have achieved individual certification/qualifications from external independent bodies i.e. BRE, postgraduate degrees etc., commencing active BIM research resulting in funding, publications etc. The next phase of the curriculum mapping exercise will be to identify opportunities for engagement and embedding BIM across the whole curriculum. Table 5.1 outlines a preliminary assessment of opportunities to embed BIM into the existing structures of the B.Sc. in Construction Management.

6 CONCLUSIONS

As the industry slowly continues with the transition towards a collaborative digital working environment, there is an opportunity for higher education to move beyond the current inertia to clearly demonstrate how BIM responsibilities and activities should be embedded into traditional industry professions and roles. The current trend towards employing 'BIM Managers', 'BIM Coordinators' etc. is understandable at this early stage but can provide a somewhat false impression of what BIM is. For the BIM Level 2 process to work efficiently and effectively on project, there need to clearly demonstrate the within traditional roles i.e. civil engineer, site manager, foreman, site engineer etc. The BIM Futures project aims to address this by embedding BIM across the disciplines to ensure that all graduates will fully understand their responsibilities in this collaborative working environment and will be fully competent to lead in these roles.

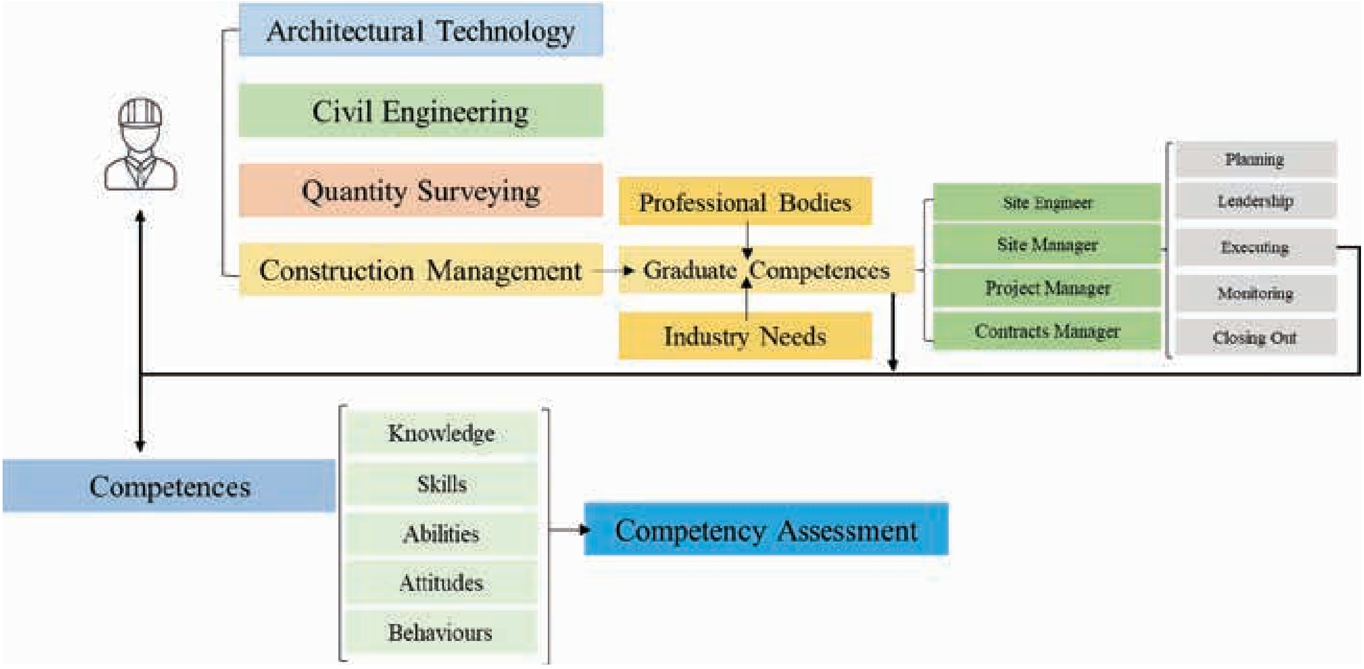

Figure 5.1 Example of draft BIM competency assessment framework structure

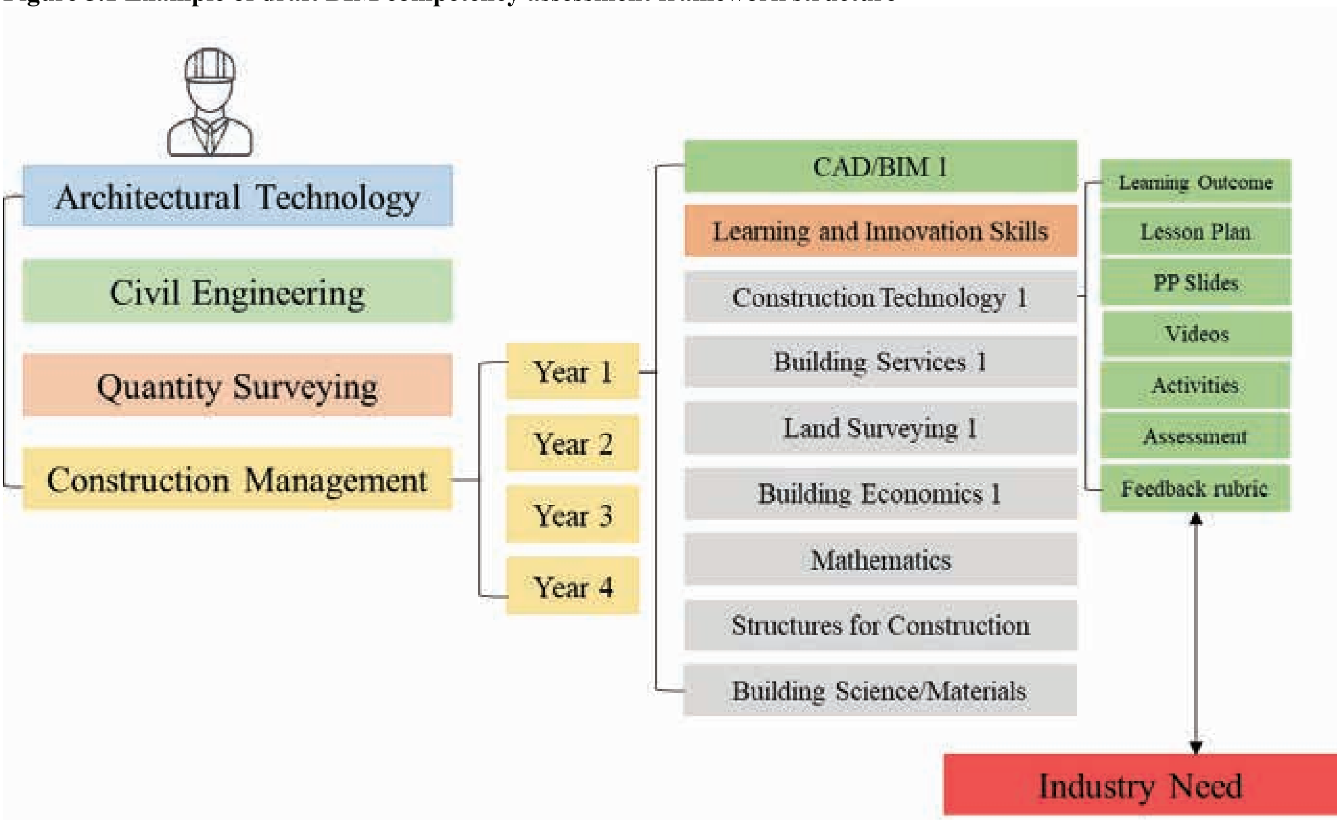

Figure 5.2 Example of draft BIM competency learning resources framework structure

Table 5.1 Preliminary analysis of the B.Sc. in Construction Management to identify opportunities to embed BIM across the curriculum

Programme	Year 1	Year 2	Year 3	Year 4
Construction Management	CAD/BIM 1	CAD/BIM 2	Building Performance and Technology	Project Management (M) (10 credits)
	Learning and Innovation Skills	BIM for Const.	Building Services 3	Resource Efficiency Strategies for the Construction Sector
	Construction Technology 1	Construction Technology 2	Financial and Business Management 1	Construction Law and Industrial Relations
				Financial and Business Management 2
	Building Services 1	Building Services 2	Innovation and Enterprise in the Built Environment	Development Evaluation
				Building Economics 4
				Dissertation
	Land Surveying 1	Land Surveying 2	Building Economics 3	
	Building Economics 1	Building Economics 2	Site Management 2	
	Mathematics	Site Management 1	Site Placement	
	Structures for Construction	Structural Design and Detailing		
	Building Science and Materials	Environmental Management for Construction		
		European Studies		
		Civic Engagement		
		Health and Safety in the Built Environment		

BIM module *Embedded as a topic* *Potential to embed* *Not applicable*

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Using asynchronous learning to enhance the pedagogical experience in teaching BIM technologies to construction students

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Abstract—

Keywords — Blended Learning, Construction Education, Quantity Surveying, Virtual Learning Environment, BIM technologies

I INTRODUCTION

The new TU Dublin will be pedagogically innovative - under the 'Re-imagining our Curriculum theme' there will be an emphasis on teaching practices that transform student learning and programme delivery (Technological University Dublin, 2015). The TU Dublin is committed to offering pathways to higher education through flexible learning and developing a digital campus that will facilitate remote, online and blended learning options to support the needs of an array of learners from diverse backgrounds and geographical locations.

The School of Surveying and Construction Management at TU Dublin is offering two level 8 undergraduate Bachelor of Science (BSc.) degree programmes in Quantity Surveying (QS); one on a full-time basis and the other on a part-time basis. There are several Building Information Modelling (BIM) related modules in these programmes that students must complete during their study. Some of these modules exclusively focus on Information Technology (IT) while others embed the technology within the module material. This research was conducted on undergraduate students in the 2nd year full time, the 4th year full-time and the 5th year part-time courses of the undergraduate degree in QS.

In December 2017, the National BIM Council of Ireland announced its 'Roadmap to Digital Transition for 2018-2021' (2017), the country's first ever construction digital strategy. The aim of the roadmap is for open standard 3D models to be used within a planning and building compliance context and simultaneously drive productivity growth in the construction industry. The Irish government has recently launched an initiative to create a new economic pathway for Ireland based on embracing innovation and technological change, improving productivity, increasing labour force participation, enhancing skills and developing talent and transitioning to a low carbon economy. This initiative is called "Future Jobs Ireland". Pillar one of Future Jobs Ireland (2019) is to "Embrace Innovation and Technological Change". Within this pillar, its main ambition is to "Implement a strategic approach to maximise the benefit from digitisation".

As well as focusing on digitisation in the Construction Industry, the government has also initiated the use of technology in Higher Education (Roadmap for Enhancement in a Digital World 2015-2017 (2014)). One of the key recommendations was to "develop a consistent, seamless and coherent digital experience for students in Irish higher education and actively engage with students and teachers to develop their digital skills and knowledge". With above factors in mind a module called "Measurement and Costing" was developed to enhance digital literacy and skills for quantity surveying students in the construction related programmes. This module is discussed in further detail in section 2.3.

The aim of the research is to examine the educational value of delivering BIM education in a blended learning environment. The objectives of the project are

- To investigate how blended learning can enhance the academic experience of students engaged in learning BIM tools
- To examine the student's perspective to asynchronous online delivery to supplement face-to-face lectures.
- To examine how technologies can be utilised to supplement traditional forms of assessment.

II LITERATURE REVIEW

The literature review highlights the key issues that need to be considered when undertaking the design and development of a more blended approach to student learning. The review examined some of the concepts and main areas around flexible learning, online education, blended learning, pedagogy and explored best practice examples in terms of construction related programmes and online/blended learning provision.

a) Blended Learning

Blended learning, as defined by Bonk and Graham (2006), entails a combination of offline and online deliveries, which combines instructional delivery in a traditional Face-to-Face (F2F) context with online learning. Desmet and Strobbe (2011) see blended learning as an integration of the traditional learning tools with information technology, to deliver a student centred experience. Blended learning is developing rapidly in academia and this growth is one of the modern-day trends in education. Blended learning firmly embeds at its core, a teaching and learning strategy which "combines instructional delivery in a traditional F2F context with online learning, either synchronously or asynchronously" (Gribbins, et al., 2007)

Technology supported education takes several forms, both in its electronic learning (e-learning) and blended learning approaches (Vladlena & Ailsa , 2015), where this research focused on the blended approach. The blended learning experience combines offline and online forms of learning by utilising online e-learning, which leverages technology and is "over the Internet" and offline learning which happens in a more traditional classroom setting. This offers the flexibility of being able to deliver material to the students while on campus and supplement with material delivered off campus" (Dhull & Arora, 2019).

Bentley et al. (2012) concluded in their study that learning is a co-operative and social endeavour with learners gaining significant benefits from being part of a cohort and interacting with staff and other students on a daily basis; with this in mind, it was essential that the design of any blended learning module would recreate this in an online environment. Success in blended learning is very much dependent on the level to which the students are prepared to work in the virtual study environment (Hubackova & Semradova, 2016). Turner (2015) echoes this by emphasising that students placed significant importance on social interaction in the classroom; the development of the module delivery was mindful of this, at all stages of the module design.

b) Asynchronous v synchronous

When designing the online method of delivery for this module both asynchronous e-learning and synchronous e-learning were considered. Synchronous e-learning involves online delivery through chat, live casting and video conferencing. This method is delivered in real time and allows students to ask questions of the lecturer and interact with other students in an online environment (Holmes, 2005). Asynchronous e-learning is pre-recorded material uploaded to a Virtual Learning Environment (VLE) where the material can be accessed at any time. Interaction is less likely and students can complete this element of the course at their own pace. If the students have access to the internet, asynchronous learners have the freedom to complete course material whenever they choose and from any location (Yeh & Lahman, 2007).

The asynchronous method used for this module involved posting video clips and text documents detailing the different elements of the module. One of the reported drawbacks of asynchronous e-learning is the lack of interaction with the lecturer and with fellow classmates (Yeh & Lahman, 2007). When designing this module, the lecturer was cognisant of this and designed the delivery of this module with a combination of asynchronous and F2F learning. The students could complete their project work by reviewing the online material and if they had any questions, they could bring them to the F2F session, which took place once a week for the duration of the module. This method was selected as it was deemed to be the methodology that would keep the students most engaged and would allow students to work at their own pace outside the classroom environment by providing online support material.

c) Enhancing transferable skills through mobile technology

Nazarenko (2015) believes that "professional competence including ICT skills, critical thinking and processing information skills are absolutely necessary for the 21st century". This requirement, for professionals of all disciplines to be competent in ICT skills, was part of the motivation for this project. The range of employment options and the diversity of career paths for graduates has increased in recent times, with graduates taking on roles that are not directly within their chosen profession (Fallows & Steven, 2000). When designing programmes within the School of Surveying and Construction Management at TU Dublin ICT is embedded in many of the curricula, ensuring students have a competitive advantage over other graduates. Embedding employability into the curriculum is seen an important for graduates gaining employment and also obtaining new employment if required (Hillage & Pollard, 1998). E-learning also enables the individual to plan and direct his/her own learning. It has the potential to motivate, develop confidence and self-esteem, overcome many barriers that learners encounter, personalize the learning experience, widen access and improve the learning experience, while also helping people to develop their ICT skills (Bonk & Graham, 2006).

d) Utilising BIM in Construction Education

Up to recently, education and training in QS simulated the traditional measurement and costing workflows, where students learned the basics of measurement by generating Quantity Take-Off (QTO) from 2-Dimensional (2D) paper drawings and derived their cost estimates and Bill Of Quantities (BOQ) from those dimensions. Subsequently, the use of on-screen QTO (CAD measurement) added a degree of efficiency to this process, by enabling digitised measurement utilising software such as CostX, Cubit, CATO, CostOS and Bluebeam. This, however just simulated the 2D measurement process by providing an on-screen electronic version of the drawings for digitisation. This electronic activity enhanced the accuracy and speed of QTO, but maintained the traditional 2D workflow.
In the last number of years, the increasing utilisation of digitisation and particularly Building Information Modelling (BIM) has heralded in a new way of working in the construction industry that goes way beyond the use of 2D information, into that of a virtual environment. Digitation is not only disrupting the construction industry, but also how students are educated for employment in a more technologically advanced environment. This is outlined in more detail in the subsequent sections, but prior to that, a brief review of existing literature on BIM and developments in leveraging BIM for QS practice is discussed, to give background and context to the research topic.

e) BIM and its Application for Quantity Surveying (QS)

Fung et al. (2014) and Underwoord & Isikdag (2010) note BIM has the potential to promote efficiency in the built environment by changing 2D information exchange to a method of delivery that increases integration and collaboration across the construction disciplines. Most definitions of BIM purport its capabilities in delivering value throughout the whole construction life cycle, including the eventual built asset's operation (Eastman, et al., 2011); (Cheung , et al., 2012). The BIM design tool produces a 3D visualisation of the building and is used by Architects and Engineers to create the design information (Eastman, et al., 2011) however, 3D BIM is more than 3D visualisation. In addition to geometric information, the model contains specification data such as an element's u-value, its fire rating and the composition of its material.
Boon (2009) and Ajibade & Venkatesh (2012) determine that by appending time and cost information to 3D BIM, a 4D time model and 5D cost model can be produced, respectively. 5D BIM is the domain of the QS and offers capabilities in automated measurements, providing efficiencies for a QS carrying out construction estimating (Matipa, et al., 2008; Monteiro & Martins, 2013: Smith, 2014). Sylvester & Dietrich (2010) and Crowley (2013) agree that with the 5D BIM process, practitioners can move from spending time on manually generating quantity and cost information, to validating automated quantities and utilising them in their construction estimates. Wijayakumar & Jayasena (2013) state that to carry out effective 5D BIM, QTO must be generated from the BIM to suit QS requirements and measurements rules. Matipa et al. (2010) and Wijayakumar & Jayasena (2013) define this process as 'model mapping', where the objects in the model are attributed to a QS Work Breakdown Structure (WBS), so that when the quantities are extracted from the model they are aligned to that structure. Given that cost information and QS WBSs are not yet ingrained in BIM objects, current practice is that QSs append them in either the 3D design software (i.e. pre-processing the model) or in their own estimating tool (post-processing). Subsequently they can generate their QTO based on this WBS and create their cost estimate. In BIM the detail and accuracy of their estimate will be a product of the level of development in the BIM.
The Level of Development (LOD) in BIM defines how definitive the information is in the objects of a model, i.e. the higher LOD in an object, the more information/specification is in that object. LOD ranges from 100 (conceptual); 200 (design development); 300 (detailed design); 400 (construction) to 500 (as-built) (Barnes & Davis, 2014). In QS, cost planning starts at inception, when indicative costs are produced on the conceptual design. As the design evolves, more detailed estimating is carried out and eventually a BOQ is produced for final price checking and tendering (Ashworth, et al., 2013; Seeley, 1996). In 5D BIM, as the LOD increases throughout the design and construction stages, the more detail the QS has in pricing the model, the more accurate the cost estimates are.
As stated previously, BIM is a new way of working for all stakeholders in the built environment supply chain (Fung, et al., 2014; Underwood & Isikdag, 2010; Underwood & Isikdag, 2010) and thus, presents opportunities and challenges in educating construction professionals. A digitised work environment potentially requires

a new approach to delivering measurement and costing modules on QS courses. Discussed in the review of literature, BIM is not a technology but a process (Cheung , et al., 2012) in effectively delivering the built asset to clients. However, technology is at its core, providing a means of creating information, integration and simulation of data and a more streamlined exchange of that data amongst stakeholders (Eastman, et al., 2011). Using traditional methods of lecture delivery and assessment such as 'chalk and talk', PowerPoint presentations and closed examinations, may not be beneficial to students learning in a digitised environment. This research evaluates whether a more practical approach with a task related pedagogy would be beneficial.

f) Module Overview and Continuous Assessment

As briefly outlined above, the module addressed in this study is 'Measurement and Costing'. The module focuses on the learner's ability to measure and price design information by leveraging BIM to control the cost and value of a building project. The following sections outline the module content, the continuous assessment and the utilisation of VLE in delivery and assessment of the module.

g) Module and Project Structure

The module was assessed through Continuous Assessment (CA) with an overarching project brief outlining the project particulars. The CA required students, over the course of the academic year, to carry out cost planning services up to detailed design on a small sports facility, with four changing and shower rooms. Four incremental estimates were required, simulating the LOD in the QS 5D BIM workflow. Task 1 asked students to carry out a conceptual estimate at LOD 100; Task 2 required students to carry out a schematic estimate at LOD 200; Task 3 was a detailed estimate at LOD 300 and Task 4 encompassed a revised detailed estimate to LOD 300, based on some minor revisions to the design of Task 3.

Each student submitted, at each task/stage, an estimate report (summary cost and elemental WBS) and the electronic files used to produce their cost plan. The students were also required to include a PDF narrative with screenshots and annotations, outlining how they utilised 3D and 5D BIM software to generate their estimates. They were encouraged to carry this out by accentuating the incremental workflow for each task (i.e. not just their finished cost estimate, but how they carried out the task, step by step).

The two main BIM technologies that the students utilised, over the course of the module, were Autodesk Revit and Exactal CostX. The students were given a Revit Architectural model by their tutor at each Task. In each task they carried out pre-processing of the model in Revit and post-processing in CostX. Pre-processing encompassed appending cost codes (QS identification) to an appropriate parameter in the objects of the 3D model. Subsequently they exported the model (with the appended QS codes) into CostX software for 5D post-processing. They then generated QTO based on the WBS they added and produced a Cost Report based on these quantities in the CostX workbook.

h) Virtual Learning Environment (Google-Suite for Education) and Assessment

As well as providing the students with course material through the Google 'Classroom' the lecturer also provided videos through a YouTube channel. The module was delivered through a weekly two-hour tutorial, during which the tutor explained each assessment task, helped the students access their files and explained the first number of steps in each task. The students continued to work on their own and the tutor was available to answer any questions in the class environment. The YouTube channel allowed the students to access the videos to supplement what they did in the tutorials. The students could access these videos directly through a search on YouTube, but they were also directed through a relevant link in Google 'Classroom'. These videos demonstrated the competencies the students needed to achieve in the module, the students were required to demonstrate these competencies through their assessment. If the students had problems completing the assessment, they could revisit the videos as often as was necessary, they could do also use these videos if they missed a class.

The assessment for this project was broken down into a number of competency-based tasks. Competency based assessment is very appropriate for this type of module as it is critical that the students are able to apply their theoretical knowledge as well as wise decision-making skills (Cotton, 1995). Before each deadline, which synced with the students Google Calendar, students uploaded their work to 'Classroom' for assessment. The tutors assessed their work and gave feedback. General feedback was noted on their assessment and specific feedback was highlighting in their documents by adding notes to sentences and images. Once all individual feedback was given, marks were returned simultaneously. It was envisaged detailed feedback at each stage would improve subsequent student submissions.

III RESEARCH METHODOLOGY

The research method adopted for this study was a qualitative approach using an online questionnaire to collect data. This research took place over a two-month period in early 2019 after the students had completed the module in December 2018. The purpose of the questionnaire was to collect data from students on their experience of using the different online elements of the module and to assess the benefit to their learning of BIM tools. An invitation with a link was sent to all the students' email addresses and the questionnaire was completed using Google forms, a platform familiar to all the students. The questionnaire consisted of 4 sections; section 1 focused on the technology being used to deliver the module; section 2 focused on the student experience using asynchronous pre-recorded video clips; section 3 related to the assessment of the module; and section 4 asked the students about their overall experience of the module and where they believed the module delivery could be enhanced. The sections of the questionnaire related directly to the objectives of the research and when constructing the questionnaire, the researcher was cognisant of the type of information that could be gained through this method.

When formulating the questionnaire, the majority of questions were closed questions. Closed questions were favoured as it was anticipated that most of the objectives could be met through these questions, they were also quick to answer for the student and ensured high participation. The closed questions took two different formats, checklists were used to gather factual information about how respondents approached the module and numerical rating scales were used to calculate a score from respondents on their experience of different elements of the module.

The questionnaire did have six open questions and these questions were selected to give the respondents the opportunity to express their views on important aspect of the module and its delivery. These questions allowed the respondent to give information that the research may not be aware of.

The students were informed that the results from the questionnaire would not be used for any other purpose and that it was independent of the quality assurance process used within TU Dublin for assessing student experiences. All students were also informed that the information provided would be anonymised and that they could withdraw from the research at any time.

IV ANALYSIS

The outcome of the questionnaire indicated broad support for the use of blended learning in teaching BIM to construction students. 37 responses were received from 50 potential respondents; this was a response rate of 74%. The data was analysed and examined how the student's responses related to the research objectives. Overall, findings suggest that the method of delivery adopted for this module was favoured by the students when compared to more traditional F2F methods. The results of the survey also showed strong support for the use of an asynchronous blended learning approach. When completing the analysis, each objective was examined individually and the results are set out below.

To investigate how blended learning can enhance the academic experience of students engaged in learning BIM tools

There was a consensus among all participants that their learning was enhanced by the use of blended learning, although there was a variance in the degree to which their learning was improved with over 86% answering 8 or above on a scale of 1-10. This result was not unexpected and any other outcome would have been a surprise as discussions with the students throughout the module were always very positive. One of the respondents felt that the *"module was very effective for the type of class that it was, it would be great if more classes were taught in this type of environment"*. When this result is further analysed the use of recorded videos and the material made available online was the reason for this learning benefit.

Students were very positive to the range of delivery methods required to deliver a module like this, which is in line with Pebedry (2017) findings, the key to successful online learning is to use a range of methodologies for delivering material. Students surveyed indicated that they benefited from having access to the learning material outside the class. Turner (2015) found a similar result with a group of undergraduate students who benefited by accessing "learning resources outside of the fixed requirement of lecture timetables"

What has emerged most consistently from the student feedback was the positivity towards the learning within the module whether through F2F or online delivery. When asked what the highlight of the module was the students did focus on the learning of the module and not on the method of delivery. This is an important finding as the learning outcomes being achieved is far more important than the method of delivery.

The students who participated in the study appreciated the flexibility of deciding where they could access the course material. One student commented, *"It was easy to access material and keep on track with the project brief"*. The students accessed the material from a number of different locations including on the daily commute (even if it was a small number). The students are not tied to a fixed timetable as they have much greater access to their learning when compared to the traditional form of delivery. Part-time students on the programme could access the material from their workplace, which allowed them to complete project work in their workplace in the evening after their day's work. According to the student's perceptions, online asynchronous videos improved their learning of BIM technologies when blended with F2F teaching. When designing the module delivery the lecturers were concerned that the new module delivery may have a negative effect on the class attendance. This however did not materialize, anecdotally class attendance was higher than normal and engagement in class was increased.

To examine the student's perspective to asynchronous online delivery to supplement face-to-face lectures.

Responses indicated that students were likely to visit the online platform on a more frequent basis with almost 57% of respondents indicating that they watched some of the videos more than once. 86% of respondents used the videos when completing revision work and of those 66% felt that "the face to face tutorials are the most effective delivery, but the videos are a good supplement"

The survey showed an interesting split in terms of student's preferred method of delivery; 38% indicated they would watch an online video if they had a problem completing project work, while 43% indicated that they wait for the class to ask the lecturer. Given that these students are probably only using this form of online learning for the first time, this outcome is probably not surprising. That stated, of the 37 respondents, 28 indicated that they have used the videos for learning outside the module. Nearly half of the respondents to this question indicated that they used the videos in the workplace. This is a very positive outcome for the module leader as it indicates how relevant the module is to current best practice in the industry.

A recurring theme that came from the survey questions was the level of flexibility this method of delivery gave to the student. One of the respondents explained the benefits that this flexibility brought him *"I was able to access it at any time or any place so even if I started it in college or at home I always had access to my most recent work and the assessment requirements".* Another respondent also identified the flexibility of the module as one of its great strengths *"Since most of the work on this module is done on a laptop or a desktop, availability to use google classroom to view the document whenever necessary was very beneficial and make the tasks easy"*. This is not the first study that has seen flexibility being highlighted as a benefit of blended learning. Poon (2012) also found that "both academics and students find that blended learning gives greater flexibility for student learning in terms of learning style and study pace".

Responses focused on the assessment of the module were very clear. 86% of respondents indicated that receiving the module assessment through the Google drive benefited their learning. The reasons given for this were varied but many referred to the possibility of immediate interaction with classmates and lecturers *"The lecturer could give you quick and immediate feedback on areas where you can improve. If you had a query it would be answered a lot quicker"*. Another respondent focused on the ability to act on the feedback on the project work *"You can go back and review the feedback multiple times when submitting the next assignment."* Some respondents did indicate that they felt it is important to maintain the personal interaction between the student and the lecturer, the lecturer's in this study was cognisant of the personal interaction and the importance the students put on it.

In relation to the second objective, it was found that while students have varying views on the benefits of a blended learning approach, most agree that it enhanced their learning. The ability to listen on multiple occasions, pause, take notes and subsequently ask questions of the lecturer was of great benefit to the majority of respondents. The students did appreciate the benefits of having access to the online asynchronous material, however many did emphasise that it must be supplementary to the F2F class time. That stated, when submitting continuous assessment work the majority of the survey group preferred to submit using the online tools.

To examine how technologies can be utilised to supplement traditional forms of assessment.

On completion of the assessment the students were very positive about three elements of the assessment, these were, the assessment strategy, the feedback received and the technology used to communicate the feedback. The assessment strategy allowed the students to complete the project work in their own time while being able to refer to the online videos or to the lecturer to clarify any issues they may have. This allowed students to bring their difficulties to the whole class group or post up online for everyone to view. The students also commented that they were more confident to contribute to class in an online environment than in a large class group

The survey showed that the majority of students were in favour of using the online feedback system. More importantly from a pedagogical point of view, 78% of the students indicated that they acted on their feedback, of these 48% said they were more likely to act on the feedback as it was sent through the online platform.

V CONCLUSION

There can be little doubt that the use of blended learning will play a significant role in future landscape of third-level built environment education. The structure of that blended approach is somewhat fragmented, but the research has shown that there is definite scope for further development of this method of delivery.

On completion of the review of the module, it was not difficult to judge whether the students preferred the module with an online element or one that is fully F2F. The benefits that the blended approach brings is well known, from accessibility, improved computer skills, cost effectiveness to accessibility. This project illustrated that online blended learning is an excellent option in built environment education, particularly for students on part-time programmes. The students can continue their education while not being expected to visit the University daily. The module delivered through a blended learning model allowed the students to access material from their workplace which brought many advantages when organising their time. Once a programme team decide to introduce a blended learning module it is important that the VLE meet the requirements of the module. On this module, the Google suite was selected, however on future modules that may change depending on the requirements of the lecturers and students. Whichever VLE is selected it is important that it meets all the requirement of the module and that the lecturers using it are fully knowledgeable on how to use it. This research did not examine the effectiveness of online learning without a F2F element, but the students in their comments did emphasise the importance of the F2F element of delivery. Finding the right mix of F2F and online learning would appear to be the key to successful online learning and if the online environment is to be fully utilised it should be combined with F2F sessions.

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CitA BIM Gathering **Proceedings**

BIM for the Quantity Surveyor

Whole Life / Life Cycle Costing during the Design Stage of a Construction Project: A Qualitative Review

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Abstract − The calculation of Life Cycle Costs (LLC) and Whole Life Costs (WLC) are an important tool in the life cycle of a project. The aim of this research is to examine Life Cycle Costing, Whole Life Costing and the possible advantages and disadvantages to their introduction and use, against the possible benefits or advantages to be derived from their use and their influence on economic decisions at the design phase of a construction project,. A qualitative methodology is adopted, encompassing an in-depth literature review, interviews and qualitative analysis using mind mapping software. This research is novel, in that there is little research that examines the use of; WLC, LCC and Sustainability in a conjoined manner during the design phase, and it is this reason the research is important, as it will add to the industry's understanding of the design process. It also highlights reasons for the success or failure of a construction project, in terms of sustainability, at the design stage and identifies areas in which gaps in our knowledge exist and enhances our understanding of them. Results indicate that the researched topics have many advantages, such as; economic, sustainability and corporate but also have inherent disadvantages, such as; complexity, lack of data, assumptions having to be made and the lack of a standardised method for calculation. It is found that the potential advantages outweighed disadvantages but uptake within industry is still slow and that better promotion and their benefits to; sustainability, the environment, society and the industry are required.

Keywords – Life Cycle Costs (LLC), Sustainability, Whole Life Costs (WLC).

I Introduction

The concept of sustainability applied to development establishes a relationship between the natural environment's ability to support development, with social and economic challenges. Therefore, an integrated methodology to design, construction, and operation is required. This could enhance; design quality, sustainability, buildability, materials management, reduce waste, reduce maintenance needs and consequently reduce whole-life costs. In conjunction with the stated aim, the research also examines the relationship of LCC and WLC to sustainability and if sustainability is considered in conjunction with the researched topics at the design stage and present the findings as a cohesive logical argument. An examination of; industry guides, journal articles and reports, reveals limited information exists on sustainability at the design stage and there is little linkage between WLC / LCC and Sustainability. This new research aims to address this gap in knowledge. This research is important because it is novel and can add to the industry's understanding of the design process.

II Literature review

a) Development of Whole Life and Life Cycle Costing

In 1962 Sir Harold Emmerson, in a report to the House of Commons on problems in the construction industry stated … 'in no other important industry is the responsibility for design so far removed from the responsibility for production'… [1]. This report led to the creation of the Banwell Committee, which noted that approximately 60% of all work carried out by the construction industry was commissioned by Local Authorities and Central Government, encouraging Local Authorities and Central Government to look at alternatives, and changes began to occur in the construction industry. This was followed in 1994 with a report [2] by Sir Michael Latham, titled "Constructing the Team." The Latham Report made wide ranging recommendations. Sir John Egan was Chairman of a task force set up to further examine the construction industry and build upon the Latham Report. The task force report, titled "Rethinking Construction" of 1998 [3] made further recommendations for changes to the construction industry. The Office of Government Commerce (OGC) [4][5] also produced guidance papers; Achieving Excellence and Constructing Excellence. These initiatives and reports encouraged change away from real and perceived negatives to a more satisfactory and acceptable project conclusion. One result has been the gradual transfer of selecting projects based on lowest capital cost, to the costing of a project over its lifespan from inception to demolition. It has been a long-established fact that the evaluation of costs in the construction industry for buildings based solely on initial costs is misleading and erroneous. Costs incurred over the life of the building must also be considered. These are costs associated with the use of building and may occur periodically i.e. cyclic maintenance costs and utilities. There are two main types of costs to be considered; Life Cycle Costs (LCC) and Whole Life Costs (WLC) and each have a role to play when planning or forming a financial model for a building or project. LCC occur at different times over the life cycle, whilst WLC encompasses all stages [6]. The life cycle costs are all the costs for that building from its first inception until the day it is demolished and therefore costs in use would be included here. Costs in use can be defined as … "The costs incurred in owning and occupying a building or other facility whether paid by the owner or occupier. These represent running costs plus the initial cost of the site, construction and associated fees" … [7] [8].

b) Definitions of LCC and WLC

BS ISO [9] published the following definitions. It states that the Life Cycle Cost (LCC) is … 'cost of an asset, or its parts throughout its life cycle, while fulfilling the performance requirements'...and Whole Life Costs are defined as ...'all significant and relevant initial and future costs and benefits of an asset, throughout its life cycle, while fulfilling the performance requirements'…These definitions were set out, partly in response to the confusion and lack of an agreed definition, which existed between LCC and WLC.

c) Time Frame of Whole Life Costing

Whole Life Costing has been the subject of much research by academics and industry experts. This research shows that there exists within the construction industry; contradictory methodologies and assumptions for the calculation of Whole Life Costs. Much debate surrounds the timescale to be used in the calculations. Several papers [10] [11] [12] report that the concept of Life Cycle Costing (LCC) was developed in the 1970's during the energy crisis of that decade. While it stated that … 'LCC was originally designed for procurement purposes in the US Department of Defence and is still used most commonly in the military sector as well as in the construction industry'… [12]. They also report that the adoption of an LCC philosophy has been very slow in adoption within other industries, but that the Public Sector has also been a significant promoter for the use of LCC calculations. There is much debate on the period or the timescale to be used in the calculations for WLC. [13] identified seven periods or time scales, whilst in the previous year, [14] stated that there were two different time periods involved, the first of which was the buildings, system or components life expectancy or an analysis period of 25 years. They further state; … 'It is important when carrying out any form of life cycle costing to differentiate between these two timescales, since there is no reason to believe that they will be equal'… [15] suggests that 15-25 years should be a typical study period for a new building. It is proposed that for long term projects such as infrastructure or prestige buildings then a period up 301 years may be used [16]. This contradicts [17] who state that … 'a whole life cost calculation should not extend beyond 30 years'… their research demonstrated that a buildings' functionality and its economics will change within this 30-year period. John et al. (2003) cited in [18] suggests five stages while Evans et al. (1998) cited in the same paper, states it is three stages. The concept of reliability is introduced and clear, objective arguments for it to be included into LCC calculations are forwarded [18] and they demonstrate the relationship between costs, LCC and reliability.

d) The Use of Life Cycle Costing

WLC / LCC are important tools to be used through the design, planning and construction processes. Balancing the time, cost, quality paradigm shows that the time and quality associated with the project will have a direct bearing on costs associated with the building and its occupancy by end users. It has been found that in projects where the design team focuses only on the reduction of capital costs can leave the client / end user with a building which is expensive to; occupy, operate, maintain and dispose of. WLC analysis is presented as an iterative process [16]. The number of iterations depending on the precision required from the results, types of assumptions made in steps 1 and 2 and the quality of data obtained for costs and timings for project activities. Decisions that are taken in the early stages of the design process can have a substantial influence on the LCC, therefore, careful thought should be given during the design and procurement phases to the costs associated with the building all through the stages of its whole life cycle. The focus on whole life cycle costs should start, if possible at the feasibility stage and when looking at the financial viability of a project.

The five basic steps in making decisions are; [19]

1. 'Identify project objectives, options and constraints'
2. 'Establish basic assumptions'
3. 'Compile data'
4. 'Discount cash flows to a comparable time base'
5. 'Compute total life cycle costs, compare options and make decisions'

The basic assumptions that are generally made are associated with the; period of study, the level of comprehensiveness, data needs, cash flows, inflation and the discount rates. This is furthered [20] by utilising the following questions to steer the use or function of the whole life approach;

- 'What is the total cost commitment of the decision to acquire a particular facility or component over the time horizon being considered?'
- 'What are the short-term running costs associated with the acquisition of a particular facility or component?'
- 'Which of several options has the lowest total life cycle cost?'
- 'What are the running costs and performance characteristics of an existing facility - asset? (Bringing into play post occupancy evaluation)'
- 'How can the running costs of an existing facility be reduced? (Bringing into play benchmarking)'
- 'For a Build Operate Transfer concession project how can the future cost be estimated at design phase and what is the reliability?'

It should be noted that making informed LCC and WLC decisions at these early stages of feasibility, viability and in the design process may prove difficult as there may not be enough detailed information to undertake the required calculations. LCC may be used during the following four key stages of a project;

- 'Project investment and planning; WLC/LCC strategic options analyses; preconstruction'
- 'Design and construction; LCC during construction, at scheme, functional, system and detailed component levels'
- 'During occupation; LCC during occupation (cost-in-use); post-construction' [21]
- 'Disposal; LCC at end-of-life/end-of-interest'

They further demonstrate the stages in which LCC studies should be carried out. LCC allows coherent comparisons to be made between project options with differing cash flows and time frames. The analysis undertaken should consider all pertinent factors throughout the serviceable life of the building, taking into account clients brief and project specific life performance of components within the building.

e) Time Frame - At project inception

WLC / LCC can be used as a constituent part in the investment appraisal process. This process is used to make decisions on capital investment for proposed projects and to balance construction and maintenance costs with the anticipated needs of the building, end users and possible rental values [6] [16] [19] [22].

f) Time Frame - At the Design Stage

WLC / LCC are a major asset at the design phase and the pre-contract phase [22]. WLC / LCC should be used for the evaluation of the various design options presented to see where financial gains can be made, and to assess the economic impact of the various designs throughout the life of the project. Whole life costing analysis is used to provide an economic appraisal of different solutions to a given problem, so that a better decision can be made, however, there are other assessments that also must be taken into account, [16] [21] … 'It is important to take a whole-life approach to the asset, whether or not the same team is responsible design, construction, operation and maintenance'… [5]. It can be shown that the use of WLC / LCC at the design stage will save significant amounts of money at later project stages. It is therefore at the design stage that the greatest gains in value can be achieved. Time and money spent producing a good design can be saved in the construction and maintenance costs. An integrated methodology to design, construction, operation and maintenance, can improve; design quality, sustainability, buildability, reduce waste, reduce maintenance needs and consequently reduce whole-life costs. The stakeholders responsible for the design and construction must therefore work together to identify the most cost-effective design solutions, covering the lifecycle of the project. When considered at this stage, WLC can cause a design to radically alter [1] [5] [6] [7] [8] [11] [14] [16].

g) Procurement

The use of LCC in procurement especially Private Finance Initiatives (PFI) is of great use and is growing. Their correct use and accurate cost profiling can help the tenderer to reduce their tender price and successfully bid for projects and protect themselves over the life cycle of the PFI. … 'Failure of contractors' quantity surveyors to consider life cycle costs had significant financial risk implications for the facilities management contractors, as there were likely to be increased maintenance costs in the future'… [23]. It is said [24] that the use of WLC should be used to make informed procurement decisions across all levels of the project.

h) Private Finance Initiative (PFI) and WLC / LCC

The use of PFI is such that the public sector becomes the buyer of the service from the private sector. This reduces demands on the capital spending of government and local authorities because the capital costs are replaced by a series of unitary charge payments. PFI offers a lot of benefits to the public sector for example, the management and maintenance of buildings are heavily influenced by the original design which can be influenced by WLC. As maintenance issues are considered as part of the design phase, it should lead to an increased efficiency in the administration of the facility and a means of reducing long term spending and risk associated with the building. The main contractors' involvement in PFI is not just for the duration of the building works but can be over the term of the contract so it is in their interest to use WLC / LCC to determine products which have a life cycle longer than his contractual involvement. … 'The use of LCC techniques by the main contractor would enable the consideration of alternatives and encourage the selection of the best value options'… [23] Research into WLC / LCC led to developing a technique whereby the capital costs in acquiring an asset could be compared with the costs in use and maintenance costs over the life span of the asset. Life cycle costing can lead the decision to increase capital costs to reduce running costs in future use, this will lead to a lowering of overall life cycle costs. [22] warns… 'The fallacy of opting simply for the asset with lowest capital costs will then be exposed - the more expensive asset often has a lower total LCC'… A benefit of WLC / LCC would then be whatever option is selected, it is done so after proper economic evaluation.

i) LCC at the Construction Stage

Whilst the correct use of LCC at the design stage should see the greatest financial benefits, it should not be considered that LCC have no further use. During this phase there are four areas in which the application should be considered. [10] [11] [12] [19] [24]. The method of construction can have an influence on expenditure, cash flow and project time. Buildability should be considered; a more efficiently constructed building will have time and cost saving implications. WLC / LCC can be used to determine the most cost-effective acquisition of plant, [25], whether the contractor should; lease, hire or purchase. Those involved in the construction i.e. the construction managers should provide an input at the design stage where they could identify LCC issues which may have repercussions on the; design, manufacture or construction.

j) LCC During Use and Occupation

LCC has an important role in the maintenance and facilities management of a building. Maintenance costs are neither static nor uniform and can be cyclic. They need to be reviewed on a periodic basis. The use of the calculations as described may reduce maintenance costs. LCC can be used as a tool to carry out energy audits on the building. Costs in use also vary and some like occupancy or rates can vary, LCC can be used to model variances and take a role in estate and asset management. [5] [6] [7] [10] [11] [12] [21] [25].

k) Sustainable Construction and WLC / LCC

Sustainable construction takes a holistic approach to the construction processes, [26] it considers issues that may affect the process of environmental and social issues. The integrated methodology to design, construction, operation and maintenance, should therefore lead to more efficient running of projects and the development of energy efficient buildings with lower whole life cycle costs. During the design phase different energy strategies may have been considered but ultimately one needs to be chosen along with any requirements regarding renewable energy sources. It is recommended [27] that these selected options are evaluated in the light of both life cycle assessments (LCA) and WLC / LCC and that a Facilities Management (FM) specialist is involved. The use of WLC / LCC therefore is becoming increasingly important as an evaluation technique in the procurement and design of buildings in sustainable construction. When making sustainability of a building a priority, full account of its whole-life costs must be considered. However, the following caveat must be noted. … 'The cheapest whole-life cost does not necessarily equate to the most environmentally sustainable option'… [28] The BSI and SCSI [9] [29], put forward models comparing WLC and LCC, but the BSI adds in environmental costs, these can prove important when considering sustainable procurement. Another identified barrier is there are many LCC tools available for use within the construction industry but … 'these tools are underused and ignored by many within the industry'… [23]. In the early stages of a project the data required may not always exist for accurate calculations and some assumptions may have to be made leading to uncertainty in calculations. … 'Life cycle costing encompasses a great deal of uncertainty, functions of which are data imperfection, randomness and ambiguity'… [30]. Ashworth (1993) cited in the same paper, argues that the acquisition of LCC knowledge and skills through research and application is still in its infancy, with a considerable gap between theory and practice. This is still the case today. During research for this paper, names of authors would appear on paper after paper and would often cite and reference each other. Most papers investigated, agree that further extensive research into life cycle costing is needed and there exists a general lack of understanding with those that should be the primary users.

l) Risk Management and LCC

The use of LCC in the management of risk is increasing. 'Owners and lending institutions now realise that there is also risk and uncertainly related to the building in use' [29]. The use of LCC as a tool in risk management gives clients better information to make informed decisions on the building and better protect their investment. As LCC looks at all possible costs and brings them back to a Net Present Value it makes it easier to compare and evaluate different buildings and designs. [25]

m) Barriers to Effective Use of WLC / LCC

The construction industry is a complex industry. It requires an immense amount of; differing materials, components, locations and personnel with differing views. For too long project financing was as discussed, looked at in terms of capital expenditure. The industry is notoriously slow and resistant to change, this coupled with a lack of understanding and standardization of WLC and LCC has been a barrier, despite the advantages to their general use, especially in the private sector. In the Building Research Establishment (BRE) report of 1999, [31] it is stated that these costings were used extensively but only in public procurement and PFI projects. A BRE report the following year [33] also noted; 'There remains a significant absence of standardisation across the construction industry in terms of scope and data available.' It is this lack of standardisation that contributes to their lack of use. The lack of standardisation is echoed in the BRE report of 1999 which produced the following 5 barriers for the implementation and use of WLC. There exists;

- 'Inconsistencies across data sets and the level of detail required to make a meaningful calculation of WLC'
- 'Lack of universal methods and standard formats for calculating WLC'
- 'A general lack of perception of client and industry interest'
- 'A need to persuade the industry that WLC is a good thing'
- 'The requirement for an independently maintained database on performance and costs that will continue to expand'

The definitions for LCC and WLC, whilst similar should not be confused. There are differences. The Society of Chartered Surveyors Ireland (SCSI) [29] acknowledges this stating 'Confusion can exist over the terminology as different publications use different terms to describe the concept of LCC.' [24] Whilst WLC and LCC are used interchangeably and is illustrated by the OGC (2010) [5] definition; 'Life cycle costing also called whole-life costing is a technique to establish the total cost of ownership.' This definition is contrast to those put forward by BSI and may cause confusion.

III METHODOLOGY

Given the nature of the paper and its subject matter, Qualitative research is utilised. The qualitative paradigm is based on interpretivism and constructivism so ontologically speaking, there are multiple realities or truths based on one's construction of reality and therefore a subjectivist approach is applied [35]. A three-tiered approach is carried out to address the stated aims this research. This includes; an in-depth literature review, interviews, a focus group and qualitative analysis. The information gathered through the literature review is enhanced by the gathering and interpretation of further results from the Qualitative analysis. The format of the interviews was semi structured, … 'This form of interview uses 'open' and 'closed-ended' questioning but the questions are not asked in a specific order and no schedule is used'… [32]. Several criteria are used in selecting those to be involved. Their location, experience within the construction industry, their client base. Their location is important in terms of obtaining different views from different parts of Ireland, the likelihood of them having previously interacted, convenience for the interviewer. Their experience within the construction industry is also important, it is felt that for this study only those with long term and design phase experience would be interviewed as they would be readily able to answer questions or discuss WLC / LCC knowledgably.

IV DISCUSSION

a) The Advantages of WLC / LCC identified by the Research

There have been twenty-four advantages identified through the research to the use of whole life and life cycle costing. These were exposed through the literature review and the discussions with industry professionals. There were common advantages identified by both types of research. For example, their use at the design stage in comparing design options and cost models was discussed and reiterated during the discussions.

b) Economic Advantages

Of the advantages revealed, the economic advantages were those most talked about during the interview process with ten of the twenty-four factors identified being economic. At the design stage they can be used to make decisions that will affect costs over the life time of the building, [16] [5] and their correct use here will have a significant impact on cost savings.

The research illustrates that WLC / LCC have the influence to affect cost savings. This can also then lead to increased value management and value for money for the client and end users. It is not just at the design stage that economic advantages can be felt, they can also be considered during construction and during the use of completed project [21]. During construction the method of construction can influence expenditure, cash flow and project time, a more efficiently constructed building will have time and cost saving implications. [23] [24] [25]. The use of WLC / LCC in conjunction with lean construction methods was also identified through the research and can be used to establish the most cost-effective procurement method for plant. Those involved in the construction phase can also provide an input, where they could identify LCC issues which may have repercussions on the; design, manufacture or construction. Their benefit can then be felt during occupation and use. They can play an important role in the maintenance and facilities management of a building and can take a role in estate management.

c) Sustainability Advantages

Selected design options can be assessed using WLC / LCC and is therefore becoming increasingly important in procurement and design of buildings in sustainable construction. [24] [25] [26] [27]. They can also be used in the procurement of sustainable materials and elements. WLC and LCC used in conjunction with energy use analysis can be used to select those technologies which not only reduce costs over the life span but the buildings reliance on non-renewable energy sources. WLC / LCC have demonstrated themselves to be useful tools in the appraisal of procurement, design and construction of sustainable buildings.

d) Corporate Advantages

Whilst the use of WLC / LCC has obvious economic advantages and elements such as reduced project costs and increased profit margins could be said to be a corporate advantage. Their use has other less obvious advantages. Their correct and accurate use in cost profiling can help the company to reduce their tender price and increase their chances in successfully bidding for projects and when linked with lean construction can help improve corporate strategy. Their use has also been discussed in relation to sustainability, but the research has shown a direct link between sustainability and corporate image and corporate social responsibility (CSR), so using WLC / LCC to improve sustainability in projects influences corporate image.

e) The Disadvantages of WLC / LCC identified by the Research

Within the literature review and interviews, many of the same problems or disadvantages for WLC / LCC were identified, amongst them were;

- A lack of a standardised model inhibits their use
- A lack of awareness of client and industry interest
- Confusion over definitions
- Early data may not exist
- Inconsistencies with data sets and level of detail required to make calculations
- Incorrect reports / models produced
- Lack of a general method and standard format for calculations
- Lack of data in the early stages of a project
- Level of difficulty in calculations
- Mistakes made by inexperienced staff
- Staff training
- The calculations required are difficult
- Uncertainty in data and the need for assumptions to be made

These disadvantages can lead to incorrect calculations being made and influencing the outcome of a project. Another disadvantage was identified in the literature review [34] and this was the lack of an independently maintained database on performance and costs, this could be solved by undertaking the calculations within BIM software and utilising the BIM database.

V CONCLUSIONS, RECOMMENDATIONS AND IMPLICATIONS FOR PRACTICE

Within the given parameters of the research, it is impossible to do justice to the whole field of whole life and life cycle costing. Whether WLC / LCC works in practice is a crucial question. The general belief of WLC / LCC is that when it is applied to capital cost works it will allow the most economic answer to the lifecycle of the project to be applied but this may not always be the case. There is a danger that the assumptions made may erroneous or inaccurate and inappropriate data used. WLC / LCC do however offer potential and many use the calculations. The philosophy of using a whole costing approach is or seems to be preferable to initial cost estimating which is a narrower and more limited approach. Research shows that it is the construction industry and the military are biggest proponents of WLC /LCC with other industries following behind. Within the construction industry they are mainly used within PFI/PPP projects, their use and advantages need to be better promoted to the private sector. There also appears to be a lack of cross industry research into WLC / LCC, this issue needs to be addressed. WLC / LCC calculations need to be undertaken at strategic decision points over the project lifecycle, from inception at investment appraisal, design stage and tender stage. The calculations need to be accurate and refined as the process continues. Despite the obvious advantages of WLC / LCC, especially in the long term, many firms are still slow to make use of the calculations. It is perhaps because the data on its use is; fragmented, disjointed and too many models for its use exist and in the early project stages assumptions must be made. The research has shown that there are also arguments over the time for the calculations to be based, as each project is unique and has differing requirements. These assumptions can be recalculated as more accurate data becomes readily available as the design evolves. It seems a need exists for a more concise and streamlined model for WLC / LCC. If such a model was developed to suit the specific needs of the construction industry then perhaps more use would be made of WLC / LCC in the design phase to produce more cost effective, efficient and sustainable buildings. There is also a need for those for whom WLC / LCC are a must to be better educated in their use and for owners and end users to be better educated in their use and how to get the best from their buildings in the most economic means possible. With the current economic climate, the industry is now under more pressure to reduce costs and deliver higher quality projects at a lower cost. This means it needs to make a more efficient use of limited financial resources. It needs to robustly deal with the; time, cost, quality paradigm. This reason alone is a persuasive argument for the development and implementation of WLC / LCC and research into a standardised model for the construction industry.

a) Main findings for WLC / LCC

Construction project funding is based mainly on capital costs with little consideration for costs for WLC / LCC. Current economic climate has increased the emphasis cost reduction. Attitude changes towards WLC / LCC, within the industry are needed to be convinced of their long-term benefits. Complicated cost models and calculations are a deterrent for both clients and practitioners and inhibit the use of WLC / LCC. A standardised cost model and calculations are required for the construction industry. Their use has many socio-economic and environmental benefits and advantages which need to be promoted by the industry and Government.

b) Implications for practice

The research has shown that a lack of understanding on WLC / LCC exists. This restricts their full potential and use. Many users stated that the calculations were difficult and in the early stages not all relevant data was available, and assumptions had to be made; many overcame this by relying on historical data. An industry wide attitude change is needed. Many companies do not use the calculations as it was felt they were better suited to publicly procured projects, however, it is clear from the research that they are equally as suited to privately procured projects. Whilst many benefits and barriers have been identified through the research it seems many companies highlight the negative aspects of WLC / LCC. The reoccurring disadvantage to their use is the lack of a standardised method for calculation. The construction industry needs wider adoption of WLC /LCC. As awareness and use increases, more reliable data will become available, making calculations easier.

c) Recommendations

An attitude change towards WLC / LCC is needed within the industry to fully promote, adopt and utilise them. Further research into WLC / LCC to provide a standardised cost model and framework for calculations is required for the construction industry. Also, further research into WLC / LCC and their use in conjunction with BIM is required. Finally, further research into WLC / LCC and their effect on sustainability is also required.

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Increasing efficiency in 5D BIM by Utilising '*BIM Interoperability Tools – Classification Manager'* to append ICMS cost codes

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Abstract – This paper discusses Building Information Modelling (BIM), notably the 5th Dimension of BIM, which covers cost management functionality in the BIM workflow. The research proposes an efficient digitised workflow that can facilitate the appendage of an International Quantity Surveying (QS) Cost Code to a consistent parameter in the objects of the model. This paper firstly outlines how QSs are currently inserting 'user defined' information by adding their cost Work Breakdown Structure (WBS) to an existing parameter, such as the 'keynote' or 'assembly code'. The QS also has the ability to create a QS specific parameter (QS IDentification), by adding an additional shared/project parameter to the model. QS WBSs are usually specific to the jurisdiction of the project, such as the 'Uniformat' in the United States or the 'New Rules of Measurement' in the United Kingdom. The International Construction Measurement Standard (ICMS) is an international standard produced by a coalition of global cost management professional bodies. ICMS seeks to provide a global standard for cost planning and cost reporting, from project conception through to the operation of the finished project. A subsequent edition will relate the standard to BIM and provide a global digitised cost management schema. In preparation for an ICMS digitised schema, this research explores a change to the current 5D BIM workflow, whereby, the 5D BIM QS can utilise the 'BIM Interoperability Tools' Revit Add-in, to efficiently append an ICMS cost code to a new QSID parameter in the object properties. This will provide efficiencies downstream in the QSs software providing users with the ability to extract QTO in line with these cost codes.

Keywords – BIM, building information modelling, international measurement standard, quantity surveying

I Introduction

This research outlines briefly how different types of Quantity Surveying (QS) Work Breakdown Structurers (WBSs), based mainly on the country or jurisdiction they cover, are used to breakdown construction costs into functional elemental cost holding categories. There is a new International Construction Measurement Standard (ICMS) which was first published in 2017, it provides a universal system for comparing international project costs within an international elemental schema. It is envisaged that this schema (or WBSs) will provide efficiency in international construction cost comparison and benchmarking. The review of literature also addresses the 5th Dimension (5D) of Building Information Modelling (BIM) and how a QS WBS can be embedded in BIM, to enable automated Quantity Take-Off (QTO). In section IV the authors outline a number of different ways QS WBSs can be easily appended to the BIM in Autodesk Revit.

Autodesk [1] note that there is another, even simpler, way to assign classifications through a Autodesk Revit add-in tool known as 'Classification Manager'. This process provides the Revit user with an easier interface to assign codes and even add their own content via a custom database. This research outlines how the ICMS was built in the custom database of Autodesk's Classification Manager and assigned to objects in the model, to enable more effective automated QTO.

II Literature Review

a) Standardisation in Construction Measurement

The International Organisation for Standardisation (ISO) are the leading authority on the production of global standards [2]. ISO [3] notes that standards are strategic tools that reduce costs by minimizing waste and errors and increase productivity. The need for standardisation to address market requirements is accepted in many sectors as a means to help companies to access new markets, level the playing field for developing countries and facilitate free and global trade [4].The World Trade Organisation (WTO) "obliges governments to use international standards as a basis for regulation, yet leaves a degree of flexibility with respect to the choice of standard, and the manner of its use" [5].

Standardisation in QS provides a consistent approach to cost planning and the production of Bills of Quantities (BOQs). Good practise in construction cost planning and cost control requires that the QS allocates the overall estimated costs into a number of cost holding categories known as 'elements' or WBSs. These elements are based on the functional components of the design, such as the substructure; external walls; internal walls and doors & windows [6, 7]. Different jurisdictions have alternative elemental classification categories but operate in a similar manner. In Ireland the elements are organised in accordance to the National Standard Building Elements (NSBE). In the UK these elements are arranged according to the framework from the Building Cost Information Service (BCIS). Elemental costs can be compared to the elemental totals in similar projects. They may also be compared to the cost of the corresponding element in the previous estimate to isolate areas in the design that could have increased/decreased in cost [6, 7].

Presently no single universal WBS or method of measurement is used by those responsible for the preparation or recording of construction costs [8]. The variance in standard WBSs on construction projects from region to region and even within different sectors of the construction industry can lead to discrepancies in cost comparisons.

b) International Construction Measurement Standards

The property sector realised that a range of discrepancies existed in the measurement of both Gross Internal Floor Area (GIFA) and Gross External Floor Area (GEFA). To address this issue, the International Property Measurement Standard Coalition (IPMSC) was formed [9]. The first property measurement standards for office buildings was produced in 2014.

Following on from the establishment of the IPMSC, it became apparent that similar issues existed in the construction sector. The inaugural meeting of the International Construction Measurement Standard Coalition (ICMSC) was held in Washington in 2015. The aim of the coalition is to "develop and implement a common standard for construction measurement which enhances transparency, investor confidence and public trust in the sector" [10].

A working group was established consisting of 27 independent experts from 17 different countries [10]. This working group is referred to as the Standard Setting Committee (SSC). The remit of the SSC is to draft and consult with industry on a new International Construction Measurement Standard (ICMS). The first ICMS was published in 2017, this provides a universal system for comparing international project costs on a "side-by-side" basis for the first time. The first edition of the ICMS establishes a basis for the comparison of international construction measurement costs, across the various construction sectors. For consistency, The ICMS took the definition of GIFA and GEFA as defined within IPMS.

In subsequent editions it is envisaged that the ICMS will be expanded for Life Cycle Costing (LCC) and the integration of construction cost information within BIM. Each of the organisations of the coalition have agreed to adopt and promote the use of the ICMS. The standard is backed by the United Nations (UN), International Monetary Fund (IMF) and the European Union (EU).

c) 5D Building Information Modelling (5D BIM)

BIM has the potential to foster efficiency in Architecture, Engineering and Construction (AEC), by changing prevailing 2 Dimensional (2D) work practices to technologies and processes that promote integration and collaboration across the construction disciplines [11, 12]. The BIM design application produces a 3 Dimensional (3D) visualisation of the building and is used by Architects to create the design [13]. However 3D BIM is more than a 3D visualisation, because it is what is contained in the model, or the objects of the model, that is of importance, such as its u-value, fire rating, specification and potentially a QS Identification (QSID) or WBS.

By appending time and cost information to 3D BIM, a 4 Dimensional (4D) time model and 5 Dimensional (5D) cost model can be produced, respectively [14, 15]. 5D BIM is the responsibility of the QS and provides capabilities in the automation of QTO, which has the potential to save considerable time when producing cost plans and BOQs [16, 17, 18]. 5D BIM, practitioners can move from manual tasks such as measurement, to validating automated quantities and utilising them in their construction estimates [19, 20]. To carry out effective 5D BIM, QTO must be generated from the BIM to suit QS requirements and measurements rules [21]. This process is defined as 'model mapping', where the objects in the model have a QS WBS appended, so that when the quantities are generated from the model they are extracted per the QS WBS [21, 22]. Unfortunately BIM objects do not come pre-processed with a WBS, also known as a 'QS Identification' (QSID), thus, the QS must add these to the BIM themselves.

The QS WBS utilised on a 5D BIM project is dependent on the jurisdiction where the project takes place. As discussed in the review of literature, there are many different WBSs depending on the country or jurisdiction they encompass. It would be near to impossible for BIM software manufactures to add all the WBS codes into the objects, for every global standard, due to the amount of standards that exist [17]. Current practice is that the QS adds these codes themselves in the 3D authoring application (pre-processing) or append them in the 5D estimating tool (post-processing), to suit the WBS they require [17 20]. Subsequently the QS can filter their QTO based on this WBS and create a coded cost estimate [23].

The ability of different BIM software varies in this regard, from being able to access and select model quantities, to comprehensive model mapping functionality, where users can define and edit rules or codes by which the quantities can be extracted [24]. If pre-processing was carried out by the Architect in their design software, even to just identify what objects are below ground or above ground, or to establish the QS WBS as a user defined parameter, this would be beneficial to the QS downstream.

The most common method of carrying out processing of model quantities is in a 5D tool [23]. However, some Architectural software, such as Autodesk Revit, has efficient functionality in this regard, providing users with a means to add a QS WBS to an existing parameter, such as the 'keynote' or 'assembly code'. In Revit you also have the ability to set up a new project parameter or use the add-in tool 'Classification Manger' to simply select and assign a WBS. If these codes were appended in the design authoring application (either by the Architect or by the QS) the subsequent downstream extraction and validation of quantities would be significantly easier.

d) Adding QSID in Revit (Pre-Processing)

The following subsections briefly outline common ways a QS or Architect can add a QSID (QS WBS) to the model in Autodesk Revit. Video tutorials, prepared by the authors in conjunction with this paper, outline these methods in more detail and are available on You Tube [25].

<u>Keynote</u>

The Keynote parameter in Revit is set up by default to assign the MasterFormat number. The MasterFormat is a US specification classification schema and thus is not applicable outside the US. Autodesk [1] note that most people use this Keynote parameter to add their own custom information. The keynote is a text file (.txt) embedded in the programme files of Revit, it can be accessed via the '*Keynote Settings'* in the '*Annotate*' ribbon panel. Users have the opportunity to change the default MasterFormat, by copying the MasterFormat keynote text file, changing the content, and subsequently assigning the new text file to the project. The new revised keynote file can then be utilised to assign a more appropriate classification to any object or objects in the model [25].

<u>Assembly Code + Assembly Description</u>

These parameters are used to assign the UniFormat cost classification structure. UniFormat is a US Cost WBS and is not relevant outside that jurisdiction. However, similar to the keynote, these text (.txt) files can be manipulated to suit any WBS. For example, the ICMS could be substituted by copying and amending the default UniFormat text file. This is carried out in the '*Assembly Code Settings'* via the '*Manage*' ribbon panel. The primary difference to the keynote, is that the assembly code is also linked to an assembly description, which correspondingly will be populated once the assembly code is selected. It is important that the same formatting is utilised from the original UniFormat text file, so as the new text file can be loaded without any errors [25].

<u>Adding a Project Parameter</u>

The QS (or any Revit user) also has the ability to create a QS specific parameter (QSID), by adding an additional shared/project parameter to the model. It is fairly common for additional parameters to be added to the object properties in the model, for example, a fire rating to a door or a u-value to a wall. Common practice in this regard, is to set up a '*Shared Parameter'* in the '*Manage*' ribbon panel. This shared parameter can be then assigned by adding it as a '*Project Parameter'*. This process makes available a user defined, i.e. QSID, in the type properties of the objects [25].

<u>Using Revit Schedules</u>

By adding a QSID, via any of the methods outlined above, the user can select and assign a QS WBS to any or all of the objects in the model. This can be carried out by selecting the object, selecting all instances of that object and then assigning the QSID, by selecting the applicable Keynote or Assembly code or typing in the appropriate code into the relevant project parameter. To increase the speed of this process, it is recommended that the user sets up a material take-off schedule and appends the following fields; *family name; type name* and the *QSID*. Once a schedule is set up, the QSID can be easily coded in the schedule by selecting an object (or group of objects) and assigning the code to the relevant field [25].

Classification Manager

Autodesk [1] note that the processes outlined above are effective, but they have developed an add-in tool (Classification Manager) which they claim provides greater efficiency and flexibility to adding QSIDs to BIM. This process provides the Revit user with an alternative to the other methods outlined in section II(d), by providing users with an easier interface to assign codes and even add their own content via a custom database. Section IV below outlines how the ICMS was built in the custom database of Autodesk's Classification Manager and assigned to objects in the model [25].

III METHODOLOGY

Design science was selected as the research strategy because there was significant participation from the researcher proposing a technological solution to a practical problem. In design science a 'solution' to a field problem takes the form of what is known as an artificial construct ('artifact'), which they describe "as an artificial object made by humans to solve practical problems" [26], i.e. a 'technological solution' that can affect change in human behaviour.

In design science research learning must be specified clearly by articulating the proposed process in creating the practical solution [27]. In this research, section IV outlines a process that assigns a QSID utilising Autodesks BIM Interoperability Tools.

There are a number of frameworks that articulate a consistent approach for design science, (albeit using different terminology) [26, 27 28]. These strategies outline four common phases; 1. Diagnosing a problem; 2. Proposing (developing) a solution; 3. Implementing the solution & evaluating the process in action; and 4. Specifying learning [26, 27 28]. In this paper the first 2 phases of a design science research strategy is presented. The review of literature presents the background and context of the research and outlines a number of ways a QSID can be added to BIM. The following section articulates a different 5D technological process utilising Autodesk's 'Classification Manager'. This is proposed as a design science technological solution while subsequent research in this area will include primary research to evaluate the solution in action.

IV RESEARCH PROJECT – CLASSIFICATION MANAGER

Autodesk [1] note in their whitepaper that 'Classification Manager' is a "user-friendly add-in for Revit that allows people to easily organise and manage classification data across multiple Revit models, no matter which system is used". The classification data that comes with the add-in can be applied to Revit elements from classification schema such as UniFormat, MasterFormat, OmniClass and UniClass. This Revit add-in also allows the user to create their own classification schema from editable MicroSoft (MS) Excel custom spreadsheets. Classification Manager and all its associated program files, including the classification databases, can be downloaded from Autodesk's website (BIM Interoperability Tools) [29]. The following steps outline how 'Classification Manager' can be utilised to create a custom ICMS database and subsequently to assign codes from that database to an applicable parameter in the object properties of the model. A video tutorial, prepared by the authors in conjunction with this paper, outline this process and is available on You Tube [25].

a) Downloading Classification Manager and Setting up ICMS database

Firstly as noted above, Classification Manager can be downloaded from Autodesk's website [29]. Illustrated in Figure 1, 'Classification Manager' is then available (as an add-in tab) in the 'BIM Interoperability Tools' panel of Autodesk Revit.

Fig. 1: Screenshot of Classification Manager in Revit

Once Classification Manager is downloaded, a number of Classification Excel Databases can be accessed in the Autodesk program files *(Program Files/Autodesk/BIT/2019/Classification Manager* – Figure 2), such as the US classifications schema, MasterFormat & OmniClass, and the UK's UniClass classification. Also available, is a '*Custom*' database, where users can add their own specific data or jurisdictional coding structure.

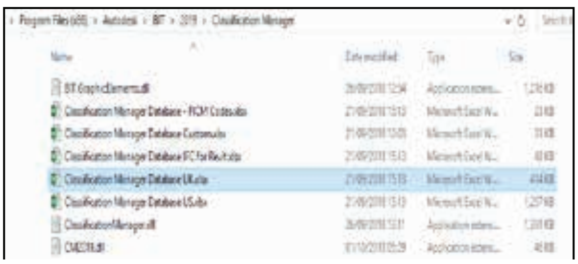

Fig. 2: File Location in Autodesk Program Files

The authors utilised this functionality, by inputting data from the ICMS into '*Classification Manager Database Custom.xls*'. An example screenshot of the completed ICMS database is illustrated in Figure 3. The spreadsheet comprises of column A which includes the ICMS codes; column B which outlines an associated code description and column C which sets out the hierarchy of levels to the codes and descriptions. Rows 1 through 6 contain the name of the database and the name of the parameters of the classification schema (in this case ICMS). It is important that the '*Number Parameter'* and the '*Description Parameter'* fields are filled out in B5 and B6 respectively.

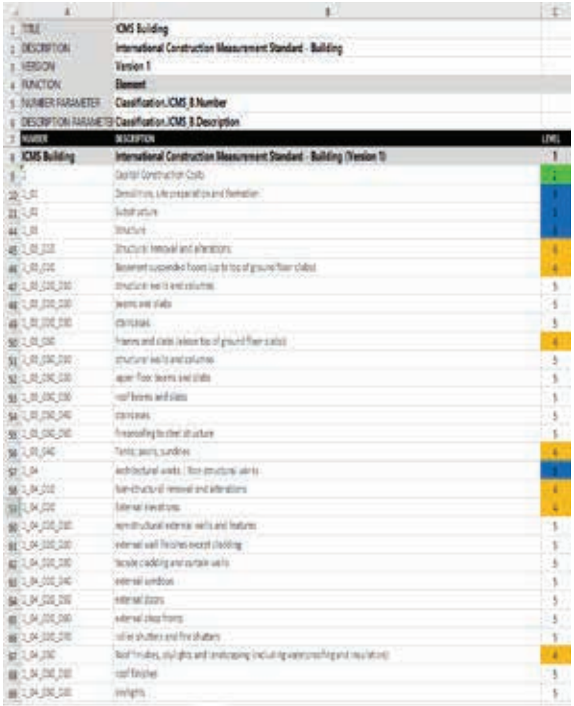

Fig 3: ICMS codes input into 'Classification Manager Database Custom.xls'

b) Adding ICMS Classification Parameters to Revit

The next step in this process is to add parameters into the Revit Model for the '*Number Parameter*' (cell B5) and the '*Description Parameter*' (cell B6) from the custom ICMS database (Figure 3). It is important that these are added as '*text*' parameters and are exactly the same name in Revit as they are in the Excel database, otherwise they cannot be populated. In this research a '*shared*' text parameter was added in the Revit Model for '*Classification.ICMS_B.Number'* and '*Classification.ICMS_B.Description'*. Subsequently these shared parameters were applied as '*project*' parameters in the model. Once this is carried out, these two parameters will be available in the object properties of the model, as illustrated in Figure 4 in the '*Text*' fields.

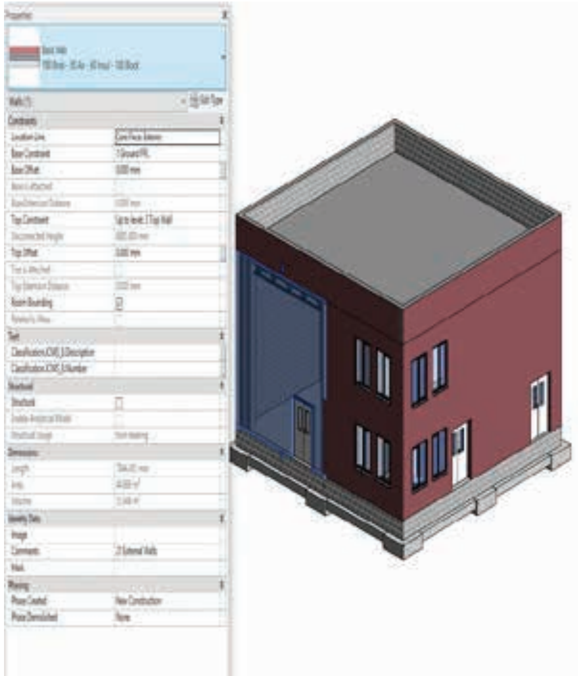

Fig 4: ICMS Project Parameters added in Revit

c) Setting up ICMS database

The next steps, illustrated in Figure 5, outlines how to setup the ICMS database in the model. Firstly the user must click the '*BIM Interoperability Tools*' (1) panel; select '*Setup*' (2) in Classification Manager; then '*Browse*' (3) to the location of the Custom Excel file and then click '*Finish*' (4). This process links the custom ICMS database to the project model and now the user can assign the ICMS codes to the model.

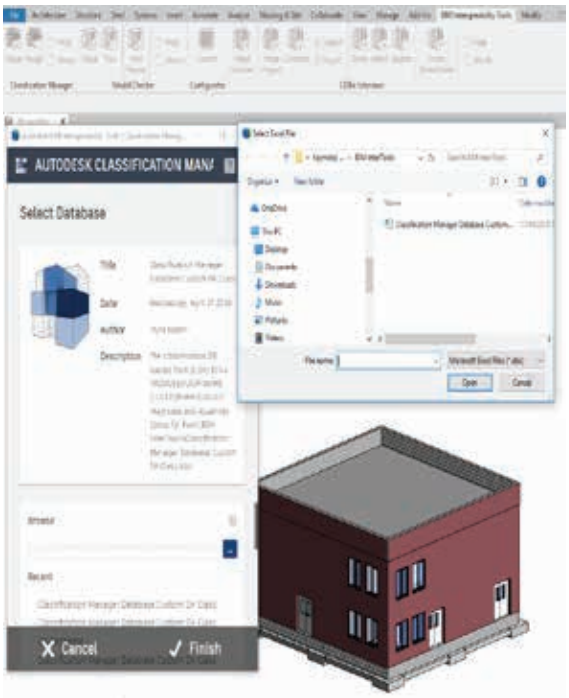

Fig 5: Setup ICMS database in Revit

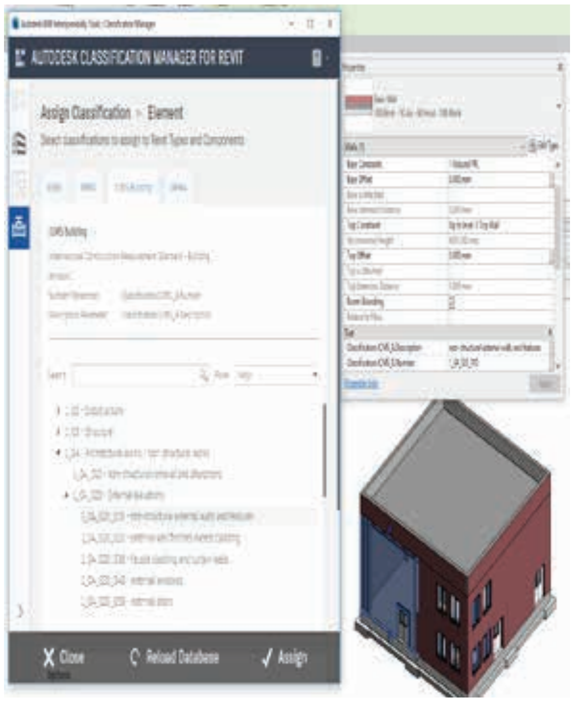

Fig 6: Assign ICMS Codes in Revit

d) Assign ICMS Codes

To assign the ICMS codes, the user must select the object that they intend to code (one of the external walls is selected as an example in Figure 6) by clicking '*Assign*' in '*Classification Manager'*. The database is then available for coding. The hierarchy level that was established via column C in Figure 3, provides a means to navigate through the codes and code descriptions. By clicking the relevant code (*i.e. 1_04_020_010 – non-structural external walls and features*) both the ICMS number and description are populated in the object properties.

An easy way to carry this out is to set up a Revit schedule that includes both the ICMS number and ICMS description parameters and subsequently code the objects by highlighting applicable groups (i.e. walls, doors, etc.) of objects and assigning the codes en-mass.

V Conclusions And Recommendations

This research addresses standardisation in QS WBSs and how the ICMS classification schema can be embedded effectively in BIM, utilising Autodesk's Classification Manager add-in. The review of literature outlines that there are many different types of QS standard WBSs published by numerous countries or jurisdictions. These WBSs are used to breakdown construction costs into functional elemental cost holding categories. The ICMS was first published in 2017 [10] and provides a global schema for comparing international project costs. It is hoped that this ICMS will provide efficiency in international construction cost comparison and benchmarking.

The review of literature also addresses 5D BIM and how a QS WBS can be embedded in BIM to enable automated QTO. In section II(d) the authors outline a number of different ways QS WBSs can be easily appended to the BIM in Autodesk Revit.

This research illustrates and articulates an alternative approach in section IV utilising Autodesk's 'Classification Manager'. This process provides the Revit user with an easier interface to assign codes and even add their own content via a custom database. From a design science methodology perspective it outlines a technological solution to a practical problem. Future research is proposed to evaluate this technological process in action through subsequent primary research.

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A Critical review of the Requirements for a Quantity Surveyor's Model View Definition for 5D Collaborative BIM Engagement

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Abstract – This paper sets out to critically review the requirements of a Quantity Surveyors (QSs) Model View Definition (MVD) for collaborative 5D BIM engagement. The paper has been set in the context of the Irish QS and her reluctance to actively and collaboratively engage in the 5D QS BIM process which was widely anticipated to deliver faster and more accurate project costings upon the wider adoption of BIM in the Irish AECO market. It is held that a QS MVD is a preliminary building block to achieve a 5D QS BIM process. A literature review was undertaken to establish the barriers (either real or perceived) that have challenged or prevented the development of a QS MVD. The data from these reviews was collected, analysed and distilled into the main challenges that require resolution to engage QS participation in the creation and utilization of a QS MVD. Original research methodology was based on the principles of Fourth Generation Evaluation, allowing for both quantitative and qualitative analysis. A broad sample of stakeholders were chosen to get different perspectives and views on the road blocks and challenges. Building on earlier research in this area, this paper has focused on the challenges of developing a QS MVD that could meet the requirements of both ARM and ICMS. The wide adoption of BIM is rapidly changing the ecosystem within which the Irish QS operates. However, a key challenge still remains due to the lack of a 5D QS MVD (Model View Definition). The Irish QS needs to collaborate with other designers and software vendors to develop a QS MVD to deliver the full benefits of what BIM can offer such as carbon & energy costing, cost data analytics.

Keywords – BIM, MVD, ICMS, ARM, IFC 4 Add 2, NRM

I THE QS ROLE IN THE IRISH AECO INDUSTRY

Applying a short PEST framework for an analysis of the environment that the Irish QS finds herself with regard to BIM:

• Political i.e. Law Regulations and Contracts. Although other countries have regulatory requirements for BIM on publicly funded projects, Ireland has only limited such requirements being set down by some public bodies without an over-arching mandate. Even within publicly funded projects there is no standard application of a common set of rules of measurement. ARM4, CESSM and NRM are all used; schedules of rates coding are not standardized and different contract forms are used.

• Economic: the economic and business reality for the professional QS practice or the owner's QS juxtaposed with contractor's QS or cost estimator is to get to a price that wins the job as quickly as possible and worry about the rest post award. As with the entire construction industry there are few big players and many, many sole trader companies. Although there are a few large QS practices it is not necessarily in the interest of the person selling hours to become more efficient.

• Sociological: QS fraternity are conservative so there is a high degree of inertia to change[1] [2]. Many QS's interact with small practice Architects and Builders. Designs continue to be done through 2D methodologies and traditional Bills of Quantities (BoQs) [3]. This is unlikely to change in the short term without some regulatory requirement or the natural changing of the guard to the 3D literate graduates who will take over the industry. Where BIM has been used is not well enough understood and in particular there is often a lack of tight quality control on the BIM potentially leading to misinformation.

• Technological: Technology is changing and changing quite rapidly. The pace of this change is also getting faster. However, there is often a gulf between the practicing QS and her understanding of the technology. Often the latest technology is at the very advanced research stage, understood by a few who have both computer science and construction backgrounds. Not the majority of practicing QSs. It is not feasible or likely that many QSs will take up computer programming and software design and nor should they have to. The take up of different technologies is happening more slowly than the technology is developed. This is not unusual; computing power and capability often exceeds the application requirements but then humans find new ways to solve more complex problems requiring high powered computing. 5D Take-Off and Cost Software is widely used as an aid to Bill of Quantity production.

Previous research by the authors which used Fourth Generation Evaluation methodology found the following key themes amongst QS practitioners in the AECO sector:

1. QSs had very little faith in the data in most current BIM Models as they were incomplete, generally of poor quality and not modelled to a level suitable for the QS automatic quantification. This was seen as the greatest barrier to QS BIM engagement by all Stakeholder.

2. In general, design teams had insufficient understanding of the role of the QS in relation to 5D BIM. This lack of understanding was a viewed as the second most significant problem by Stakeholder.

3. No QS MVD is available that allows for automatic Quantification. This was viewed by the Stakeholders and the Stakeholder as the single biggest advantage of BIM to the role of the QS in construction i.e. increased speed and accuracy of QTO (Quantity Take off)

4. There was a shortage of suitably skilled 5D BIM QSs who fully understood the BIM Process as well as having the necessary digital skills for interrogating models, pushing and pulling cost rich information.

5. BIM was not yet mandated by the Irish Government and was therefore not a requirement. This however has been categorised as a short-term problem by the author as the Government Mandate is imminent.

6. The BIM protocols, Standards, Contracts etc. were either adopted from the UK or pre BIM without being fully integrated into Irish BIM context. There are issues around IP (intellectual Property), copyrights, insurances, the legal status of the BIM model, and so on. This was further complicated by Brexit. However, this was seen more as a problem and an issue common to all the professionals than just a QS item.

The authors have focused on the third one of these themes – QS MVD. As the authors' research found: there is a 'commonly held fictional "push button myth" associated with automatic take off [that] would evolve into a reality eventually'

II Introduction

The move to digitization is inexorable, driven by the promise higher quality, lower cost, better time certainty and fewer disputes[4, p. 11]. In more and more countries BIM is being mandated for some or all large publicly funded constructions. The UK has mandated a limited form of BIM on large public projects since April 2016. Holland and the Nordics have mandated BIM delivery on certain public projects since 2007. Denmark in particular has mandated BIM submissions as part of its building controls process. Singapore too has mandated BIM delivery since 2007 for all buildings with an expansive plan to have models registered for all buildings as part of its building controls processes. The US GSA requires 3D-4D BIM deliverables[5] since 2007. The EU BIM Task Group has delivered a strategy document which aims to provide a roadmap for "Strategic action for construction sector performance: driving value, innovation and growth", within which it includes "Assess and address legal, regulatory, procurement and policy barriers in order to facilitate collaborative working and sharing of data"[6].

There is a great lack of 5D case studies[7] from which to learn from others, to evaluate the findings, to stress test and learn lessons. Coupled with this, the UK Government in its level 2 BIM mandate (UK mandate 2016) only stated that this level of BIM may utilise 4D construction sequencing and /or 5D cost information. In sharp contrast to this the forthcoming level 3 BIM mandate states that 4D, 5D and 6D project lifecycle management information must be used (Digital Built Britain (2015).

However, costs are not being mandated in any specific way nor have they to this point been included in any standard way as part of the BIM. The cost breakdown or Bill of Quantities for any given project can vary widely in form and methodology depending on country norms, QS preference, form of contract chosen, method of measurement used. Cost management and coding is firstly dependent on country normative processes. So, we must first examine the normative processes in Ireland and compare those with others.

The objective of the QS is to establish the cost of the building project; be that the actual (or likely) cost; or the sale price (the buyer's cost). Cost is a commercially sensitive and confidential area. Every organization takes a different approach to costing and does not share or easily facilitate cost benchmarking between organizations. Cost is politically sensitive on marquee public projects as we have seen, with much gamesmanship on cost comparisons in order to get a project to land and get past point of no return.

However, things could be beginning to change with the introduction of the ICMS[8]. Heretofore, there was no internationally accepted standard of construction cost coding. With 50 professional organizations and the IMF and World Bank supporting the ICMS[9] there becomes an imperative to capture and retain costs in a standardized way.

What better way to capture those costs than to include them in the BIM, where the cost associated with the delivery of a group of elements can be retained alongside visual and other data.

ICMS[10] is a construction cost classification tool and, therefore, does not require detailed measurement of construction quantities of itself. However, in order to arrive at a construction cost, it is typically required to have a detail BoQ prepared in accordance with a contracted set of rules of measurement.

ICMS requires key metrics relating to cost, quantity, volume, mass, length and area. Not just a cost amount. Many, if not all, the inputs necessary to calculate these quantity metrics are readily available in the BIM.

III Current Situation

The current practice is to calculate costs using 3rd party software which uses a model or information exchange from a model to enable the quantity take-off which is then compiled and coded in accordance with the contracted method of measurement and schedule of rates or costs. Although this is a considerably faster and more quasi-automated approach than wholesale manual take-off and preparation of a bill of quantities (which in a tender situation is typically repeated by all parties where the requirement is some form of lump sum), it still remains a time consuming and costly task requiring a high level of professional QS experience. BIMs provide information on the finished building or at least the design for same. It is not common for BIMs to provide directly the necessary means of construction in order to calculate those costs. For example, a foundation requires a trench that requires additional working space and differing supports and ancillary equipment depending on depths and ground conditions. The trench maybe machine or hand dug. The typical BIM shows none of this. Calculating the cost relies on information and data that is typically outside of the model currently.

Fig. 1 below shows the current practice using model inputs to take-off and cost software. Typically, they take in information in many formats including drawings, models and direct input. In order to 'key' the data correctly a Uniformat type classification system is relied upon. In the US Omniclass or UK Uniclass, identification of components is used.

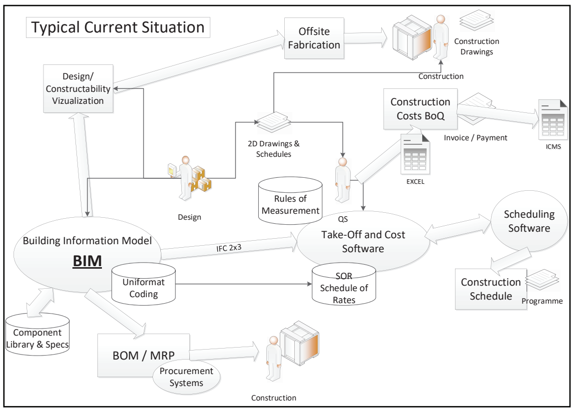

Fig. 1: Current practice using model inputs to take-off and cost software

The 'current practice' relies heavily on many different sources of data and information being compiled and assessed for costs by the QS. The output produced, which on large projects is weeks of work for a team of QS's, is a standalone BoQ that is often not easily reconcilable with the design. So for value engineering or optioneering activities the take-off process is repeated over and over again; taking weeks and eating into design time. The result is that decisions may be made with incomplete cost detail or understanding of cost impact.

The USACE completed a study using such methods in March 2011[11] . They found after testing that:

"1. The linkage required any CAD operator to use very specific PSets for BIM model elements or the linkage would fail. Disseminating the required PSets appeared to be insurmountable for the wide variety of USACE centers and vendors.

2. The database developed in Vico would not be considered "universal". For example, different regions would have variances in methods and resources.

3. It was not clear whether the USACE would adopt Vico for use at various centers.

4. Vico does not support IFC."

(It should be noted that: PSets are property sets defined for different model components; Vico was the take-off and cost software that was used in this test).

Recent upgrades to the ifc schema enable the development of a quantity take-off for resources and costs. IFC 4 Add2 TC1 [12] contains '4.10 Resource Limits' - A resource represents usage of something, having costs and environmental impacts.

Fig. 2: IFC 4 Addendum 2 extract

So, the necessary functional parts are included in the schema. However, the rules of measurement vary widely depending on country, contract and local custom and practice. A Bill of Quantities is not a Material Take-Off. In order to calculate the costs of building, in accordance with ICMS a bill of quantities is required. Once calculated, the difficulty of writing the elemental costs back into the model via an authoring tool with the correct and universally accepted PSets will likely remain. Different model zones, spaces and elements would have to have different PSet containers to hold the ICMS cost data if it is to exist alongside the design or as built model so that costs per floor area (for example) could be calculated. Once stored then an MVD (model view definition) would be required to enable extraction and use to as yet unknown information systems.

However, what would be immediately helpful to the AECO sector is to enable fast and accurate cost calculation for a given design. The current requirement to wait for the QS team to provide a cost for a given design option is very costly to design development.

An IDM for a quantity take-off in accordance with a given set of rules of measurement is required. IFC 4 Add 2 should enable this. Developing an IDM[13] for quantity take-off in accordance with any set of rules of measurement will be a substantial undertaking. This means software undertakings will likely only provide this for more widely used rules of measurement such as NRM. Localized or niche industry methods of measurement are unlikely to be supported by the software industry since they represent such a small sector of the market. In addition, badly coded or subjectively written rules of measurement will present real difficulties to implement.

The context of the desired future outcome is an MVD that will deliver a QSie (Quantity Surveyor information exchange) to the chosen rules of measurement. Fig 3 below provides an overview of future QS interaction with BIM.

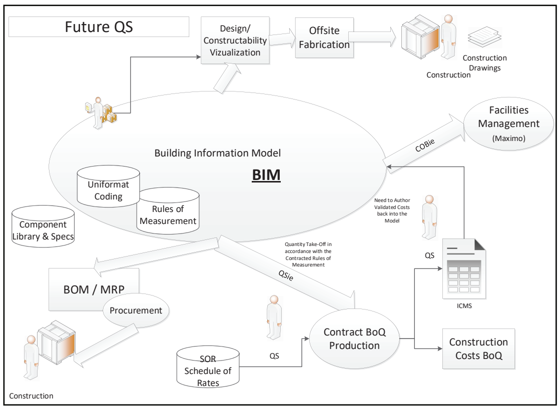

Fig. 3: Future QS and BIM interaction

IV Irish Rules of Measurement – ARM4

Each country and often industry sectors within each country has developed its own set or sets of rules of measurement. The different sets of rules are continuously evolving under the auspices of local professional associations. In Ireland this is the SCSI. The rules of measurement used for buildings and commonly specified in public contracts for buildings is ARM4 – Agreed Rules of Measurement[14] .

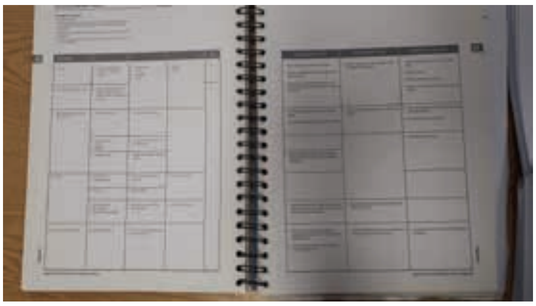

Fig. 4: ARM4 page 98

These rules were written for a different time! They have no clear coding and are often subjective requiring a great deal of experience to implement them. Fig 4 above shows a typical ARM4 page. In this case it shows Page 98 – Pipework.

There is re-write of these rules imminent by the volunteer group charged with this activity. ARM4 is associated with the RIAI form of agreement. ARM4 does not lend itself to mapping of its 'line-items' to either Uniformat or ICMS, although the former has been done on some larger projects per Fig. 5 below.

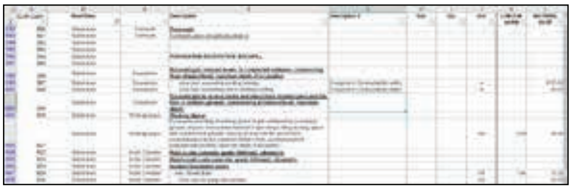

Fig. 5: SOR (Schedule of Rates) based on ARM4 rules of measurement

Each rate must be mapped to the Omniclass or Uniclass coding system (Uniformat) depending on what is used in the BIM. Since ARM4 has no standardized coding this activity must be done by each project or practice wishing to apply the technology. In the case above, the contracted SOR for the project was generated based on ARM4 descriptions and then assigned a sequential line item number. Setting up the project in this way is very expensive so it only makes sense for larger projects or practices.

A very good starting point for the volunteer group will be look at the NRM – New Rules of Measurement – developed by the RICS and for use with NEC form of contract. These rules are directly coded to the Uniclass classification system and this is available from Vico Office®, CostX® and other take-off and cost software vendors already. NRM has also already been mapped to ICMS[10] enabling the extraction of cost reports in an ICMS format relatively straightforward as shown in Fig. 6 below

Fig. 6: NRM mapping to ICMS

V International Construction Measurement Standard (ICMS)

ICMS Cost Coding is designed for all types of construction activities (Industrial, Civils, Infrastructural and Building). We will focus on Building domain only.

ICMS "Schedule 1- Project Attributes and Project Values for Each Type of Project and Sub-Project" [10] provides the role up summary data for a project. For buildings cost per square meter measured in accordance with The International Property Measurement Standards (IPMS) ver 1 and ver 2 is the standardised single cost metric being sought.

ICMS is structured in 4 Levels as follows:

Level 1: 'projects or sub-projects' – these relate to either 'buildings', or 'civil-engineering /infrastructure'

Level 2: 'cost categories' – these are individual categories that provide for a suitable split or classification of the overall project cost into three level 2 cost categories: Capital construction costs; associated construction costs; site acquisition and client's other costs. Fig. 6 below shows the layout for Level 2 building.

Level 3: 'cost groups' – these capture the sub-division of the three cost category totals into a more detailed breakdown in each case

Level 4: 'cost sub-groups' – these are intended to capture further sub-divisions of cost within each of the level 3 cost groups, thereby providing an even more granular level of detail of cost classification. These cost sub-groups at level 4 are discretionary and can be formulated to suit local custom and practice. In effect Level 4 is the priced BoQ.

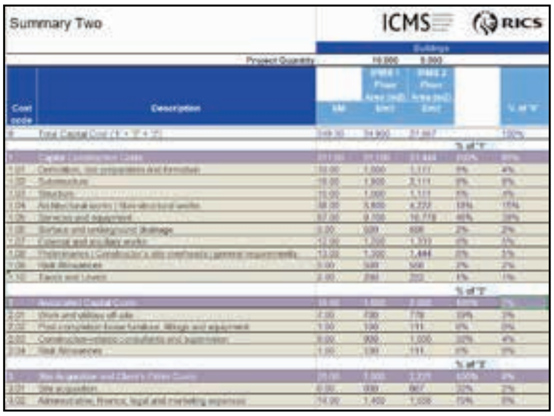

Fig. 6: ICMS Level 2 Cost Summary for Buildings

"ICMS is designed to be used, if applicable, with BIM models. Project values and attributes are designed to be used with drop-down lists to ease data input and subsequent analysis. It should be noted, however, that almost all BIM models are classified by Uniformat II and there would need to be an element of mapping between it and ICMS."[10]

For simplicity Omniclass includes Uniformat as a subset in Table 21 (albeit with different numbering). UniClass is a similar elemental approach.

"Although ICMS contains the word 'measurement' in the title, it is a construction cost classification tool and, therefore, does not require detailed measurement of construction quantities (as set out – for example – in guidance on measurement rules in SMM, NRM, POMI, CESMM or similar). However, there are project quantities stated that are intended to be set out within the details of each project, although these are not intended to be arrived at by detailed measurement, but are merely an approximate quantity to provide an indication of the size and scale of the various attributes of the project. Indeed, such approximate quantities may be taken from other sources such as a client brief or similar. The construction cost adviser should use appropriate skill and judgement to arrive at a suitable level of accuracy for such approximate quantities."[10]

ICMS requires both cost and quantification data to be captured for pre-requisite items. However since "cost advisers appropriate skill and judgement" should be used and an exact calculation is not required then ICMS cost inputs to models via pre-defined Psets will be a manual input. Quantity Take-Off from the model however, should be an exact and automated process.

For ICMS to take hold it must be specified in contracts as a required output. Contracts can require that a construction BIM and As-Built BIM shall be provided and amongst the information components included shall be cost conforming to ICMS

V CONCLUSION

BIM has improved productivity in the production of BoQs through the use of standalone take-off and cost software. However, this is external to the BIM. There are projects that are using PSets in an as yet unstandardized approach to capture cost data within project models. It is to be expected that this trend will continue and grow over the coming years as more surveyors become familiar with these methods and as take-off and cost software becomes incrementally better. ICMS has provided an impetus to standardised cost management that could be implemented through PSets.

IFC 4 Add 2 schema should enable the next leap forward in software tools and methodologies where the QS becomes part of the model authoring team, in future years. In order for this to come to pass standardized IDMs and MVDs are needed for BoQ production, which we have termed QSie. BoQs are governed by the contracted rules of measurement. Rules of measurement need to be digitizable so that they can be incorporated into IDM. Software providers will likely develop and implement over the coming years.

In Ireland ARM4 is commonly used but is not digitizable in its current form. As a small software market, in the global sense, it is unlikely that niche rules of measurement will be implemented through software, requiring ongoing manual manipulation. There are other rules of measurement already in use in Ireland that have already been digitized such as NRM. If ARM4 is to be used then it needs to be upgraded to a digitized form that can be mapped to both Uniformat classification and ICMS. This will be a substantial undertaking.

There are many advantages to the QS in enabling digitization of the function. Improved efficiency will aid the expected shortfall of QS resource in the future[15]. Providing immediate and accurate costings to the design teams will deliver better value based decisions for the client enhancing the QS position with the design team.

ABBREVIATIONS

5D	5th Dimension – Cost in BIM context
2D/3D	2 Dimensional / 3 Dimensional - Drawing representations
AECO	Architect Engineer Contractor Owner
ARM4	Agreed Rules of Measurement ver.4
BIM	Building Information Model
BoQ	Bill of Quantities
CAD	Computer Aided Design
CESMM	Civil Engineering Standard Method of Measurement
GSA	General Services Adiministration (US Federal Government body)
ICMS	International Construction Measurement Standard
IDM	Information Delivery Manual
ifc	Industry foundation class
IMF	International Monetary Fund
IPMS	International Property Measurement Standard
MVD	Model View Definition
NEC 3	New Engineering Contract 3rd Edition
NRM	New Rules of Measurement
Pset	Property Set
QS	Quantity Surveyor
QSie	Quantity Surveyor information exchange
QTO	Quantity Take Off

RIAI	Royal Institute of Architects of Ireland
RICS	Royal Institute of Chartered Surveyors
SCSI	Society of Chartered Surveyors of Ireland
SMM	Standard Method of Measurement
SOR	Schedule of Rates
USACE	US Army Corps of Engineers

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BIM in Operations and Maintenance

Digital Engineering, Data Analytics and Model Calibration – The Future of Building Operation?

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The construction industry is not renowned for being open to change, but Digital Engineering concepts are driving the application of 3D modelling and digital information management methods as a way to design and construct better performing buildings. However, can these same Digital Engineering concepts be effectively applied at a building's operational stage too? This paper will discuss the utilisation of operational building data alongside advanced analytics to enhance 3D energy modelling which has traditionally only been used at a buildings design stage.

In the context of building energy modelling, the process of adjusting and improving inputs to close the gap between simulated and actual performance is referred to as calibration. Model calibration is widely acknowledged as a complex and a sometimes costly undertaking. However, a calibrated model which represents the operation of a building has a range of benefits and uses, including identification of control issues and poor performance in a building, testing which improvements or retrofit strategies will yield the best performance improvements, and measurement & verification of the post-retrofit performance once implemented.

Keywords – Digital Engineering, Calibrated Energy Modelling, Data Analytics, Building Operation

I Introduction

The authors firmly believe that in order to significantly reduce building energy use, tackle the performance gap and ensure that design intent is followed through into operation, the use of simulation tools and operational building data as part of a Digital Engineering approach must be embedded across the entire lifecycle of a building.

To achieve this the market needs to consider and value performance at all stages, from investors/developers and client occupiers, through to designers, contractors and facilities managers as well as Set and track energy/environmental Key Performance Indicators (KPIs) across the whole design-build-operate process.

"If you can't measure it, you can't improve it." From Lord Kelvin [1] talking about mathematical physics to Peter Drucker [2] on business management the premise is the same, in order to see an improvement you need to measure what you want to see. Digital engineering, data analytics, energy performance simulation and calibration offer us the opportunity to do just that across the entire lifecycle of a building.

The aim of this paper is to discuss the utilisation of operational building data alongside advanced analytics to enhance 3D energy modelling, which has traditionally only been used at the design stage of a building lifecycle and then review how this approach can be used to identify operational control issues, sensible improvement strategies and measure & verify post-retrofit performance.

II The Problem

a) Data, Data, Everywhere

In recent years, there has been a huge increase in the quantity, quality and accessibility of operational building data. In July 2013, the UK Government published: 'Construction 2025' which suggested that the emergence of new capabilities such as the internet of things will drive a step change in how we build and how our built environment operates [3].

The Internet of Things (IoT) has unlocked the potential to collect real-time data about the individual components that make up our buildings. Smart Meters can deliver half hourly utility meter readings and Building Management Systems (BMS) monitor and control a wide range of building services.

However, in practice such systems are often not set up in a way that provides meaningful information. There is often a lack of “effective” commissioning undertaken prior to a building being handed over. Routinely clients inherit buildings with design flaws, inefficient control strategies, and insufficient capability to collect or report energy performance in a way that is meaningful to operators.

Even when data is collected it is often not very usable. The Project Haystack initiative, which aims to streamline the use of building data has the following to say: “Most operational data has poor semantic modelling and requires a manual, labour intensive process to "map" the data before value creation can begin. Pragmatic use of naming conventions and taxonomies can make it more cost effective to analyse, visualize, and derive value from our operational data.” [4]

b) Modelling Beyond Compliance

As found in the Carbon Trust “Closing the Gap” report [5], there is a persisting misconception in Industry in the UK that Part L/Energy Performance Certificate (EPC) Compliance models should somehow suffice for design analysis, and in some cases can mistakenly be used as a form of operational energy prediction.

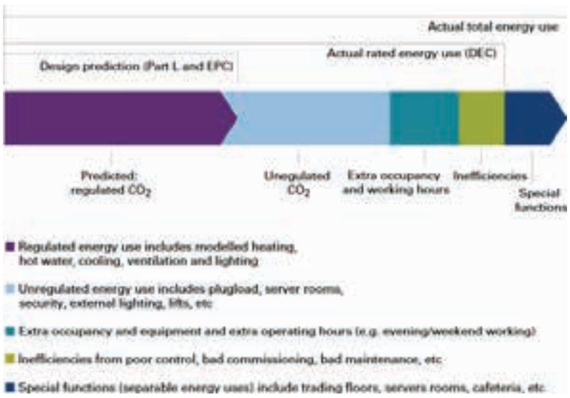

Fig 1: Design predictions for regulatory compliance don’t account for all energy used in a building. From Carbon Trust Closing the Gap report [6] who adapted from Carbon Buzz.

The Part L/EPC compliance model is simply a benchmark exercise and omits key design/energy elements within the building in its calculation. For example, unregulated loads such as plug loads, server rooms, external lighting and so on. This is ultimately why an EPC won’t align with a Display Energy Certificate (DEC). There is a growing consensus within our industry that a design model would align better with the buildings actual operational performance, including guidance from CIBSE with TM54.

The reliance on Compliance models in lieu of design analysis contributes not only to un- realistic energy expectations, but also to unexploited energy saving opportunities, as well as overheating and other internal comfort issues. Its wastes capital expenditure, operation expenditure and leads to dissatisfied end users.

A recent report [6] highlighted the importance of utilising accurate data in energy and thermal comfort design modelling from the early stages and throughout, the building development process. The discrepancy between the UK Compliance NCM (National Calculation Methodology) data proved to be significant in many areas. In the case of hospital bedrooms, the real world energy consumption and associated heat gain was as much as six times higher than the NCM data assumed. And the overheating risk was found to be 1,000 hours greater.

While the NCM, utilised for Part L/EPC calculation, may produce more favourable results at the modelling stage, the comparison in this report proves that the unsatisfactory operational performance of the buildings is more or less inevitable and could have been predicted from the start of design.

In 2013, CIBSE produced a standard methodology for ‘Evaluating Operational Energy Performance of Buildings at the Design Stage’ to assist designers. TM54 outlines a methodology for going beyond compliance modelling by providing an approach for estimating operational energy use at the design stage, accounting for all end uses in the building alongside realistic operating patterns and behaviours. [7]

The authors have found that this comprehensive technical memorandum has yet to be fully embedded in the industry. TM54 is starting to filter through on public projects, however, feedback from engineering clients has been that a lack of demand from their clients is a major reason for this. The client just won’t pay for a more advanced model and so they just get the bare minimum - a compliance model.

There is clearly more education required on the benefits of a ‘modelling beyond compliance’ approach; especially at the investor, developer, client occupier, and contractor levels.

However, there is change happening, the Design for Performance (DfP) initiative has been campaigning for a number of years to create a building-rating scheme based on measurable performance outcomes. The project seeks to emulate the Nabers Energy Rating and Commitment Agreement that has transformed the prime office sector in Australia. In November 2018, the DfP team secured the commitment of seven developers to fund the establishment of such a scheme. [8]

III The Opportunity

a) Value of Advanced Modelling

The key finding from the recent DfP feasibility study was that the power of advanced modelling, now routine in Australia, is rarely used in the UK because clients do not ask for it and don't know why they should. [8]

The additional cost of undertaking advance modelling is minimal compared to the returns you can get. In 2016, HOK in the US published Return on Investment figures related to Energy Modelling undertaken on their projects. They tracked both modelling costs and predicted energy savings for a large number of projects over several years. Energy modelling was found to have a typical payback period of 1 or 2 months! In fact, modelling sometimes paid for itself immediately by identifying unnecessary costs before construction ended and the building was occupied. The most common example of this was through the elimination of oversized and unnecessarily expensive, HVAC systems. [9]

Project Name	% Modeling Fees vs Gross Fees	Annual Modeled Energy Cost Savings	Payback on Modeling Fees in MONTHS
Office Building	0.7%	$122,876	2
Office Building	0.5%	$306,692	1
Justice Center	0.8%	$350,000	1
Convention Hotel	0.6%	$233,781	1
Regional Hospital	2.4%	$3,300,000	1
Government Office Building	3.3%	$186,000	4
Government Building 20	1.1%	$224,276	2
Cancer & Critical Care Tower	0.6%	$853,013	3
Institutional Research Center	0.6%	$340,000	1
Energy Institute	2.5%	$169,432	7
Institutional Research Facility	1.0%	$302,169	1
Science Teaching and Research Facility	0.8%	$419,599	1
Corporate Headquarters	1.0%	$239,835	4

Fig 2: Architecture Firm HOK Calculated Payback of Energy Modelling [9]

A frequent question about the value of energy modelling is how much energy savings should be attributed to the modelling process, as good engineers can create energy-efficient designs using simple calculations plus experience and professional judgment. According to Anica Landreneau, director of sustainability consulting at global architecture and engineering firm HOK, "Owners and project managers do not accept reduced HVAC systems based on engineering judgment—they demand to see numbers!" Modelling may not be necessary to designing an energy-efficient building, but it is necessary to getting that energy-efficient design built. [9]

In the UK and Ireland, the value of advanced modelling is being increasingly recognised as firms such as Arup, Hoare Lea, and WSP set up building performance and digital engineering groups. Arup bills its Advanced Digital Engineering group as "comprising over 300 advanced engineering, digital and project consultants, bringing together a seamless combination of digital and data-related capabilities with Arup's traditional engineering and design strengths." [10]. While Roger MacKlin Associate Director WSP, Performance talks about their "unique blend of engineering expertise and data analytics providing transparency on building performance." [11]

b) The Link between Modelling, Commissioning, and Metering & Monitoring

Buildings are frequently delivered with a "first cost" focus, with designers and contractors working to tight profit margins. During value engineering, in order to cut construction costs, the budget available for commissioning and metering are regularly slashed.

Commissioning is the process of verifying that building systems are performing in a way that meets operational requirements. In practice, it is often not effective, as it is viewed as a single point in a construction project carried out just before handover. Done correctly, commissioning begins at the start of the project and continues post-handover to a minimum of one year after construction. [12] Both Soft Landings [13] and LEED V4 [14] recognise the value of commissioning in project delivery, but both these schemes are voluntary limiting wide scale adoption.

Metering, despite being mandated by Part L of the building regulations in England & Wales [15], frequently fails to deliver on its potential. Sub-metering regularly consists of "put a meter on each distribution board" with little thought given to how operators can make use of this information. Meter selection must be driven by a metering strategy that provides insights into what building equipment is consuming energy and when. Good commissioning would help catch frequent failings in sub-meter installations including ill-thought-out metering strategy, faulty meters, badly sized meters, and meters which require manual reading.

The use of energy models for little more than Building Regulations Compliance is a tragic waste of the potential utility of modelling throughout the design and construction phase. A well-developed model which produces an accurate estimation of building consumption is a valuable tool during the commissioning process. Differences between building performance and modelled behaviour can be investigated to determine whether the differences are driven by building faults or by incorrect assumptions in the model. A well thought out sub- metering strategy which provides granular data on end-uses facilitates this comparison between model and reality reducing uncertainty in the diagnosis of building issues.

Recognising the value of good energy modelling, with the introduction of its new energy prediction and verification methodology [16], BREEAM New Construction 2018 proposes to award additional credits for more detailed prediction and verification of actual energy performance at design and post occupancy. Extending the CIBSE TM54 procedure on into operation.

IV A POTENTIAL SOLUTION

a) Calibrated Modelling

The common thread running through all these initiatives is the need to design for and incorporate measurement and verification of performance across the whole life cycle of a building, from the earliest design stages on into operation.

3D models of buildings are being recognised as a way to gather, store and pass-on important data related to a buildings' operation.

Ultimately, using advanced modelling to align design intent with the operational use of a building makes a lot of sense. Why discard the effort which has gone into creating models of buildings at design. If these models are evolved and enhanced at each stage of construction, the additional effort and cost is incremental and minimal. Building Simulation Models can and should become important digital assets for buildings.

The final step in this approach is where real operational data rather than design data can be used directly in calibrated energy/simulation models to enable more accurate building performance predictions, optimise controls and give tools to facilities managers so that informed decisions can be made on improvement/refurbishment measures under consideration.

Fig 3: Example Calibrated Energy Model undertaken in IESVE [6]

Calibration is the process of improving and verifying the accuracy of a simulation model by systematically comparing model outputs to real measured data from a building. Simulation models are capable of producing hundreds of different outputs, but for calibration only an important subset is typically required. Identifying these outputs will depend on the availability of real data to compare model outputs against, and also the purpose of the model calibration. Generally, at a minimum, whole building electricity and heating fuel energy will be the key model outputs but additional comparisons against sub-metered energy improves model accuracy and reduces uncertainty.

The applications of calibration are growing rapidly, but can be classified into two main areas:

• Measurement and Verification (M&V) of achieved savings due to the implementation of an Energy Conservation Measure (ECM) whether that is a retrofit or an operational/control measure.

• Prediction or targeting of future savings; to assess impact of potential ECMs before their installation, undertake fault detection or use existing/past data to set future targets of energy reduction. [17]

However, there are no existing guidelines or steps to follow when calibrating an energy model using detailed simulations programs. This is expressed in numerous research papers (20/21) such as:

• Raftery et al (2011): "Despite the numerous published case studies, there is still no accepted standard method for calibrating a model." [18]

• Gallagher et al (2018): "Lack of a rigid, prescribed, analytical calculation process." [19]

ASHRAE 14 provides info on how to use a calibrated model but no guidelines or instructions on how to actually calibrate a model. [17]

Therefore, model calibration is rarely done on commercial projects, and when it is, the level of data available dictates what accuracy can be achieved.

b) The Benefits of Calibrated Modelling

A recent project [17] between Herriot Watt University and IES, demonstrates that using a calibrated building energy model can result in better certainty during M&V compared to other non-model options established in the International Performance Measurement and Verification Protocol (IPMVP). The different processes were rated/evaluated against two key parameters, effort and strategic value.

Essentially a calibrated model is a "digital twin" of the building in operation; a virtual representation of the physical elements and the dynamics of how it operates, works and responds throughout its lifecycle. [20] Such models can be used in identifying sub-optimal performance, system faults, and can better determine and measure and verify the implications of proposed ECMs and retrofit options to the building in terms of consumption, cost and comfort.

Another benefit of calibrated modelling is "Monitoring and Targeting" (M&T). By using not only past data (monitoring) but also calibrated model results to define targets for reducing energy consumption it is possible to eliminate operational drift within a building. [21]

c) Barriers to Calibration

Despite the benefits, model calibration is a time-consuming process which typically requires expert user knowledge. The main barriers to calibration can be grouped into issues linked to lack of standards and the time/cost expense of model development. [22], alongside the need to use different tools/methods to achieve high levels of accuracy.

The concept of what constitutes a calibrated model varies significantly, which is exacerbated by there being no standard approach for model development. Further, the time and resources needed to obtain the required sub-metered data, system information, etc. can be prohibitive.

With modelling, the quality of the outputs is only as good as the inputs available and model complexity means the sheer number of inputs required makes it almost impossible to obtain accurate measures for all parameters. Additionally, it is often difficult to accurately diagnose the underlying cause of discrepancies. As a result, ad- hoc manual adjustments are frequently made based on user judgement rather than scientific reasoning.

A paper [23] on work carried out as part of the European funded project "Energy in Time." details a methodology focused on improving and automating elements of the calibration process to make the model calibration a viable and less costly undertaking.

It recognises that calibration is over-specified (in that simulation programs require hundreds of model inputs) and under-determined (where the number of output parameters for comparing actual versus simulated performance are relatively few).

The approach investigated involved feeding metered data into a building energy model, followed by sensitivity analysis to identify the most relevant parameters to focus on. Finally, optimisation techniques were applied to the model to determine appropriate values for the remaining uncertain and influential parameters.

The methodology developed showed that even where high levels of metered data were not available, accurate calibrations beyond the current best practice levels of IPMVP were achieved. It also greatly improved the speed of the calibration process through the introduction of and automated and semi-automated processes, and reduced the amount of user intervention and expertise requirement, making the approach replicable across a range of building model types.

d) Calibrated Modelling in Action

The methodology from the "Energy in Time" [23] project was tested and validated as able to achieve accurate calibrated models quicker, and with less user intervention. Calibrated building models for four demonstration sites were created for a range of building types across Europe:

- Airport in Portugal
- Office Building in Finland
- Office Building in Romania
- Hotel in Northern Finland

The calibration results achieved across the four test buildings exceeded current best practice M&V targets for the model's simulated energy performance matching the actual performance. The Normalised Mean Bias Error (NMBE) for each model ranged between -0.301% and 3.2% for hourly calibration, meaning all models adhered well within the required ±10%.

While another more encompassing project [24] looked at the effectiveness of different levels of energy models for different performance analysis requirements from master planning to calibration at the BCA Academy Campus in Singapore. They created a highly calibrated detailed model of an existing Zero Energy Building, where measured data was used to improve the level of accuracy between the model and the actual performance to within +/- 5%, and options to improve the buildings' performance were virtually assessed, ahead of making actual changes in the building.

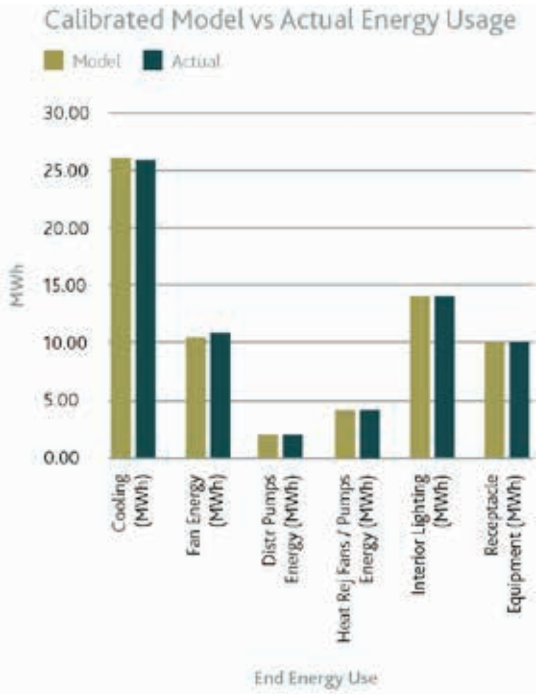

Fig 4: Level of Calibration achieved on BCA Zero Energy Building using IESVE and iSCAN technology (24)

An exceptional 1.1% Mean Bias Error (MBE) and 2.3% Coefficient of Variation of the Root Mean Squared error (CVRMSE) variation between the actual building and the calibrated model energy consumption was achieved because of the quality of the data available.

Even in this tightly controlled and monitored building, it was possible using the calibrated model to find a number of potential data issues, sub-optimal performance and potential retrofit measures. Their effects and resulting savings were simulated in the model. This included lighting savings of 12% if night-time lighting was eliminated and a fan energy saving of 7% if it was only operated when required.

These case studies show both the impact a calibrated model can have on the operation of a building and how methods for automation, or semi-automation, of model calibration are starting to significantly aid the process.

e) Real-Time Automation and Control

Looking to the future, there are a number of European and other research projects focused on creating a set of tools which will significantly improve building operational efficiency and management by incorporating real-time data and advanced simulation feedback through model calibration. [25]

The aim is to utilise a calibrated model as a baseline against which real-time building data can be compared. This facilitates fault-detection, testing ECMs prior to deployment, and elimination of operational drift. The process is made possible by technology developments such as IoT and machine learning which reduce the cost and time involved in collecting and cleaning input data, and undertaking modelling.

This vision would also allow for intelligent prediction of the control settings needed to keep the building operating at maximum efficiency/minimum cost based on future weather and usage predictions.

V CONCLUSIONS

The construction industry is at a digital engineering technology cusp - CAD (Computer Aided Design) techniques being used at the design phase are the default choice, and are being joined by BIM (Building Information Modelling), building analysis technologies and digital information management methods in an attempt to better manage the design-build-operate process.

Extending the design of building's beyond compliance requirements to effectively design for their actual operation requires integration of performance into digital design across the whole building lifecycle.

The market needs to value and embed performance at all stages, with buy-in from investors/developers and client occupiers, through to designers, contractors and facilities managers. Setting and tracking energy/environmental Key Performance Indicators (KPIs) across the whole design-build-operate process will help dramatically reduce building energy use and embed efficiencies in operation.

The Intergovernmental Panel on Climate Change (IPCC) has been issuing reports for many years on the potential short and long term impact of climate change. The loud and clear message from the Special Report (26) Global Warming of 1.5ºC issued In October 2018, is if we are going limit the earth's temperature increase to 1.5 degrees above pre-industrial levels, we need to act now.

Julie Hirigoyen, Chief Executive at UKGBC [27] said; "This report from the IPCC is a wake-up call for governments and businesses across the globe. The construction and property industry in the UK is an economic juggernaut, and our buildings account for approximately 30% of carbon emissions. It is also the industry with the most cost-effective means of reducing carbon emissions so it will be a vital catalyst for change in the wider economy."

In addition, Sustainable buildings bring significant added value in many ways other ways, including asset value, risk mitigation, cost savings and improved interior environments, from which all stakeholders can benefit: property developers, assets' owners and building end users. [28]

Given the benefits presented through this paper on the use of digital technology and data in the better design and operation of the building stock, the construction industry needs to radically transform its current processes to really take advantage of the opportunities.

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Trinity Business School: BIM to Digital Twin – The Journey

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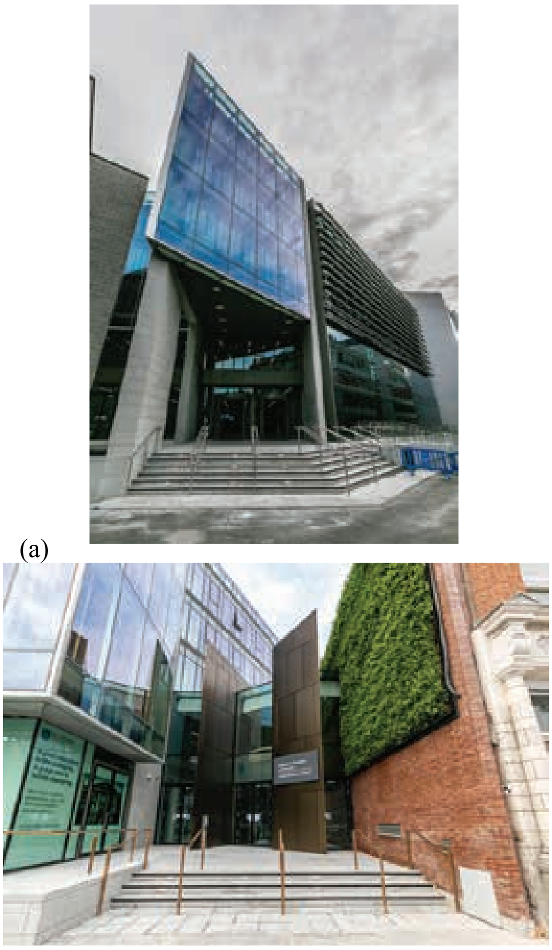
Abstract−The Trinity Business School implemented BIM to design and build a new six-storey building, which is almost 12,000 m² in size, housing various facilities including a 600-seat auditorium and several smaller lecture halls. In addition to the benefits to be expected from the use of BIM in capital programs, Trinity College Dublin's (TCD) Estates and Facilities team also wanted to utilise BIM to build an asset information model (AIM). TCD would leverage the AIM to create Digital Twin solutions for the building and to identify specific data management challenges and practical solutions that work in real world implementations. The primary challenge in getting a facility operationally ready is having access to all the data that is produced during design, construction and commissioning. If the project team waits until the end of the project to gather the handover data, information will be lost and the data gathering cost will be significantly higher. TCD therefore put in place a strategy to use the BIM process to progressively aggregate data throughout the development phase to transform handover and streamline operational readiness. The process and tools to achieve this were new to TCD and to the supply chain. This paper will describe the process, tools and lessons learnt from this experience. The authors conducted a series of interviews with the TCD facilities team, contractor and consultants to uncover insights. The case study determined that while BIM can be an excellent foundation on which to build Digital Twin solutions for operations, success is predicated on (i) a well-defined information management strategy being established early, preferably prior to the start of design development and (ii) the choice of an appropriate technology platform that supports a flexible and extensible data model that can represent and associate data from many sources. It is shown that a Digital Twin is best seen as a connected set of solutions that leverage a unified data model, feed off each other and together having the potential to transform operational efficiencies of a built asset. Significant challenges need to be overcome for successful implementation including information management process skills, the right technology framework and the need for all stakeholders to commit to producing a "digital asset" that support operations, with the same duty of care as to produce the "physical asset".

Keywords – Data Management, Asset Information Model, Digital Twin, BIM, Integrated BIM

I. INTRODUCTION

During the current digital transformation of the construction industry, the notion of a Digital Twin for the built environment is generating a lot of attention but its definition remains fairly nebulous. It tends to mean many things to many people in the design, construction, own and operate ecosystem and, therefore, needs to be examined in the context of specific roles and use-cases. This case study, which presents the factors affecting and surrounding the use of a Building Information Model (BIM) in the construction and delivery of the recently opened €82m Trinity Business School (Figure 1), is in the context of an asset owner and, therefore, the stated purpose of this case study is constrained in that context. TCD Estates and Facilities department kindly consented to support this case study.

The growth of interest in BIM, its processes, procedures and techniques has been expanding rapidly globally [1]. In the last five years, the Irish construction industry and academia have similarly experienced accelerated adoption of BIM and what it implies for construction efficiency, while being aware that some other countries are further advanced in their BIM journey [2]. The work of the BIM Innovation Capability Programme (BICP, [3]), under the auspices of CitA, has been instrumental in advising the Irish National BIM Council, which gave rise to the Roadmap to Digital Transition for Ireland's Construction Industry [4], leading towards mandatory BIM for public projects in the next four years.



(a)

(b)

Figure 1: Entrance to Trinity Business School from (a) within the campus and (b) from Pearse Street.

The potential for asset owners to derive enhanced value from BIM has been one of the main drivers in the Digital Twin conversation [5], such as facilitating real-time data access, visualisation and marketing, creating and updating digital assets, and personnel training and development. While BIM has delivered value in the production of coordinated construction documents and offers the possibility for planning and scheduling of construction (4D BIM), for estimating quantities and costs (5D BIM), all of these levels of utilization of the BIM model do not directly benefit the asset owner. It must be recognised that the asset owner pays a fee for the design team to produce coordinated construction documents, irrespective of the methodology used for doing that. It can benefit the contractor to use 4D and 5D BIM, but has the asset owner not paid the price to get the physical asset built and delivered on time and within budget? At times, the added value of BIM in the operations stage has been marginal [6].

Evidently these expected outcomes are not achieved consistently and yet the asset owner believes that the use of a mature BIM process on a project would help to reduce the risk and enhance the likelihood of on time and on budget delivery. As BIM processes continue to mature, asset owners and the industry at large will accrue benefits from improved productivity, reduced waste and better quality although a number of challenges still need to be overcome to reach this state.

The immediate opportunity to leverage BIM to achieve a digital handover and to create an Asset Information Model (AIM) for operations has strongly resonated with asset owners. Consequently, industry stakeholders have invested signficant effort to create and communicate the need to implement standards, tools and processes to achieve this goal. The implementation has not been easy or efficient and, therefore, has resulted in limited adoption. Where implemented, it has resulted in the production of as-built record models in the native design tools, with an enormous amount of data massaged into it, with building operators finding it very hard to access, update and maintain such during operations. The models serve as a data source to populate the database of a maintenance management system, but even that has many challenges and limitations. How then does BIM become an AIM and ultimately will it be usable? Can it serve further cases to operate and manage buildings better? This case study addresses these questions.

The assertions in this paper are based on original research where the authors have interviewed various stakeholders involved in the development of new TCD Business School.

II. What is a Digital Twin?

Generally described as a virtual representation of a physical asset, the notion of a Digital Twin for buildings can mean many things to different stakeholders. A Digital Twin is a digital duplicate of the physical environment, states and processes. While a BIM model contains as-is and historical data, it can be used to assess the current state and to potentially forecast the future state, of a digital duplicate of the built environment [7]. Depending on his/her role, every stakeholder may expect the Digital Twin to provide information and insights relating to the processes for which they are responsible. A Digital Twin can be based on massive, cumulative, real-time, real world measurements across an array of dimensions and the consequent use of a digital model across the entire lifecycle of an infrastructure. The model comprises of geometry of the infrastructure components as well as a comprehensive set of semantic information, including materials, functions, and relationships between the components [8].

The Digital Twin can also be defined as a cyber physical system that aggregates and visualises information and insights to support design, construction and later operational processes when the building is in use. At each stage of the building's lifecycle, the Digital Twin can be expected to deliver certain outcomes, through a combination of static information that describes the building, its contained systems and assets, as well as the dynamic information that reflects its use during that phase. 3D models produced from BIM authoring tools serve as a "seed" to create a Digital Twin, in combination with information from other data sources.

During the concept or programming phase, the Digital Twin may be expected to represent data relating to planning requirements and help to optimise the building mass to maximise the developed gross area, estimate income, operational costs and as a result improve yield. In the case of an interior fit out, the Digital Twin may be required to evaluate various possible test fits for a given floor plate against defined business requirements.

During the design phase, the Digital Twin may be expected to represent and visualise results of simulations that help optimise the structural design; optimise orientation, design elements and materials to achieve higher occupant comfort, lower energy use, lower both capital and operational costs and improved safety amongst others. As a consequence, it may allow the design to be optimised applying the combined constraints.

During construction, the Digital Twin
may represent the progress of \
the earned value of the contracto
given milestone, job site condi
locations of material, available
age space, locations of people, a
vehicles on site and much more
Digital Twin can then be used to
thoroughly visualize and prio
maintenance options, pro
collaboration among stakehol
and accurately estimate assoc
costs and technical issues encountered
by physical constraints at any pre-determined location [9].

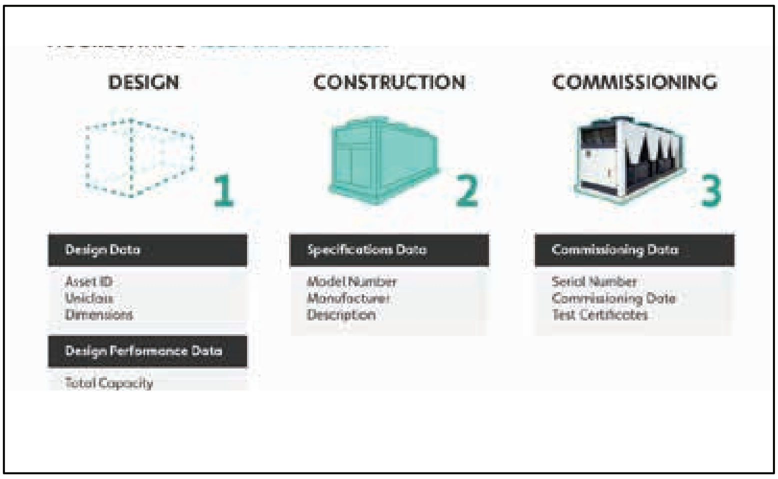
When the building is in use, which is the subject of this case study, the Digital Twin may initially represent the "as-built" status of the building at handover, together with relevant data and documents about its maintainable assets and the rooms and spaces. This AIM is at the very core of a Digital Twin and becomes a "Digital Building Manual" for the operations and maintenance teams. The Digital Twin becomes dynamic through the integration of information with other systems to (i) update its AIM to reflect the "as-maintained" conditions, (ii) track building performance "as-used" against the "as-built" expectations in respect to energy demand, occupant comfort, space and asset utilization, and (iii) enable analytics and potentially, through machine learning, predict outcomes to optimise utilisation of space, utility consumption and the lifecycle of assets. In addition, the Digital Twin may enable implementation of new solutions, applications and expert systems as requirements evolve.

The Digital Twin of a built asset, in each phase of the buildings lifecycle, is best seen as a network of connected systems with a foundation of a common information model, delivering various outcomes enabled by its data. The Digital Twin must be seen as a platform for digital transformation rather than a product that does a certain defined job.

III. BIM, a data source

3D models produced by any BIM authoring tool can be a very good seed to build a Digital Twin. One of the major advantages of BIM is the ability to create, manage and exchange information throughout the life of a project. To this end, the use of a Digital Twin is an asset which will evolve over time [10]. However, it is only so if the models are built to support data workflows when aggregating
Figure 2: Aggregating asset information through design, construction and commissioning

asset information (Figure 2). What does this mean?



A human is able to look at an object in the model and figure out what it is. However, if one wants machines to do that easily, it is important to ensure

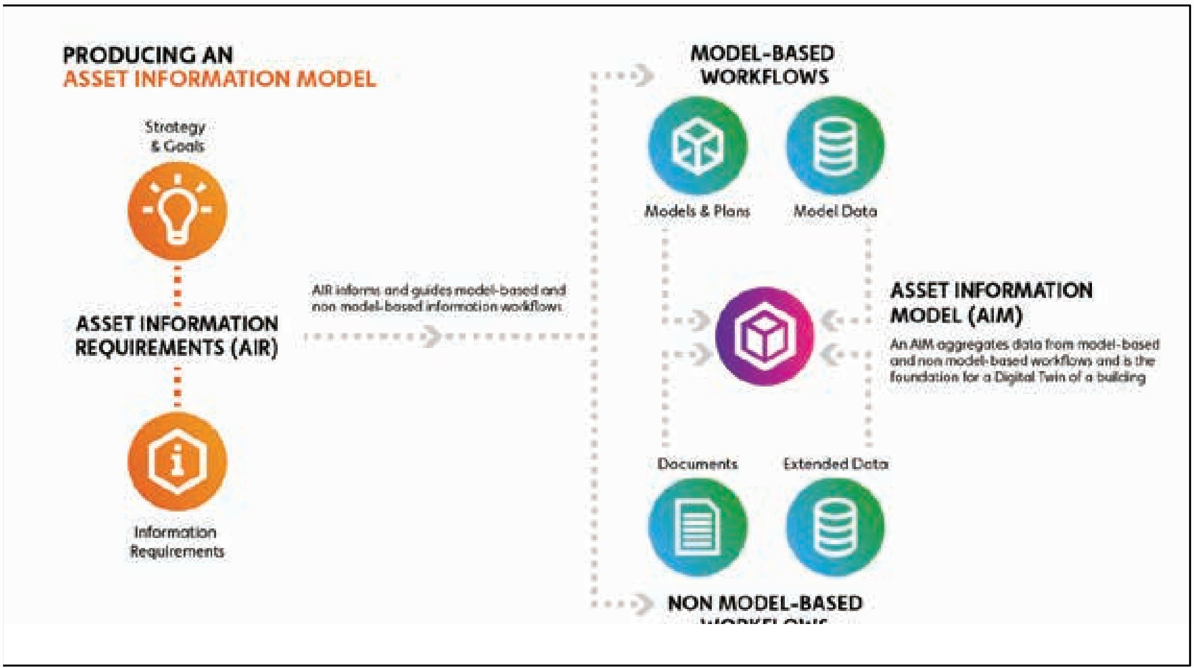


Figure 3: Workflows involved to produce an Asset information model for the TBS

that all objects in a model are given a machine readable and understandable identity. Classification standards, such as Uniclass and Omniclass, are excellent resources to use to this end. The way a model is classified is determined by its end uses. Different downstream solutions, such as model-based construction sequencing, scheduling and estimating, require different types of classification codes and processes for classification. While this paper does not explore those requirements, it serves to highlight that in the context of developing a Digital Twin, the models need to be classified to suit that purpose. The maintainable asset categories in a model need to be identified to allow evaluation and further break down to more type level definitions within the Digital Twin, in the context of the data, documents that will be produced and associated to it during construction, commissioning and later during operations.

The models become consumable in a Digital Twin when the properties that describe the asset categories provide certainty as to what they are and where they are in the building.

Models produced in authoring tools are not the ideal repository of information as they are not designed for data management. They lack the ability to version the data, apply access controls based on roles and permissions in the context of specific workflow, and do not support flexible and extensible object models.

While BIM is a great source of data if models are built to support downstream data workflows, as described here, they should not be seen as the repository for all building information that is required for operations.

TCD developed their Asset Information Requirements (Figure 3), that defined the asset categories that need to be tracked. These were very specific pieces of data that must be produced within the models, in the context of each tracked asset, assigned responsibilities to the deliverables and the stage at which it must be delivered. TCD also assigned the classifications to the asset categories to ensure the assets in the model could be queried, aggregated and, where necessary, disaggregated through the use of other variables that described them.

IV. Less is more

The volume of information that can be produced on a construction project is enormous and can easily overwhelm everyone, from producer of the information to the final consumer and this can add large overhead to the process.

It is very rare that more than 10% of all building elements need to be tracked and, if that is the approach, it becomes practical to focus on the information that is needed to manage these assets. Starting with the end in mind, TCD defined information requirements that were critical and useful to support the workflows of the Estates and Facilities team that manage all the buildings and infrastructure on the TCD campus.

Asset information is produced at several stages of a development and by many different stakeholders. If the information is not captured when it is generated, it becomes challenging to verify and validate it later. While TCD defined the stages at which specific information must be delivered, the process was not introduced at the inception of the project, causing some later difficulties.

V. Producing an Asset Information Model, the foundation for a Digital Twin

The notion of a Digital Twin has been well developed in the manufacturing industry. The concepts and process to producing a Digital Twin in manufacturing does not translate precisely into construction. The primary difference between the two stems from the fact that, in manufacturing, the manufacturer of the product defines, governs and manages the tool chain, object libraries and data dictionaries, very tightly. Everyone in the ecosystem is committed to a fully integrated framework defining how design and data is produced and managed. This is diametrically opposite to how work is done in the construction world in which every project is unique, where attempts to overcome the consequent challenges with information exchange standards, the successful and seamless implementation have proven to be very difficult for a variety of reasons. Therefore, it is important that the systems used to create a Digital Twin for buildings recognise and allow for the challenges of a fragmented and often contentious supply chain.

As the project matures, the actual assets involved become more certain, as does the information that must be collected, the provider of the information, the workflow involved to collect and validate it, the different roles and permissions involved in the process. The system used must be flexible to adapt to these.

While a general definition of the targeted data sources, data flows and data model can be established upfront, the actual data model required to represent the AIM tends to evolve, for the reasons described in this section and, therefore, systems that utilise a fixed schema and a rigid data model defined upfront, can be highly limiting. Unlike the manufacturing world, where a product is designed and produced possibly millions of times, each buildings is unique and is produced just once. Therefore, the ability to adapt the data model across each building, while preserving the ability to build relationships across and between buildings within a portfolio, becomes vital.

The AIM will normally consist of several data sets including:

1. Design data: 3D and 2D graphics representing the geometry of the building together with design attributes that reflect "what" and "where" these assets are that need to be traced. These data sets flow from the BIM authoring tool. The responsibility for this information rests with the design team and, subsequently, with the contractors.

2. Performance data: Information relating to how assets are expected to perform when in use. By integrating checklists and measured values observed during the testing and commissioning of systems, the AIM provides the baseline for Digital Twin solutions to track building performance when in use.

3. Commissioning data: Information gathered from the field. This identifies each individual asset by its serial number and RFID tag and provides information relating to installation date, commissioning date, etc.

4. Specification data: Asset specific information that assists maintenance teams to easily get the information most often required for preventive and break down maintenance. Warranty information is also generally part of this data set.

5. Documents: A large part of the information delivered by contractors is documents. The AIM needs to bring together documents such as model files, drawings, manuals, data sheets, warranty certificates, inspection reports, product certifications and such other, typically handover submittals, making up the "Safety File" (a misnomer) and associate them to the assets to which they relate in the 3D model. The AIM needs to efficiently manage such files using attributes and tags to allow the files to be filtered and found easily.

TCD chose to build its AIM on the Invicara platform, which provided them with a flexible approach to define the AIM data model, to suit the initial outcomes and to be further enhanced progressively as information gaps are filled. This provided the TCD Estates and Facilities team with the comfort that they do not receive an unusable Digital Twin with an AIM, as delivered at project handover.

They were also able to separate the concerns between building the AIM and implementing solutions for various use-cases, because the Invicara platform enabled them to implement solutions progressively either as "Apps" on the platform or by enabling integrations with other business systems. As the Business School building is the first experience for TCD with Digital Twins, the initial focus was to try to achieve a reasonable level of maturity in the AIM and as a future step, define and develop Digital Twin solutions to serve defined use-cases.

VI. Digital Twin use-cases

A number of use-cases are being considered by TCD Estates & Facilities (Figure 4), to develop their vision for a digital future, as follows:

1. Solving the problem of organizing building information in a form that provides easy and instant access to support maintenance. By producing a rich AIM that is accessible over the web, TCD Estates & Facilities achieved an effective solution for this primary problem.

2. Managing information produced during operations and maintenance. During the operating life of a building, a lot of data and documents are produced, such as inspection reports, which contain checklists and measured values. They tend to be filled out in printed forms and filed in binders, rendering the data produced hard to search, track and trend. Implementing a system to digitalise inspection management will enable inspection results to be integrated to the AIM, allowing TCD to easily track actions and trend outcomes. This will enable data-driven decisions for ass

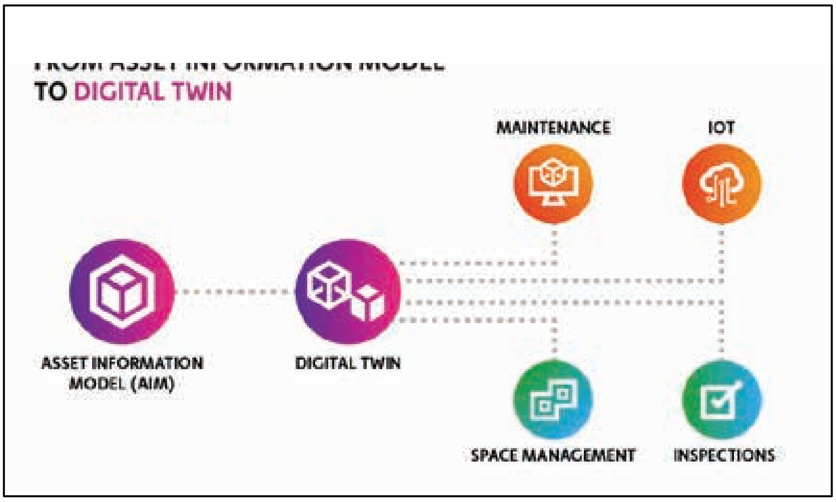
3. TCD has implemented a Computerized Maintenance Management System (CMMS) that will integrate with the AIM to support various business workflows around preventive maintenance, warranty tracking, service request and work order management and asset lifecycle cost management. By versioning the changes to the data managed in the AIM, the solution will also enable maintaining a “Digital Thread of Information” as it relates to the tracked assets.

4. Integration with the IoT will enable situational awareness providing oversight to building performance in respect to comfort, energy and air quality, by blending sensor data with information relating to the involved assets, their maintenance and inspection records, their expected baseline vs as-operating performance metrics and occupancy data.

5. Effective space management requires a deeper understanding of occupancy and usage of rooms and spaces within the building. Integrating occupancy sensors, the timetable of activities in the building and room booking systems will enable solutions to visualize planned vs actual building usage to help better optimize space usage and relate that to building services to optimize energy costs and asset life.

Other uses that have been considered and expected to evolve with time range from incident response management, predictive maintenance using machine learning, to enabling the building to be monitored in demand response programs of energy utilities.

Figure 4: Applications enabled by transformation



VII. Conclusions

A Digital Twin for buildings is a relatively new concept and will evolve considerably over time. An example of a Digital Twin in daily life are digital maps like Google Maps. Just as Google Maps has evolved rapidly over the last 15 years, solutions related to Digital Twins of buildings will evolve rapid and in unexpected ways as well. While geographical information is the core data set that powers Google Maps, a range of solutions have been built to address use-cases ranging from navigation to travel planning to e-commerce. Likewise, an AIM becomes the core dataset to enable Digital Twin solutions for buildings.

A very carefully thought through information management strategy is key to developing a successful AIM in new construction projects. Early engagement to define the process and technology framework, BIM standards including model element classification and design attributes, is essential to get everyone to buy into the program and plan for the deliverables. A clear definition of the assets, asset specific data requirements, data sources and data flows, together with a system to aggregate and validate the deliverables are essential.

The choice of the right technology platform is also vital for many reasons. The flexibility and the extensibility of the technology will make the difference between a dead-end database and having a true platform for digital transformation. Digital Twin solutions not only consume data from the AIM, but also produce new information as a consequence of its processes, some of which will enhance and extend the information contained in the AIM. The ability to manage an ever enlarging data model offers the possibility for new solutions to be built and to enhance the value of the existing.

It is evident from this discussion that it would be very limiting to consider the Digital Twin as a single product. Every solution or expert system is contextual to the specific building and use-case that needs to be addressed. Each solution will have its own relevant data sources, business logic and user interaction. Implementation of several independent point solutions to address each use-case will result in several silos of data and disconnected applications that will simply not scale well.

This study, based on observations of a live project, the construction of the Trinity Business School, leads to the recommendation to build a platform approach to Digital Twin solutions, with a flexible and extensible data model at its core, to represent the AIM. A data model is needed at the outset that can evolve to represent not only the information produced from the capital phase, but also all the information produced during operations by different connected systems. The ability to build each solution as an independent App on the platform, each leveraging the core data model, user and permissions management framework, provides the basis for a scalable and interconnected set of Digital Twin solutions.

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Academia - Estates Management Synergies in HEIs – The Low Hanging Fruit

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Abstract - Higher Education Institutes (HEIs) remain at the forefront of Building Information Modelling (BIM) teaching and research around the globe. As the construction industry continues to adopt and implement emerging digital technologies, such as BIM, to improve efficiencies and productivity levels, HEIs will be key to ensuring that industry continues to be provided with a supply of graduates that possess the necessary knowledge, skills and education ahead of entering employment. It was established, through the undertaking of research for this paper, that if academic and practice-based BIM expertise exist within a HEI, then a knowledge transfer partnership (KTP) could be formed to benefit both the academic and administrative support/estates management areas of a HEI in the fulfilment of their relevant functions. The potential benefits of such collaborative partnerships are manifold and the synergies that exist between both areas remain largely untapped and unexplored. By possessing the required expertise to teach, research and practice BIM and through the availability of valuable digital asset information within HEI campus's built assets and infrastructure, it is suggested in this paper that there is considerable potential to develop a KTP where both parties can share complementary digital technologies, data, knowledge and expertise. This synergy will enhance staff's capabilities and efficiencies to alleviate the ongoing pressures on education, training and operational budgets. It will also help to support the development of staff's and graduate's digital technology skills and HEI's strategic objectives through the creation of mutually beneficial collaborative partnerships.

Keywords - Building Information Modelling, Education, Estates, Facilities, HEIs, Research, Knowledge, Transfer, Partnership

I INTRODUCTION

This research examined the adoption of Building Information Modelling (BIM) in Higher Education Institutes (HEIs) in Ireland through the creation of a local mutually beneficial partnership to share often complementary knowledge and thereby improve teaching, research and administrative support services by utilising the expertise that already exists within academic and administrative areas. Specific areas of investigation in Irish HEIs were identified, as follows:

(i) To investigate the current state of adoption of BIM both academically and in the administration/management of built assets and infrastructure.

(ii) To explore the challenges, barriers, risks and benefits of adopting BIM in academic and administrative areas.

(iii) To examine the potential for academic and administrative support areas to create a partnership to successfully adopt and implement BIM and to investigate if this can be mutually beneficial.

(iv) To assess if the successful adoption of BIM in an Irish HEI could lead to improvements in both constituencies, namely teaching and research and delivery of capital infrastructure and essential support services.

In short, the focus of this research was to establish if it is possible and beneficial for a HEI to adopt and implement BIM, independently utilising the knowledge and expertise that already exists within the individual academic and administrative support areas, to improve the relevant functions of both through the creation of a mutually beneficial partnership.

Since the publication of the the NBC Roadmap 2018-2021 [1] in 2017, the Irish government has launched its strategy to increase the use of digital technology in vital public works projects, with BIM to be mandated in the design, construction and operation of public buildings and infrastructure over a 4-year timeframe ending in 2021 [2]. This statement of intent from the Irish government demonstrated an acute awareness of the importance of BIM and how it brings together technology, digital information and process improvements to radically improve project outcomes and asset operations [2]. These initiatives have been encouraged by the ongoing revival of the construction industry with the sector expected to grow by 20% in 2019, with a total output of €24 billion [3].

II BACKGROUND

In Ireland, the National BIM Council (NBC) has acknowledged academia's role in supporting BIM adoption in Ireland, by providing industry with graduates that possess the required knowledge and skills through the development of core BIM capabilities, in their new roadmap for the Irish AEC industry [1]. This could accelerate BIM adoption by HEIs and help to address existing skills shortages in information communication technology (ICT) and science and engineering [4]. In 2016, a national survey undertaken to benchmark the level of BIM adoption in Ireland found that of the 97 leaders within the AEC industry who responded to a questionnaire, 76% possessed confidence in their BIM skills and knowledge (up from 67% in 2015), with 79% of the same sample group reporting an increase in demand for BIM in Ireland [5]. In 2019, the National Building Specification (NBS) and the Construction IT Alliance (CITA) undertook the first national BIM survey in Ireland focused specifically on design professionals [6]. From a total of 116 responses, 75% reported that clients will insist on using BIM and 76% reported that they had adopted BIM but that this varied depending on the size of the design practice, with those employing 15 or fewer people being less likely to have adopted BIM, with only 54% using it. In the same report it is noted that BIM use on public sector projects was increasing which could be argued is due to the issuing, in 2017, of the Irish Government's BIM Adoption Strategy [2] and the NBC Roadmap 2018-2021 [1]. The NBS [6] identified that lack of in-house expertise (74%), no client demand (67%) and lack of training (67%) were amongst the main barriers to BIM adoption (Fig.1).

It is important that relevant academic areas of HEIs continue to embrace BIM and other new digital technologies and processes to help to address these barriers and provide graduates with the required knowledge and skills to assist them with their future employment within the AEC industry. Equally, estates management/administrative support areas of HEIs can embrace BIM and other new digital technologies and processes as they attempt to improve efficiencies and reduce the cost of capital and operational expenditure. This is made more relevant as Ireland continues to emerge from a financial crisis with a €200 billion debt legacy [7], where efficiencies and productivity continue to be sought in the educational sector.

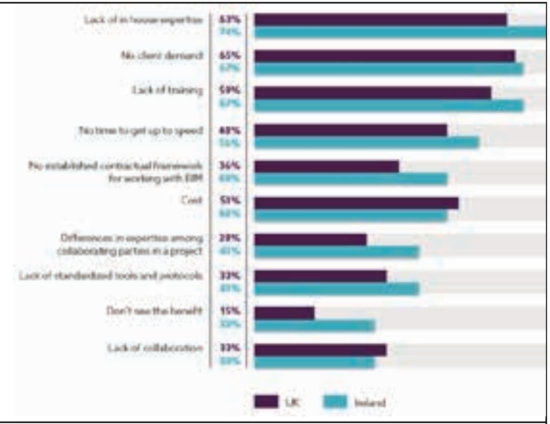

Figure 1: Top 10 barriers to adoption in Ireland [6]

A knowledge transfer partnership (KTP) is an undertaking between a HEI and a private company to share knowledge to assist with industry development [8]. In theory, establishing a BIM KTP to support academic and administrative functions within a HEI makes perfect sense. Students can gain knowledge and skills associated with emerging digital technologies and processes using real on-campus case studies. Researchers can use this digital information to support their own research and teaching needs. On the other hand, administrative support staff can aim to realise efficiencies, such as improved productivity, reduced duplication of effort and better decision making through access to accurate data on built assets and infrastructure, using the tangible research outcomes of the on-campus researchers.

The reality, however, is different. BIM adoption can be disruptive and requires changes to processes and workflows [9]. Upskilling and training in the use of such new technologies will also be required. To some existing employees, this could appear to be a daunting challenge. Change can be difficult for institutes, groups or individuals - when a specific task has been undertaken in the same way for a long time, staff and students within a HEI could find it difficult to adapt. However, in order to maintain the high standards HEIs set for themselves, it is essential that new technologies and processes are regularly embraced.

Research undertaken for this paper allowed the authors to develop a better understanding of how different areas of HEIs were, or were not, addressing BIM adoption and to identify any deficiencies related to it. Of particular interest was the potential for setting up a KTP between the two often independent and non-communicating expert constituencies within HEIs, that is, academia and estates management/administration.

One KTP project identified, between the University of Salford and an architectural firm, John Mc Call Architects, developed and tested a set of key performance indicators (KPIs) through an action research strategy [8]. During this research it was noted that the implementation of BIM technologies, socio-cultural aspects of BIM adoption, change management and the adoption of new strategies posed particular challenges [9]. It was noted that business related KPIs that measure risk to annual goals or strategic objectives must be established in order to justify a business case for BIM adoption because it will only be of value if it enables an organisation to fulfil its mission. From the list of KPIs identified for the architectural industry partner, a number of these stood out. In particular, the ability to compare man hours spent on a project that utilised BIM versus one that does not and how development of a partnering approach with a client are critical in order to establish a shared understanding of how to achieve client satisfaction. This KTP project concluded that while BIM adoption is as much about people and processes as it is about technology, the project was successful in realising improvements to the industry partner's practice, including the elimination of risks of duplication of effort by staff, improving communications and streamlining processes [10] which are potentially valuable lessons to be learned for HEIs working towards becoming more efficient.

BIM is seen as an enabler that may assist the AECFM industry to improve its productivity levels [11]. In Europe, productivity levels within the construction industry have increased by only 1% in the last 20 years [12]. In the USA, productivity has not experienced significant increases since the mid 1900's [13]. According to recent research undertaken by McKinsey & Co., productivity levels within the construction industry have remained unchanged for decades [14] while within the manufacturing industry it has doubled over the same period (Fig. 2). Productivity levels are expected to change with the growing use and impact of digital technologies on the engineering and construction industries [15]. In this context in Ireland, the Construction 2020 Strategy [16] recognised BIM as a powerful tool in driving efficiencies and increasing productivity in construction.

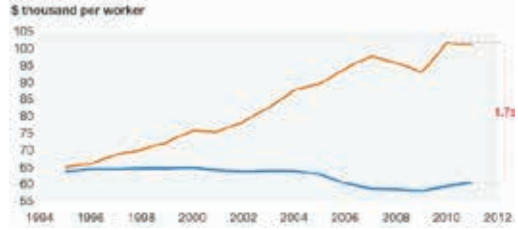

Figure 2: Overview of USA productivity improvement over time (red manufacturing, blue construction) [14]

Benefits claimed to be derived from BIM can range from improved collaboration, co-ordination and cost control in design, avoidance of clashes and negative impacts on programs and scheduling in construction and optimisation of lifecycle management in the operation stages of a built asset [17]. Mc Graw Hill Construction [18] suggested that there is a clear indication of the benefits to the return on investment (ROI) from the continued use of BIM to reduce errors, omissions, rework and construction costs. However, for a HEI, the rationale for adopting BIM will not be to generate profits.

HEIs can support the adoption of BIM within industry, which has heretofore been delayed due to the lack of sufficiently trained BIM personnel, by adopting BIM themselves which will be important for graduate's future employability [19]. Despite the difficulties with the integration of different areas of the curricula [20] or resistance to changing established teaching methods and processes [21], HEIs have responded to industry demands for BIM-enabled graduates, with programmes ranging from dedicated full-time BIM courses, to individual BIM modules on existing courses (Table 1). In 2012, Waterford Institute of Technology (WIT) commenced an academic-industry BIM partnership, having been focused on teaching BIM compatible software tools since 2010 [22]. WIT has recently extended this partnership to a "Tri-varsity, inter-disciplinary BIM workshop" with HEIs in the UK and Denmark to help introduce collaborative BIM workflows for students from different disciplines across the three institutions [23].

HEI	Title of Programmes
Athlone Institute of Technology (AIT)	Revit Building Information Modelling (BIM) Project Management and Collaboration Advanced Revit Building Information Modelling (BIM) Project Management and Collaboration Beginners
Cork Institute of Technology (CIT)	Higher Certificate in BIM
Dublin Institute of Technology (DIT)	MSc in Applied BIM & Management MSc in Construction Informatics
Dundalk Institute of Technology	Certificate in Building Information Modeling
Galway Mayo Institute of Technology (GMIT)	Higher Diploma in Engineering in Building Information Modeling
Institute of Technology Carlow	BIM Management module on the MSc in Management in the Built Environment
Institute of Technology Sligo	module on the 4th year of the BSc BIM and 3D surveying model on the BEng (Hons) in Civil Engineering and the BEng in Environmental Engineering
Institute of Technology Tralee (ITT)	Certificate in Building Information Management
Letterkenny Institute of Technology (LKIT)	Higher Certificate in Science in Construction Technology with BIM Bachelor of Science in Digital Construction
Limerick Institute of Technology (LIT)	Construction Management and BIM module in year 2 on the BSc (Honours) Construction Management and BSc (Honours) Civil Engineering Management Degrees
Ulster University	Postgraduate BIM module as part of the MSc in Commercial Management
University College Cork (UCC)	MEngSc in Information Technology in Architecture, Engineering and Construction
University College Dublin	BIM components within the Design & Materials on the MSc module for the BEng Honours in Mechanical Engineering
Trinity College Dublin	BIM modules in Façade Engineering and third year on the Bachelor Programme in Civil Engineering
Waterford Institute of Technology (WIT)	Higher Diploma in Science in BIM BSc Honours in Architectural and Building Information Modelling Technology

Table 1: Sample of BIM programmes within Irish HEIs [1]

With the NBC's acknowledgement of academia's role in supporting BIM adoption in Ireland [1] and with the potential for HEIs to address existing skills shortages in information communication technology (ICT), science and engineering [4], it is encouraging to observe this level of activity within the academic areas of Irish HEIs.

Academic areas of HEIs are positioned at the forefront of research into BIM. In Ireland, there are examples of this at the Technological University of Dublin (TUDublin), [24], Trinity College Dublin (TCD) and at the National University of Ireland, Galway [25]. There is some evidence of BIM adoption within the administrative support/estates management areas of Irish HEIs. The BICP [26] reported on BIM being used within administrative support areas of Irish HEIs and case studies undertaken with TUDublin and TCD reporting that both HEIs required BIM to be used on the Greenway Research Hub and the Trinity Business School (TBS) [27] respectively. The GGDA and TUDublin directive for BIM adoption includes a plan for BIM utilisation on future buildings with a "lessons learned" exercise to evaluate the clients' roles and responsibilities in using BIM for delivery of the new campus and FM functions [28]. Indeed, the planning for the new E3 Learning Foundry in TCD allows provision for the use of BIM Aware for data management during construction so that the facilities management team, working with the academics, can also utilize the BIM digital twin during the building's lifespan.

The NBC plan [1] to engage administrative support staff in Irish HEIs could identify more evidence of BIM adoption to support a more efficient public estate [29] because sourcing information on how these staff have embraced BIM can be difficult when statistics may not yet have been published. Building trust between the academic and administrative support areas of HEIs will be required [30]. Gannon et al. [31] suggested that a BIM implementation strategy (BIS) can support successful BIM adoption within a HEI. A HEI may look to develop a BIS to map new processes and procedures and include training for staff, to assist it to use digital technologies and data-rich information models for administrative support functions in an attempt to gain benefits for either or both academia and/or administrative support areas [28].

In Ireland, Goggins et al. [32] reported on the installation of sensors into the New Engineering Building (NEB) at the National University of Ireland, Galway (NUIG) which have helped create a living laboratory [25] to support teaching and research functions. At Carleton University (a Canadian HEI) its "Digital Campus Innovation" (DCI) project utilises campus building information to integrate teaching, research and operations [33] with evidence of sensor information being used by the administrative support area for their facilities management functions [34]. Data-rich information gathering is also being used within the academic area of the HEI to form open and innovative collaborative centres that are user-centric integrated learning spaces to promote close collaboration between researchers and building operators. The HEI required an innovative framework to address the divisions between teaching, research and operational functions and to break down existing traditional silos to encourage access to knowledge that exists within the HEI to educate future generations. The same HEI has also recognised that it possesses in-house knowledge and expertise and that combining this with real experiments for maintaining and operating its campus could lead to *"knowledge capital without any precedent"* [34].

The Canadian BIM Council [35, 36] reported that the HEI was planning a capital development that would be used for asset management, space scheduling and maintenance planning, that will be used by its academics to develop a new course.

III METHODOLOGY

The research undertaken followed a structured approach (Fig. 3) concurrently converging quantitative and qualitative data in order to provide a comprehensive analysis of the research problem [37]. Research was based around a Master's thesis

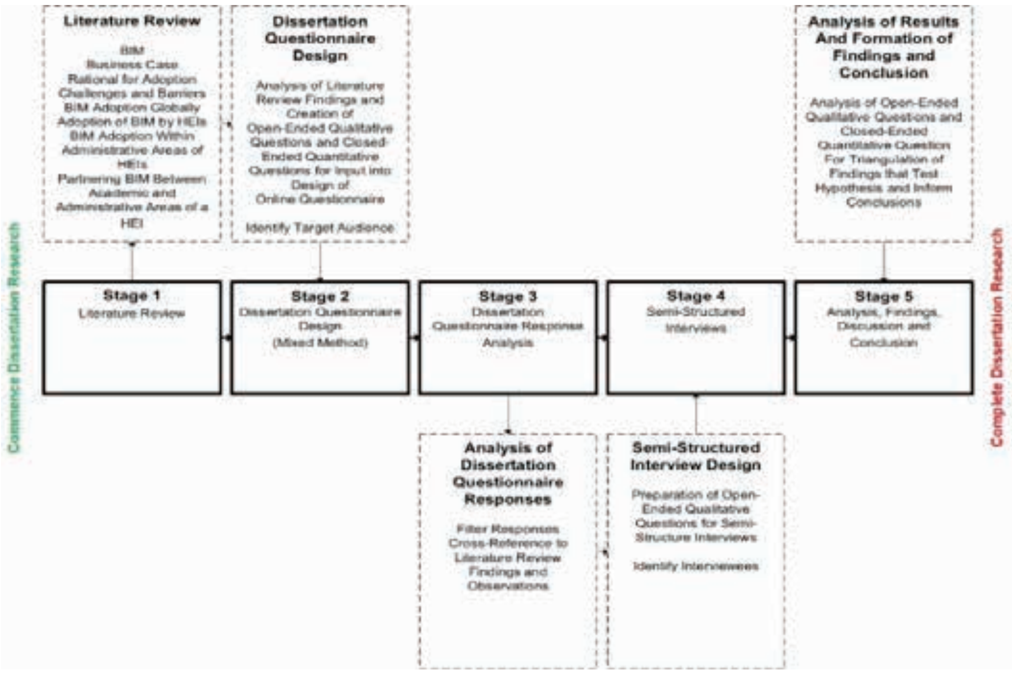

Figure 3: Research methodology structure [37]

hypothesis [38] that focused on the creation of a partnership that encourages both the academic and estates management/administrative support areas of a HEI in Ireland to collaborate to successfully adopt and implement BIM. This could lead to improvements in the fulfilment of the relevant

functions of each area. The primary research undertaken comprised of a survey with data being extracted from a large sample of respondents, totalling 61 people, from within HEIs in Ireland. The target audience was identified via the literature reviewed, attendance at conferences and membership of subject-related groups. A questionnaire was chosen as a time-efficient way of gathering both qualitative and quantitative data from respondents in order to test the research hypothesis. The following section presents a summary of the key questions posed and responses gathered. In each case, respondents were invited to provide comments should they have any additional details that may be useful to the researcher.

IV OUTCOMES

Necessarily, only some of the questions posed have direct relevance to this paper and the key ones are discussed in turn here:

<u>Question 1:</u> *Where do you think there is BIM expertise within your HEI?*

Optional answers were offered as to whether

participants thought that BIM expertise existed in neither, either or both areas or if they did not know. From the responses, 31% of respondents were of the opinion that BIM expertise existed in the estates management/administrative support area, 28% in the academic area and 34% in both areas. Only 6% did not know if there was BIM expertise in their

HEI. The responses to this question indicated that BIM expertise was spread evenly amongst both areas and thus some synergies may well exist which could be exploited.

<u>Question 2:</u> *Do you think that there is a need for BIM adoption within any area of a HEI (for example, to improve teaching and research or the design, construction and operation of built assets)?*

A number of examples were offered to assist participants in answering this question. An overwhelming majority (of 90%) of respondents reported that there is a need for BIM adoption within HEIs in Ireland, while only a small number of respondents (10%) did not know. From the comments provided, it was evident that many different applications for BIM were identified, such as for research, technology and learning development, improving efficiencies in capital projects and operational functions, such as facilities management, space planning, room usage monitoring and timetabling.

<u>Question 3:</u> *Is there a BIM implementation strategy (BIS) to support BIM adoption and implementation within any area of your HEI?*

An optional answer was offered should participants be unsure of the existence of a BIS within their HEI. A total of 41% of respondents reported that there was no BIS to support BIM adoption and implementation within either area. Similarly, 41% reported that they did not know if a BIS existed. Only 17% of respondents reported that a BIS did exist within their HEI. Three respondents' comments suggested that there was some awareness of a BIS that was currently being worked on within their HEI with two of these identifying that this was happening within the estates management/administrative support area. These responses suggest that irrespective of individual and sectional initiatives in respect of BIM adoption, the HEIs as a whole have not been proactive in developing a BIM policy in either constituency.

Question 4: *Do you think the estates management/administrative support area and appropriate academic areas of a HEI could benefit significantly were they to adopt BIM to fulfil their relevant functions?*

No specific benefits were proffered to this question. An overwhelming majority of respondents (of 90%) were of the opinion that a HEI could benefit significantly in the fulfilment of their relevant functions through the adoption of BIM while only 3% did not agree. A small number of respondents (7%) did not know if their HEI could benefit significantly were they to adopt BIM. It was interesting to note that as few as one respondent was aware that there should be collaboration between both areas and only two respondents thought that sharing of information or knowledge would be beneficial.

Question 5: *Have the academic and estates management/administrative support areas of your HEI collaborated to form a partnership for BIM adoption in order to enable both areas to benefit from it?*

38% of respondents reported that there was collaboration for BIM adoption in an informal relationship between the academic and estates management/administrative support areas of their HEI, while 45% reported that there was none. 17% reported that they did not know if this was happening. While not directly answering the question, it was encouraging to learn of such collaborations, though no-one seemed to be aware of the benefit of formalising such collaborations in a KTP.

Question 6: *If there is BIM expertise already available within a HEI, do you think this could be used to form a BIM adoption knowledge transfer partnership (KTP) to benefit both the academic and estates management/administrative support areas?*

Responses gathered show that 66% of respondents believed that existing BIM expertise within their HEI could be transformed to form a BIM adoption KTP to benefit both the academic and estates management/administrative support areas with only 7% reporting that they did not think it could work. Readers are referred to the Master's thesis for more in depth discussion on the topic and questionnaire [38]

V DISCUSSIONS

The research was based around the hypothesis that the creation of a formal partnership to encourage both the academic and administrative support areas of an Irish HEI to collaborate to successfully adopt and implement BIM would lead to improvements in existing teaching methods, research and support services. A number of findings were established from the research undertaken, as follows:

(i) While most construction-related academic areas of HEIs in Ireland are adopting BIM for teaching and research purposes [1], there is a lack of evidence to show that all administrative support areas of Irish HEIs are following suit. While case studies have reported that two Irish HEIs required BIM to be used on large capital projects [27] neither was yet using BIM for operational functions such as facilities management.

(ii) There are potential benefits to be realised from the adoption of BIM within HEIs in Ireland, but there are also significant challenges, barriers and risks that will need to be overcome. Less than 20% of respondents to the questionnaire reported that a BIS exists within their HEI and the lack of a clear strategy/business case ranked high in terms of how respondents to the questionnaire thought a HEI would find it difficult to adopt and implement BIM.

(iii) Almost 40% of respondents reported that there was some collaboration in a relationship for BIM adoption between the academic and estates management/administrative support areas of their HEI, though none had been formalised into a KTP. Evidence suggests that BIM expertise was spread evenly amongst both areas of HEIs in Ireland and that this could be used to form a BIM adoption KTP to benefit both areas.

VI CONCLUSIONS

This research has established the need for HEIs in Ireland to more fully and formally adopt BIM to further improve relevant teaching, research and operational functions. Benefits from BIM adoption could be realised if a strategy were in place to support this. Equally, any challenges or barriers that may exist can also be addressed with the use of a strategy to help to reduce or remove these. BIM adoption has the potential to offer many positive opportunities to HEIs in Ireland. It is recommended that a collaborative KTP and a strategic plan, to identify and communicate clear benefits to be gained by moving away from inefficient traditional paper-based processes to smart digital technologies, should be developed to support BIM adoption in HEIs. There is evidence to support the synergistic adoption of BIM by both the academic and administrative support areas, through the creation of a strategic collaborative partnership to facilitate the sharing of existing knowledge and expertise to improve teaching, research and operational functions, linking pedagogy, digital technologies, operations, collaborative working methods and processes. These could include education and training, business case development and the realisation of potential benefits from the introduction of collaborative working methods for all stakeholders, be they undergraduate and postgraduate students, educators, researchers, administrators, design consultants or supply chain service providers. It is recommended that both constituent areas of a HEI would begin to formulate beneficial KTPs through the development of innovative living laboratory learning spaces that help to improve engagement and collaboration between them, development of existing pedagogy through partnerships where both constituents shared BIM data for use in academic projects and to develop operational improvements. For a HEI in Ireland to not actively explore and realise the potential benefits that BIM can offer when they already possess the necessary knowledge and expertise is undoubtedly currently a wasted opportunity.

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Achieving Smarter Buildings and More Efficient Facilities Management: The Implementation of Big Data

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Abstract−As buildings become more complex, smarter, interconnected and self-reporting, can existing technologies be used to the advantage of the end user and society? This study looks to determine if implementing big data to create smart buildings can improve sustainability and increase efficiency in Facilities Management (FM). The following objectives emerge; investigating the application of big data and Internet of Things (IoT) in the construction industry, in particular the improvement of sustainability by creating smarter buildings and more efficient FM. A mixed methods methodology is employed, using a critical literature review, primary qualitative research by three semi-structured interviews and quantitative data research by questionnaire. Mind mapping is used to analyse the interviews, with SPSS providing statistical analysis of the questionnaires. The key findings determined an industry concept of big data and the IoT, identifying data collection from any source on AEC projects and Building Information Modelling (BIM), a primary data contributor. Improvement in the decision-making process, due to new technologies was identified, with the inception and design phases most assisted by implementing new technologies. The research determines that sustainability and FM can be improved through new technologies, such as big data analytics, with BIM now an essential element in FM. The implications for industry lie in having mixed and unrelated use of the terminology and technology and that misunderstanding the terminology has ramifications across all project phases and industry sectors. Additionally, the speed at which the industry is adopting new technologies is shown to be slow, which could leave it playing catch up to other industries. The originality of the study identified space for further research into the topic.

Keywords− Big Data, Building Information Modelling (BIM), Facilities Management, Internet of Things (IoT), Smart Buildings, Sustainability.

I INTRODUCTION

Big data is one of the buzz words across all industries these days and has numerous associated meanings all built around a concept more than a direct detail. One concept describes big data as colossal amounts of detailed digital information [1], another identifies big data as all information not normally circulating within a company [2], while others propose big data is to be big data analytics; information filled with variety, volume with high speed sharing and usage in various forms, declaring the Vs (volume, velocity, variety) the core of big data and big data analytics while arguing over the number of Vs in big data [1], [3], [4], [5]. These explanations of big data assist in understanding what it is and indicate that computer technology and business sectors are driving the interpretation of the subject.

Coupling big data, ICT has introduced the Internet of Things (IoT), again with more than one similar explanation of the subject. The IoT has been described as the interconnectedness of objects, the application of connecting devices through the internet or the use of sensor application to collect and share data, [6], [7], [8],

[9].

Further research on the topics has shown that big data and IoT are developing concepts and although the concepts are realised and are in use in industries, such as business, manufacturing, information technology and robotics, they are still in their infancy and are continually developing. Further the research shows that the IoT is making headway in the construction industry and is driven by sub-sectors such as energy, mechanical and electrical and facilities management through the employment of Building Management Systems (BMS) [10], [11] yet there is very limited research into how big data can be applied within the construction industry.

Preliminary empirical research has identified gaps in knowledge surrounding big data, its application to the construction industry, project phases, design, sharing and project collaboration, the linking of technology platforms and how applications can improve sustainability. The study's hypothesis suggests that big data can be used to gain knowledge in relation to the performance of existing projects, which can then be used as the basis for the design of new smart buildings, promoting sustainability from the outset, which will allow for more efficient facilities management during operation, ensuring sustainability across all project phases, thus proposing that big data can lead to smarter buildings and more efficient facilities management. The study looks to fill the gaps in the knowledge and provide essential information for the industry.

II Literature Review

The literature review outlines the existing research relating to the concept of big data, big data analytics, obstacles to big data and cloud working. The purpose of the review is to provide a background and understanding of the subject area, progressing to its application across the construction industry.

a) Big Data and Big Data Analytics

Big data has been identified as not only colossal amounts of detailed digital information [1], but the term applied to all available data outside that traditionally circulating within a company [2]. Differing descriptions were provided by [12] and [13]. The literature review further identifies the exponential increase, evolving importance, popularity, need for good practice, regulation and standards for big data [1], [13].

Further highlighting the difference between big data and big data analytics, research shows big data analytics encounters data collection problems and processing challenges, building around themes of business use of data analytics, data mining, statistics, and artificial intelligence for determining business health and the ability of that analysis to improve decision making and progress operations [1], [14]. While highlighting the difference between both, the research demonstrates that big data should be considered alongside big data analysis thus giving rise to multiple definitions of the V concept; 3Vs, 4Vs, 5Vs and 7Vs of big data [1], [3], [4], [15], [16]. The 3Vs; volume, velocity, variety [1] expand to the 4Vs concept, adding either veracity [3] or value [4]. The 5Vs concept adds variability [15] while the 7Vs concept adds visualization [16].

Focusing on big data analysis shows that companies are not fully exhausting the analysis and those that are, show its link to competitive advantage [2], [17], [18], [19]. Coupling the positives of using big data are the obstacles to it. These have been identified as existing Information Technology (IT) infrastructure, complexity of the data, employee skills, privacy, security issues, sharing, exploitation, risks, open source and progression toward cloud platforms for storing and processing the data [5],[17],[19],[20].

b) Cloud computing and the IOT

Further investigation into big data and sources within the industry identifies cloud computing platforms and how they can be adapted to reduce complexity across the construction industry, its processes, information transfer, and data sharing, facilitating virtual team and working, in turn reducing fragmentation and improving communication [21], [22], [23], [24], [25], [26], [27]. Further existing platforms and programmes such as Hadoop or Spark along with continual growth of programmes and technologies are assisting in transforming big data into usable information, [28], [29], [30].

A major contributor to big data is the (IoT); with research identifying sensors as the largest provider of data, due to their ability to collect data from numerous sources, process the data in real-time, in tandem with the sensor networks and at an intensive speed. Further advances in digital solutions, wearable technology, embedded objects and embed sensors to gather, predict and compute data is becoming crucial for the industry, providing applications across the industry from health and safety to structural monitoring, encouraging smart materials, smart buildings, greater information flow and lean construction management systems all assisted through the IoT and cloud technology [6], [7], [8], [9], [31], [32], [33].

c) Smart buildings and sustainability

Smart buildings are becoming more

common, with the ‘smart’ not solely distinctive of the industrial or commercial sector anymore with ‘smart’ showing strong growth in the residential market thanks to continued development of smart homes which thrive on their connection to the smart grid [34], [35], [36], [37].

A single definition for sustainability was not found, but the concept of the three pillars of sustainability; social, economic and environmental for promoting sustainable development was well favoured. The research also identified that sustainability and sustainable development are interchangeable terms within the industry [37], [38], [39], [40]. [41].

The traditional approach to sustainability, focusing on improving the built environment by reducing energy consumption, improving renewable energies, energy consumption and environmental practices, is still very much the norm, but the influence of technology, education, innovation, legislation and new practices are driving improved sustainable development and encouraging the three-pillar approach. [44], [43].

d) Facilities management and new technologies

The research identifies numerous definitions for Facilities Management (FM), encompassing, effective management, promoting efficient operation, maintenance, building redevelopment, consciously managing running costs and monitoring energy consumption. Growth and expansion in the sector is advanced by new technologies, BIM, embracing collaborative working and early FM contractor involvement [44], [45], [46], [47], [48].

BIM is shown to assist in the design process of new builds, infrastructure, retro-fit, and renovation, with research suggesting that utilising cloud computing in combination with webpage technologies will facilitate the inclusion of big data into BIM, thus creating a ‘Dynamic BIM’ allowing for the reliable management of massive BIMs. However, attempts to merge big data, big visual data and BIM are still in their infancy [49].

The literature review identifies the existing research available on the topics of big data, IOT, cloud computing, sustainability and complementary technologies within the Architecture, Engineering and Construction (AEC) Industry. The research examined these main themes individually and collectively, identifying any interconnectivity available within the themes. The literature review identified gaps in knowledge, which are investigated through the interviews and questionnaires.

III Research Methodology

Generating from an interpretivist paradigm, this study uses a sequential exploratory mixed methods research approach. This approach combined an in-depth critical literature review examining themes including big data, smart buildings, the IoT, efficiency, FM, sustainability and technology, in construction. These provided existing opinions and revealed gaps in the knowledge. Secondly qualitative data collected through three semi-structured interviews, conducted with experienced industry professionals, obtained additional knowledge and opinion. Quantitative data collection through a questionnaire and use of statistical analysis of the responses determined industry opinion in relation to the research.

IV Discussion and Results

The literature review provides good background on the existing theories for big data in business, IT and general management with progression of these theories into construction identified. However, the newness of the concept and its adaptation within construction shows several major gaps in current knowledge.

a) Interview

Building on knowledge gained during the literature review and to gain opinion, three semi-structured interviews were conducted for the research with senior managers, working in Northern Ireland, Ireland and the United Kingdom. The results of the interviews are interesting and contrasting with variance in the answers to similar questions, an unexpected outcome having picked participants with similar experience, time in the industry and similar fields. The variance in the answers spurred many of the questions in the questionnaire, with the researcher looking to determine if the cross-section of the industry surveyed were of the same opinion as the interviewees or if the opinions of the participants differed – how and why. Cognitive mapping of the interviews identified concepts representative of the goals, purposes and values of each interviewee. This provided for comparison and contrast between the interviews and identification of goals for each, based on the specific nature of their business. The mapping showed that each require and use data, but in differing formats. Primarily, the mapping identified the IoT as an essential concept for achieving control in their projects and further showed CAD and technology (smart) as additional important factors. The interviews identify integrated project approaches and removing silo working as essential for achieving their key objectives.

a) Questionnaire

The questionnaire builds on the research provided through the interviews. The largest participation is from Mechanical and Electrical Engineering (40%), and the second largest group of respondents are from Consultancy (18%). This is an interesting and important point as participants are from sub-sectors of the industry that are focused on improving efficiency, especially energy consumption, embracing new technology and improving sustainability as found in the literature review [6], [14] and [44]. This suggests that both due to their responsibility for consulting and execution, are well placed to influence project decision-making leading the researcher to interpret that the results are meaningful in the context of this research. Further backing up this interpretation is analysis showing the largest participation is from the Building and Construction sector (44%). The validity of the results is further improved by the analysis indicating that the majority of those partaking are at Project Manager (36%) and Engineer (32%) level, making them responsible, technical and decision-making peoples within the context of their projects. 44% of participants hold a middle management position and 34% of participants have in excess of 20 years' experience, making them well placed to discuss the topics under research and provides for favorable comparison with the results of the interviews. The similarities in position, role and experience between the interviewees and questionnaire participants indicates that the research is being conducted across a cross-section of the industry, which provides an even basis for analysis.

The research indicates that the construction industry is now technology focused and embraces the use of new technology, but that the industry is unclear on the meaning of big data and that some confusion exists around the meaning of the IoT.

The research identifies that the project-based nature of the industry can be fragmented but that use of virtual and cloud-based technologies can assist in project team management, collaborative working and project delivery with BIM leading to improved collaborative working on AEC projects. The primary research suggests a holistic approach is commonplace challenging research in the literature review which identifies a fragmented approach with some treating each concept individually. The research also identifies that industry wants to integrate big data and BIM as there is a wish to integrate BMS with BIM, all of which can assist in improving sustainability.

The research aimed to satisfy six primary objectives; for ease of analysis the results have been tabulated below against each of the research methods used in the study.

Table 1: Research Objectives 1 and Results

Research Aspect	Requirement / Result
Objective 1	To establish the levels of understanding and use of big data and the IoT within the construction industry and throughout the life cycle of a project.
Literature Review Results	Indicates extensive research on these subjects and their concepts but limited within the context of the construction industry.
Qualitative Research Results: Interviews	Determines that there is not a clear understanding of the terminology or concept for either big data or the IoT.
Quantitative Research Results: Questionnaire	Determines that much confusion exists around what is big data, but those surveyed favour the description that big data is large amounts of detailed digital information, large in size, volume, velocity and variety that can be collected from any source on an AEC project. Further identifying the IoT as the 'interconnectedness of objects that use a wide variety of interconnected sources to share information' with the IoT essential for creating smart buildings, grids and smart cities

Table 2: Research Objectives 2 and Results

Research Aspect	Requirement / Result
Objective 2	To examine what data the industry is collecting and examining from big data and the IoT.
Literature Review Results	Extensive research on this subject shows sensors as the largest contributors to the IoT and big data, that the technology is in its infancy with some application within the industry though embedded sensors. Predominantly applications are limited to energy efficiency, structural health monitoring or wearable technologies.
Qualitative Research	Determines that there is limited collection of data within the in-

Results: Interviews	dustry and that much of the data collected is done with the focus on efficiency, temperature, environmental control, customer satisfaction or for legislative requirement.
Quantitative Research Results: Questionnaire	Determines BIM creates big data, that big data can be collected from sources on any type of AEC project and that AEC companies are using information from big data and big data analytics daily, with BIM creating a lot of the big data that AEC companies are using and analysing daily.

Table 3: Research Objectives 3 and Results

Research Aspect	**Requirement / Result**
Objective 3	To investigate how big data and new associated technologies are influencing decision making.
Literature Review Results	Identifies limited research into how big data is assisting or influencing decision-making, business performance and competitive advantage in business. Limited research on how big data can influence decisions within the construction industry.
Qualitative Research Results: Interviews	Determines that participants interviewed use data to assist with decision-making.
Quantitative Research Results: Questionnaire	Determines that big data, big data analytics and new technologies are improving decision-making for AEC companies.

Table 4: Research Objectives 4 and Results

Research Aspect	**Requirement / Result**
Objective 4	To investigate which phase of the project lifecycle is best assisted by big data, the IoT and new technologies.
Literature Review Results	Identifies limited research on this subject, identifying the existence of new technology, big data and the IoT, but not making any connection to project phases.
Qualitative Research Results: Interviews	Determines all project phases are assisted, with the majority identifying feasibility and design phases while others identify post-construction as most assisted by big data, IoT and new technology.
Quantitative Research Results: Questionnaire	Returns similar results as qualitative research identifying the early phases of the project at inception and design as most assisted by big data, IoT and new technology.

Table 5: Research Objectives 5 and Results

Research Aspect	**Requirement / Result**
Objective 5	To determine if sustainability can be improved through employing big data analysis technology in creating smarter, greener and efficient buildings from inception.
Literature Review Results	Identifies limited research on this subject, discussing sustainability, smart buildings and identifying links between efficiency and sustainability but no research identifies how big data analysis could be used to predict best design for future projects putting sustainability at the forefront.
Qualitative Research Results: Interviews	Determines participants are of mixed opinions on this but majority is adamant that technology and big data can assist in improving sustainability.
Quantitative Research Results: Questionnaire	Identifies big data, big data analysis and technology can come together and through design to improve sustainability.

Table 6: Research Objectives 6 and Results

Research Aspect	**Requirement / Result**
Objective 6	To investigate if the implementation of big data, IoT

	and new technologies creates more efficient FM and sustainable smart buildings.
Literature Review Results	Identifies limited research on this subject, with existing research discussing facilities management, sustainability and smart buildings in segregation.
Qualitative Research Results: Interviews	Determines that improvement through use of big data and technology can be achieved, especially if implemented at the early stages of the project.
Quantitative Research Results: Questionnaire	Determines that facilities management can be improved by using big data analytics and that BIM is essential for facilities management. Further identifies an opinion that BIM and BMS should be integrated leading to improved facilities management. Also identifies that those surveyed are of the opinion that big data, the IoT, BIM and new technologies will improve the efficiency of facilities management.

V Conclusion, Recommendations and Implications for Industry

New technologies and advances in technology are leading the world, in general, into a reliance on artificial intelligence and although traditionally slower to adapt new technologies, the construction industry is now embracing new and developing technologies, especially in order to keep up with the requirements of clients and end users.

As emerging industry tools, big data, big data analytics, the IoT and cloud technologies offer industry the opportunity to improve, grow, and become more sustainable and efficient in all it does.

Looking for a definitive definition on big data and IoT in the context of the construction industry is not an easy search, but the primary research from this study determined that while there is still much confusion on this, the favoured description is: big data is large amounts of detailed digital information, large in size, volume, velocity and variety that can be collected from any source on an AEC project. Further the favoured explanation of the IoT as the interconnectedness of objects that use a wide variety of interconnected sources to share information, establishes the IoT as essential for creating smart buildings, smart grids and smart cities.

Within the industry big data can be collected from sources on any type of AEC project, with AEC companies using information from big data and big data analytics daily. More specifically BIM is creating a lot of the big data that AEC companies are using and analysing daily, with evidence that this analysis is improving decision making for AEC companies.

This research identifies the early project phases of inception and design as most assisted by big data, the IoT and new technology, but it also shows differing opinions relating to the ability of technology alone to improve sustainability unless big data, big data analysis and technology come together through design to improve sustainability.

Through incorporation of big data and technology in the early stages of the project, an improvement in facilities management can be achieved, especially through use of big data analytics and BIM. Expanding on this, an interesting side point identified by the research is that those surveyed are of the opinion that BIM and BMS should be integrated to further improve facilities management, bringing efficiency of facilities management and advantage to end users.

The research has proved the hypothesis and determines that improved sustainability can be achieved through the implementation of big data to achieve smarter buildings and more efficient facilities management.

Implications for Industry

The willingness of the industry to adopt new technology is positive however as the research shows having mixed, unrelated use and misunderstanding of the terminology coupled with slow adoption of these new technologies could leave it lagging other industries.

Recommendations

The subject area is continually growing within the industry bringing a necessity for further research around best approaches to technology adaptation and integration, integration between BIM and BMS, and how technology can improve collaborative working would be invaluable to the industry. The movement across all industries to bring technology to the forefront puts all technology related research for the construction industry in a prime position for providing innovation in the subject area.

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The Post-Occupancy Digital Twin: A Quantitative Report on Data Standardisation and Dynamic Building Performance Evaluation

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Abstract - Originally defined by the UK Government, Level 2 Building Information Modelling (BIM) involves the creation of digital project information, following industry standard guidelines. Through the application of Level 2 BIM, the construction industry can now develop digital representations of physical assets. By combining BIM with digital technologies such as the Internet of Things (IoT), an opportunity is created to link integrated building sensors to digital representations via advanced Computer Aided Facility Management (CAFM) systems. Successfully combining physical elements with digital elements through CAFM results in the creation of Digital Twins (DT). This provides an opportunity for dynamic data analysis throughout the capital delivery phase into the operation and maintenance (O&M) phase. A major aspect in the creation of DT involves the ongoing relationship between physical and digital versions of assets. To ensure that physical and digital elements remain aligned, bi directional updating of data is required. This is achieved through the collection of real-time data via interlinked sensors, generating an opportunity to analyse the performance of the asset and it's occupants. Level 2 BIM enables delivery of clearly defined project data at various intervals of maturity which are termed "data drops". Where project outcomes are poorly defined, the process of digital information delivery often results in a return to traditional methods of data exchange, resulting in static data analysis. Traditional methods of information exchange include graphical and non-graphical data in the form of PDF and Construction Operations Building Information Exchange (COBie) data in Excel format. Static methods of delivering data do not present the DT with the dynamic data required to constantly adapt and reflect the physical version. In order to benefit from these technologies however, dynamic information deliverables should be considered at project commencement, reinforcing the BIM vision of "beginning with the end in mind".

Keywords – BIM, Product Data Templates, Digital Twin, Internet of Things, Cognitive Environment

I Introduction

The McKinsey Report [1] proposed the global construction industry as the second least digitalised and technologically innovated of all industries. The report also discussed that research and development (R&D) investment in construction was less than 1% of revenue, when compared to other sectors, including the automotive and aerospace sectors, with a 3.5–4.5% investment [1]. This suggests that the construction and building sector has not adopted digital technologies in line with other sectors and is still heavily reliant on traditional processes and deliverables [2].

To implement and improve digitalisation of the construction industry, efficient management of data generated from Building Information Modelling (BIM) is critical. Implementation of digital technologies such as Digital Twin (DT) and Internet of Things (IoT) throughout all phases of a building's lifecycle can ensure that buildings are performing as intended, with early identification of any anomalies.

a) Digital Twin Technology

The Digital Framework Task Group (DFTG) refers to Digital Twin (DT) as *"a realistic digital representation of assets, processes or systems in the built or natural environment"*. This may refer to a real-time updated collection of data, models, algorithms or analysis [3]. A DT is a digital representation of a physical element or product which mimics its real-world behaviour. To create a DT, three main criteria are required: (1) Physical element, (2) Virtual representation and (3) Interconnecting graphical and non-graphical data and documentation to link the physical and virtual [4].

A further nine aspects of DT-enabled service innovation in the manufacturing field were identified by Pourzolfaghar, et al. [5]. They include: (1) Real-time monitoring, (2) Energy consumption analysis, (3) User management and behaviour analysis, (4) User operation guide, (5) Intelligent optimisation and update, (6) Element failure analysis and prediction, (7) Maintenance strategy, (8) Virtual maintenance and (9) Virtual operation [5].

DT differ from other digital models by the connection to a physical element (Fig. 1). As data is uploaded to the DT from the physical asset or system, values are unlocked, which improve decision making and integrate positive feedback with current performance data, into the physical twin via live data flows from sensors [6].

Within BIM projects all information is moved through a central repository called a Common data Environment (CDE) [8]. Owing to the largely fragmented nature of the industry and multiples variations of preferred software applications in use this represents a significant challenge [7].

Within a DT framework all information relating to the creation and management of DT should be stored in cloud-based data management platforms native to the DT application such as Invicara [9] or Willow [10]. Both platforms are examples of system providers for DT and provide an online platform with a database for non-graphical data and a model viewer for graphical information.

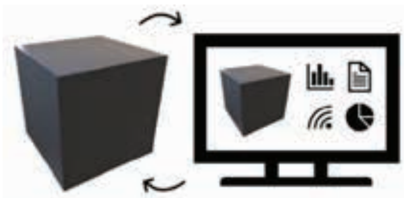

Fig. 1: Overview of a Digital Twin

Fig. 1 displays an example of a DT by illustrating the connection between the physical element and virtual element through integrated sensor technology.

b) Industry 4.0

Technology can enhance the quality of our lives. This was defined in 2016 by Klaus Schwab, founder of the World Economic Forum, as "*the fourth industrial revolution*" or Industry 4.0 [11]. Further development of the internet has led to the creation of an interconnected network of devices commonly referred to as the Internet of Things (IoT). Examples of connected devices range from portable devices such as mobile phones and tablets to Radio Frequency Identification Device (RFID) building sensors and Global Positioning System (GPS) devices [12].

One of the many benefits of DT is the ability to update data in real-time with any changes in the physical object. This is achieved by connecting the DT to physical elements via sensor technology and IoT [13]. Sensors in a building can collect data relating to the internal environment, such as temperature and carbon monoxide levels. This information is referred to as "big data". Big data requires the implementation of data management strategies, leading to increased efficiency in data retrieval by focusing data analyses locally and reducing large volumes of data relating to the DT [14]. The evolution of IoT has led to an increase in sensorisation of physical spaces, resulting in growing functionality of applications such as Building Management Systems (BMS) that acquire data relating to the surrounding environment in real-time [15]. BMS can be improved further by integration with BIM to digitally represent physical and functional characteristics of physical spaces providing current information about the building and environment [16]. A study by Dave, et al. [17] described the development of a platform to integrate built environment data with IoT sensors. Information relating to occupancy, user comfort and energy usage was integrated with BIM and IoT devices through Industry Foundation Classes (IFC) models and open messaging standards. This research collected data relating to occupied building spaces and provided data to the occupants on a mobile application ensuring they had instant access to real-time building usage data [17].

c) Dynamic Building Performance Evaluation

By implementing digital technologies such as DT and IoT into current or existing projects, an opportunity is created to monitor and improve the performance of a building, and in time, the built environment (Fig. 2). Research by Royapoor et al. [18] has shown that vast savings can be made by implementing these technologies, and as pricing relating to sensors and technology reduces, the construction industry can expect greater savings on a variety of projects in the future [18].

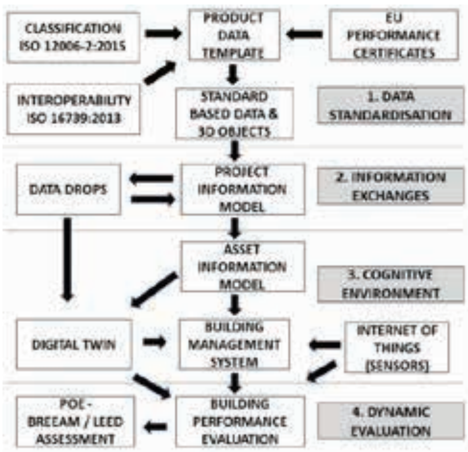

Fig. 2: Dynamic building performance evaluation

Fig. 2 displays an overview of the creation of a cognitive environment through the standardisation of data throughout the design process.

II Literature Review

Digital technologies can enhance the delivery and maintenance of assets by creating and managing data generated through digital construction. The role of DT in the creation of smart cities and high performing assets, using connected data, was recognised by the Centre for Digital Built Britain (CDBB), leading to the creation of a framework for a "Digital Built Britain". This framework included the publication of The Gemini Principles [3] along with the publication of a roadmap for delivering the information management framework for the built environment [19].

a) The Gemini Principles

The Gemini Principles were published in December 2018 by the Digital Framework Task Group (DFTG) on behalf of the CDBB. The Gemini Principles address key recommendations in the National Infrastructure Commission's report "Data for the public good" [20].

By identifying DT as a means to enable better use, operation, maintenance, planning and delivery of assets, systems and services, the CDBB proposed the creation of a National Digital Twin (NDT) [3]. The core focus of this research paper is the standardisation of data with a focus on Gemini Principle number 5 (openness) which relates to the creation of open data, an essential aspect for DT. Openness encourages sharing of data amongst project collaborators and the creation of trust through collaborative modelling. Open standards ensure that data extracted from digital models is readable by software applications supporting an open standard such as IFC. Open standards facilitate collaboration between disciplines, allowing for exchange of data regardless of what application the data was created in [21].

Data generates value when it is contributed to and maintained. In order to generate the most value from the NDT, it must be as open as possible, whilst retaining security principles identified in Publicly Available Specification (PAS) 1192-5 [22]. This can be achieved by developing an open culture within industry through the implementation of international standards and the development of interoperable Application Programming Interfaces (API), allowing a vendor-neutral approach [23].

To create openness, and fully benefit from the creation of a DT, data must be consistent and structured. Baron [24] reported that structured data ensures Building Management Systems (BMS), such as Maximo by International Business Machines (IBM), can interpret data and associate said data with corresponding elements within the model during the operational phase [24]. According to Kaseem et al. [25], the operational phase is the main contributor to the lifecycle cost of a building. It has been found that the life cycle cost can vary between five to seven times of the initial cost of the building [25]. These figures show that operation and maintenance of a building must be prioritised within the design process, as it is then that challenges are identified relating to data management. The availability of different BIM authoring tools (Revit, ArchiCAD and Tekla) has led to inconsistent data flow between disciplines. Examples identified by Mecheri and West [26] include inconsistent modelling practices and construction data and a lack of adherence to standardised classification systems. To ensure accurate data transfer between future software systems, all data should be consistently structured ensuring a seamless flow between all disciplines involved in a project [26].

Management and digitisation of data is essential for successful implementation of DT. To achieve this, data needs to be traceable and consistent, follow international standards, pre-defined data structures and definitions. Andriamamonjy et al. [27] reported that open BIM is currently being standardised by two technical European committees CEN/TC 442 (European Committee for Standardization) and ISO/TC 59/SC 13 (Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)) [27]. International standards involved in the creation of open BIM and Product Data Templates (PDT, Fig. 3) include classification (ISO 12006-2:2015) and interoperability (ISO 16739:2013). Classification of objects in the model ensures information is easily accessible and managed throughout the project [28], while interoperability ensures that data is available in multiple formats, languages and software tools [29].

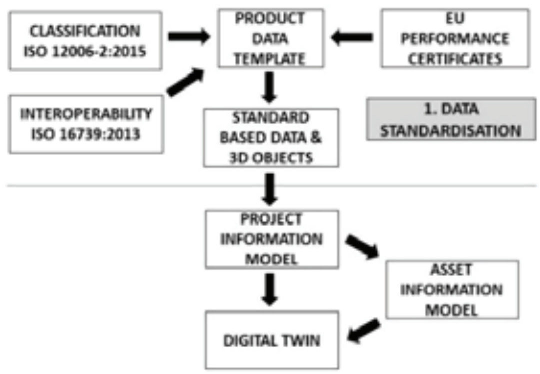

Fig. 3: Standardisation of data

Fig. 3 demonstrates how structured data created through PDT is developed during the design stages.

b) Standardisation of Data

Data standardisation can be achieved through the creation of PDT (Fig. 3). PDT adhere to European Harmonised Standards, resulting in a Declaration of Performance (DoP) certificate for construction products in compliance with the Construction Products Regulation (CPR) [30]. Product performance data is combined in a common technical language known as Digital Data Dictionaries (DDD). With DDD, information relating to product performance from different countries can be amalgamated to create a database of current material properties including: structural stability, fire resistance, acoustic properties and energy efficiency [31]. An example of such a definition was described by Farghaly et al. [32] in relation to a u-value (Fig. 4). A u-value is a measurement relating to thermal performance, or heat loss through a material or building element. Different countries have different definitions relating to the transfer of heat, as a u-value is sometimes referred to as thermal transmittance. The DDD framework enables BMS to read the data irrespective of geographical location, by mapping similar definitions in the DDD to unique codes in the BMS, ensuring the values are correct [32].

Sharing of structured data is crucial for the creation of DT. Implementation of international standards can lead to the creation of interoperable data, which can be distributed between multiple operating systems, eliminating design data silos. The creation of PDT ensures a common data structure which manufacturers can populate with up-to-date product information. Examples of PDT include the BIM Databook by the Building Research Establishment (BRE) [33] and GoBIM, which is provided by Cobuilder [34].

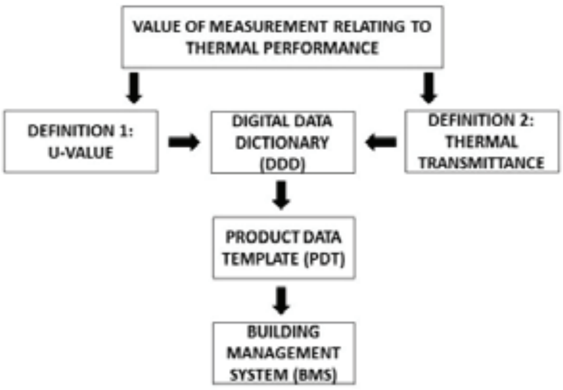

Fig. 4: Digital data dictionaries

Fig. 4 displays an example of how alternative definitions combined into a universal definition through DDD

c) Asset and Information Management

Asset management generates value from assets by converting business objectives into asset-related decisions throughout the asset's lifecycle [35]. An information management process (IMP) is created in accordance with standard processes and procedures identified in BS ISO 55000, which was used to develop United Kingdom (UK) BIM standards including PAS 1192-2:2013 and PAS 1192-3:2014. These standards relate to the creation and management of building information. PAS 1192-3:2014 provides guidance on managing the Asset Information Model (AIM) post-handover by linking to enterprise systems (BMS) such as Maximo [36].

d) Information Exchange Requirements

Since 2016, Level 2 BIM is a requirement for all Government buildings in the UK. Level 2 BIM involves the creation and management of digital assets in compliance with the PAS 1192-2 suite of documents [37]. Level 2 BIM generates vast volumes of data generated and developed across the full lifecycle of the asset from design through construction into operations and handover. This information is often un-coordinated and not fit for immediate translation to the Operations and Maintenance (O&M) phase at project handover due to interoperability issues relating to BIM technologies and Facility Management (FM) systems [25].

The information delivery cycle is introduced in PAS 1192-2:2013 and represents all stages of a BIM project in alignment with the Royal Institute of British Architects (RIBA) Plan of Work 2013. PAS 1192-2:2013 requires information exchanges, also referred to as "data drops", at designated intervals during the design phase [36]. Data drops, as outlined in PAS 1192:2 are a staged mechanism for approval of project information against Employer's Information Requirements (EIR) which are aligned to contractual levels of project maturity. As the project progresses, the information contained as attributes within the model increases.

e) Information Exchange Deliverables

Documentation is defined by the British Standards Institute (BSI) [36] as "*information for use in the briefing, design, construction, operation, maintenance or decommissioning of a construction project*". Data drops contain documentation (drawings, schedules, specifications and spreadsheets), along with graphical and non-graphical data for each stage of the project.

In 2019, ISO19650-1 and ISO19650-2 were published. These standards were founded on UK BIM standards BS 1192:2007 + A2:2016 and PAS 1192-2:2013 and relate to information management using BIM. This represented a major step for BIM as it advanced from a PAS document to an internationally recognised standard. One of the changes contained in ISO19650-1 is the renaming of graphical and non-graphical data to alphanumerical information and geometrical information [38].

Graphical data is defined by BSI [36] as *"data conveyed using shape and arrangement in space"*. Examples of graphical data include native three-dimensional (3D) models and interoperable IFC files. Non-graphical data is defined by BSI [36] as "data conveyed using alphanumeric characters". Examples include: Construction Operations Building Information Exchange (COBie) data in Excel in accordance with BS1192-4:2014 [39].

COBie is an open database containing information for the operation, maintenance and management of the asset by the FM [40]. When COBie is required for information exchange, COBie data should be extracted from the BIM model using an Autodesk BIM interoperability COBie extension tool in Excel format for linking into a Computer Aided Facility Management (CAFM) system [41].

Although COBie is identified as a BIM Level 2 deliverable, O'Sullivan and Behan [42] showed that COBie data was not included in over 70% of cases surveyed and indeed highlighted that the safety file for the Grangegorman Greenway Hub was handed over via compact disc [42].

f) *RIBA Plan of Work 2013*

RIBA Plan of Work 2013 Stages 7, 0 and 1 relate to briefing and initial design stages. By starting with Stage 7, emphasis is placed on incorporating lessons learned from previous projects into current and future projects through feedback and data analyses [43]. Harnessing the results from Post-occupancy Evaluation (POE) and Building Performance Evaluation (BPE) can lead to improved efficiency in the early project stages through better decision making and planning, ensuring the best possible platform for design stages. Stage 0 involves the creation of project documentation including the BIM execution plan (BEP), while the creation of a CDE in Stage 1 enables multi-discipline collaboration [44].

RIBA Plan of Work 2013 stages 2 and 3 emphasise the needs of the client and ensure that project outcomes are identified and achievable through the creation of concept models. Project programme, budget and procurement strategies are put in place, along with concept models to create a co-ordinated design between disciplines, suitable for planning submittal [45].

RIBA Plan of Work 2013 stages 4, 5 and 6 encompass the final stages of the project. Stage 4 involves finalising documentation for commencement of construction in Stage 5. Following construction, the asset is handed over to the client in Stage 6 with the Project Information Model (PIM). The PIM developed during the project is now referred to as the AIM. The AIM contains digital data relating to the maintenance of systems in the building, Health and Safety (H&S) information, as-constructed information and live links to data within the model [46]. Following the creation of standardised data from PDT's during the design stages, the AIM can now be linked to the BMS, leading to the development of a Digital Twin (DT, Fig. 3). It was proposed by Jarvinen [47] that DT are not only representations of a real building, but of a building's components, systems and functionalities. DT can act as a user interface for AIM (Fig. 5), ensuring that information from multiple disciplines can be viewed and operated through a single interface [47].

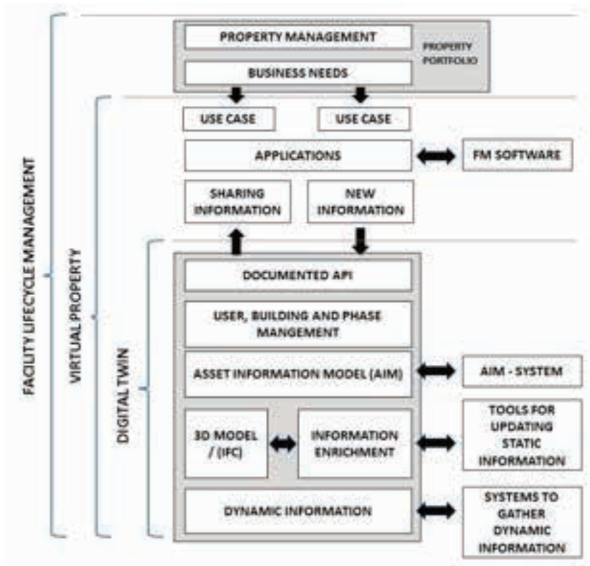

Fig. 5: Facility lifecycle management [47]

Fig. 5 illustrates how Digital Twin can act as a user interface for the Asset Information Model (AIM).

g) *Soft Landings*

When Level 2 BIM was mandated in the UK (2016), one of the supporting frameworks was Government Soft Landings (GSL), also referred to as Soft Landings (SL). SL ensure that BIM is implemented in current and future developments to support Facility Management (FM) throughout the Operations and Maintenance (O&M) phase of an asset [48].

In 2018, the SL Framework 2014 [49] was updated [50]. One of the main changes was the replacement of the term "Stage" with "Phase". This change was implemented to ensure SL are not related to any plan of work, but rather to activities occurring during certain phases of a project [50]. The other main change was the replacement of five stages (2014) with six phases (2018), with an extra phase added for RIBA Stage 5 (Construction) (Table 1).

SL help the project team focus on client requirements, throughout the project, by smoothing the transition from RIBA Stage 0 (Strategic Definition) through to RIBA Stage 7 (In Use). Key features of SL include: (1) A reduction in cost while improving performance and delivery of assets, (2) The creation of a 'golden thread' of information throughout the design and construction stages, through to building operation, (3) Early end user involvement in the project, (4) Analysis of asset performance through POE and BPE analysis, and (5) Creation of a fully populated AIM and supporting data to link into CAFM system [51].

Table 1: A comparison of SL 2014 and 2018

Soft Landings 2014 and 2018 Framework

RIBA Stage	Soft Landings 2014	Soft Landings 2018

0	Stage 1. Briefing	Phase 1. Inception and briefing
1		
2	Stage 2. Design development	Phase 2. Design
3		
4		
5		Phase 3. Construction
6	Stage 3. Pre-handover	Phase 4. Pre-handover
7	Stage 4. Initial Aftercare	Phase 5. Initial Aftercare
	Stage5. Years 1 to 3 Aftercare:	Phase 6. Extended Aftercare and POE

Table 1 compares stages and phases between the 2014 and 2018 SL Framework's with the additional phase (Phase 3) highlighted.

h) Post-Occupancy Evaluation (POE)

Following building handover in Stage 6 (Handover and Close Out), a three-year POE analysis is performed (Table 2). The extended aftercare phase of SL focuses on the operation and occupancy of the building for a period of three years.

Table 2: Post-Occupancy evaluation stages

RIBA Plan of Work 2013 Stages

Stage 6	**Stage 7**		
Handover	Post-occupancy Evaluation		
	Year 1	Year 2	Year 3

Table 2 displays the three-year POE phase following project handover.

An example of where POE and BIM were utilised was the construction and delivery of a new Enterprise Centre on the University of East Anglia (UEA) campus [52]. The Building Services Research & Information Association (BSRIA) implemented SL and provided POE support including life cycle costing, airtightness testing and thermal imaging analysis. The Enterprise Centre Estates team were engaged from the design stage through to completion and worked with the design team and building occupants to ensure that the building met expectations after handover. The handover process was planned ahead of completion, which ensured all staff were pre-trained in the operation of the building and building systems. An example of one building system is ventilation. As no artificial cooling is provided on the main floor areas, windows are the only source of ventilation. Controls are located on the windows which included indicator lights to advise occupants when it is necessary to open and close windows [52].

i) Building Performance Evaluation (BPE)

A BPE provides an overview of which aspects of the design, construction and installation were, or were not, effective. BPE gives building owners and FM an opportunity to identify problems relating to the building's operational systems. BPE studies can also help in the development of a robust database for benchmarking purposes that may assist the wider built environment. Along with providing feedback for future developments, BPE can reduce running costs, optimise building performance and increase occupants' satisfaction.

The actual performance of a new or refurbished building can be very different to the design intent. Discrepancies in energy use and occupant comfort can arise from a variety of sources including construction quality and building services installation [50]. The gap between actual and expected performance of buildings continues to be an issue. A contributing factor is the non-involvement of construction teams in operation and limited feedback from the occupiers. BPE can play a vital role in facilitating this feedback and help to close this gap. The test methods and techniques employed in a BPE study should be selected appropriately. Some commonly used methods are: (1) Physical testing of building fabric, (2) Physical testing of mechanical services, (3) Energy assessment, (4) Understanding user perception and (5) Indoor Environmental Quality (IEQ) evaluation [53].

Using Digital Twin (DT) and Internet of Things (IoT) to measure real time environmental conditions can lead to increased building performance and energy. Lee et al. [54] utilised BIM as an energy monitoring system through the implementation of Autodesk Revit. Revit allows end-users to acquire and monitor building energy data. Data was obtained from sensors monitoring geothermal energy and lighting and an energy baseline was established. Energy-saving procedures were implemented to improve the existing heating system, control HVAC and lighting, resulting in an overall reduction in energy consumption of 12% [54]. Presidion [55] reported a feasibility study conducted by Tesco Ireland along with International Business Machines (IBM). Collected data reflected variations in refrigerator temperatures in their stores. To rectify this, an improved process was required to ensure refrigerators continuously operated within optimal temperature ranges. Data was acquired and predictive analytics was used to validate refrigeration performance. By applying the results from one store, refrigeration performance was validated, and any anomalies were identified, leading to a reduction in total energy costs. Operation of freezers at the optimal temperature generated a net saving of 20% in overall energy cost, namely 25 million pounds a year throughout the UK and Ireland [55].

j) Building Research Establishment Environmental Assessment Method (BREEAM)

BREEAM offers a verifiable and independent assessment of the performance of building design and construction over three stages: Pre-assessment, Design stage assessment and Post-construction stage assessment [56]. BREEAM certification levels are divided into six categories: (1) Unclassified, (2) Pass, (3) Good, (4) Very Good, (5) Excellent and (6) Outstanding.

The focus of a BREEAM examination include: (1) Visual comfort, (2) Acoustic performance, (3) Indoor air quality, (4) Water consumption, (5) Thermal comfort, (6) Reduction of CO_2 and N_2O levels, (7) Energy monitoring, (8) Low and zero carbon technologies, (9) Reduction of night time light pollution, (10) External lighting, (11) Energy efficient equipment, (12) Water monitoring, (13) Insulation, (14) Emissions and (15) Sourcing of materials [56].

Buildings that achieve a BREEAM rating of Excellent or Outstanding are required to undergo a BREEAM In-Use Assessment within three years of completion in order to maintain their rating and certify ongoing performance. This encourages the continued high performance of the building, even after occupation. An example of a BREEAM "Outstanding" building is the Central Irish Bank in Co. Dublin, Ireland, which was awarded the BREEAM Outstanding rating for sustainability in 2017. Achievement of this standard was centred on an intelligent HVAC system linked to a BMS. The ventilation strategy involved linking louvers in the facade and internal $C0_2$ sensors to the BMS. When CO_2 levels reach 900 parts per million, the sensors inform the BMS to activate the louvers, allowing fresh air into the building. Meeting rooms are controlled by ventilator sensors to monitor the supply of incoming air. Ventilators have passive infrared sensors (PIR) that detect motion and shut the ventilator down if the room is left unoccupied. In addition, the lighting system contains photocells on each light-emitting diode (LED) which turn the light on when natural light levels fall below a programmed lux level. Each LED light is fitted with a PIR sensor to detect motion [57].

k) Leadership in Energy and Environmental Design (LEED)

LEED is a sustainable rating system for buildings. LEED certification levels are divided into four categories: (1) Certified; (2) Silver; (3) Gold and (4) Platinum. Certification is achieved following assessment of the following areas: (1) Sustainable sites; (2) Water efficiency; (3) Energy and atmosphere; (4) Material selection; (5) Indoor environmental quality and (6) Innovation and design process [58].

Research by Jalaei and Jrade [59] identified problems relating to delivery of sustainable designs through LEED by conducting full building energy simulation, acoustical analysis, and day lighting analysis. To resolve these issues, it was proposed to integrate BIM with LEED at the conceptual design stage by automating LEED certification categories and allocating points for individual categories [59].

l) Actual Operational Building Data vs Proposed

BIM enables the development of a semantic association between object geometry and information [60]. By combining static information (BIM) with dynamic information (IoT), a cognitive environment is developed, which encompasses physical buildings with technology. This provides the asset with cognitive capabilities, allowing it to learn from previous tasks and to re-apply that same learning to the subsequent task.

Teizer et al. [61] focused on providing real-time energy performance data to workers in an indoor work environment. This was achieved by integrating BIM technologies with IoT information sources and radio frequency identification device (RFID) sensors. The BIM was synchronised with lighting and proximity IoT sensors, providing workers with real-time environmental conditions. Results demonstrated successful integration of connected digital technologies, highlighting the potential that connected technologies can provide to post-occupancy O&M processes [61].

Ciribini et al. [62] devised a cognitive environment linking BMS to a BIM environment by collecting real time data from sensors measuring building heating, lighting and energy usage [62]. Another example of this association is Project Dasher 360 by Autodesk (Fig. 6) which combines physical building components with real-time project data. Sensors are inserted into rooms to capture data relating to energy consumption, CO_2 levels, humidity, temperature and occupancy. These sensors are represented in an online browser and display an overview of sensor information ranging from minutes to months [63].

Fig. 6: Autodesk Dasher 360 [63]

Fig. 6 displays Autodesk Dasher 360. Dynamic data is generated through building sensors and displayed in an online 3D model with real-time data feed and analysis.

III Discussion

a) Visualisation of Post-occupancy Evaluation (POE) Data

Although SL is a requirement of Level 2 BIM projects, results show that despite all participants being familiar with SL, the number of projects providing SL information was between 0 to 20%. One interview participant proposed limitations of technology for processing and visualisation of SL data as a reason for non-implementation of SL.

POE and BIM were similarly criticised in a study undertaken by Goçer et al. [67]. The study proposed combining both types of data sets and presenting data through Geographic Information System (GIS) technology as a viable solution. Data was collected via onsite surveys, questionnaires and in situ-measurements relating to occupant's comfort levels, satisfaction levels, indoor environmental quality and level of perceived performance. Visualisation of building performance data was achieved by the creation of floor plans containing different layers and colour codes to represent performance conditions. Results proved that it was possible to link performance data with spatial BIM geometry and improve POE data management [67].

b) Integrated BIM

The creation of common data through PDT, and the use of a common environment to store, check and validate data is essential for successful BIM projects, and is referred to as "Integrated BIM" [26]. The creation of a Common Data Environment (CDE) is a requirement of BIM Level 2 projects and is often referred to as the "single source of truth", a database of current documentation and data. The technology now exists to create an online database where data relating to multi-discipline model elements is instantly accessible to project members. Introduction of digital technology at the concept design stage will ensure that all data and metadata is fed directly into the AIM prior to project handover, resulting in an improvement in co-ordinated documentation, and reducing the level of fragmentation between disciplines and software applications.

Automation of data acquisition is possible through the digitisation of production systems. However, fully automated systems are still not in use by small and medium sized enterprises (SME) leading to traditional methods dominating data collection, which may be inaccurate and error-prone [68].

c) Bi-Directional Updating of Data

To create DT, the digital version must represent the physical version in all aspects. To ensure that the two elements remain in sync, bi-directional updating of data is required in the digital version to reflect changes made to the physical version. A current Level 2 BIM requirement is the delivery of COBie data at specified stages throughout the project. COBie is delivered via an Excel spreadsheet containing data relating to elements contained in the model at the time of extraction. Once the data contained in the Excel file is extracted from the model, it is out of-date, as it is a snapshot of the model at that point in time, and therefore it does not reflect current conditions.

It was reported by O'Sullivan and Behan [42] that COBie data was not included in over 70% of cases surveyed, while interview results show that although all participants are familiar with COBie, the number of projects delivering COBie was between 20% and 40% . With such a high level of awareness of COBie, but a low percentage of projects delivering COBie, future research is required to determine if COBie should remain a requirement for future Level 2 or 3 BIM projects, as it cannot feed DT with the bi-directional data updating required to remain a digital twin of a physical element.

IV Conclusion

BIM is often termed a "disruptive technology". This is not a negative accusation however, as the disruption merely relates to the replacement of traditional methods with cutting edge digital technologies such as BIM, DT and IoT. Digital technologies have the potential to enhance all aspects of everyday life by assisting in everyday tasks and adapting and responding to the surrounding environment. The ever-increasing need and reliance on digital technologies has led to an immense improvement in the quality of wireless components such as radio frequency identification device (RFID) sensors and antennae. This in turn has led to an increase in the production of wireless components, resulting in greater variety and a reduction in cost for the consumer. This is welcoming news for the construction industry, as the creation of Smart Buildings through an interconnected network of sensors is now a more viable option than ever before. The creation of a cognitive environment within a network of inter-connected buildings can lead to the digitisation of the construction industry and improve the findings of the McKinsey Report [1]. Findings have shown that integrated building sensors can warn against issues such as health concerns, increased levels of carbon monoxide, while reducing operational costs. Real-time data feed ensures that unused areas of buildings can be scheduled to shut down through recording occupational data from motion sensors, leading to an increase in the performance of new and existing buildings.

Smart technologies and smart buildings have the potential to improve the health and performance of buildings, but in order to create smart buildings, building operational data needs to be compiled that is consistent and compliant with recognised industry standards such as the BS1192 suite of documents and ISO 19650. Following the mandate of Level 2 BIM in the UK in 2016, the focus is now on Level 3 BIM and how this will affect the industry, and how best to proceed in the future. Ensuring that data generated through BIM is correctly structured and compliant with internationally recognised PDT is vital for the creation of building information data, and the subsequent creation of DT. While PAS 1192 and ISO 19650 offer guidance on best practices for the creation and sharing of digital data, users need to be rigid and ensure compliance to these standards in order to successfully transit to the next level and phase of BIM.

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Innovative Technologies

The Quality Dimension (qD)

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Abstract - The construction sector in the UK has been closely scrutinised in relation to workmanship standards and general build quality in the aftermath of the incidents at Grenfell and Oxgangs Primary School. Construction quality concern comes at a time when the sector has been reinvigorated thanks to digital transformation in relation to the design, management and delivery of projects, mainly driven by the introduction of BIM working processes. This has seen organisations transform their workflows, deriving benefits in terms of greater efficiencies, clarity and certainty on projects. The wider benefits, aligned to the dimensions of BIM (3D, 4D, 5D, 6D and 7D), are also well recognised at this stage. With the industry beginning to accept and embrace technology, there is the potential to further innovate and investigate technological solutions which have the potential to align with the BIM process for the purpose of inspection and ultimately improving construction quality. Hence, the need for a focus on an additional dimension, the Quality dimension (qD), is proposed. However, before this stage is reached, a full understanding of the challenges faced is required. This paper presents the findings of an online survey which was undertaken to provide a deeper understanding of quality concerns within the industry from the perspective of professionals specialising in technical design. This was followed by a series of focus group sessions aimed at creating a benchmark for common construction defects against which technological solutions could be evaluated. The findings would suggest that inadequate construction quality is a concern both within the UK and internationally, with common defects identified posing a risk in relation to life safety. The paper discusses the potential for digital technologies to assist with ensuring a robust approach to inspection of quality in relation to material usage and workmanship detailing on-site, before concluding by calling for greater research into the area of technology assisted inspection.

Keywords - Quality, Digital Technology, Verification, Inspection

I Introduction & Background

The construction sector within the United Kingdom (UK) has come in for close scrutiny in relation to workmanship standards and general build quality. This has arisen, in the main, due to the content of three independent inquiries and reviews resulting from the incidents at Grenfell Tower in London [1] [2], Oxgangs Primary School in Edinburgh [3] and the construction of a Leisure Complex in Dumfries [4]. The content of these reports raised major quality concerns, primarily in the areas of structural and fire safety, although other defects were reported. Research undertaken by the Chartered Institute of Building (CIOB) provides additional evidence of sector inadequacies relating to quality management [5]. The concerns are exacerbated by there being no single building type to which these failings can solely be attributed, with quality failings identified in a range of building types from the Schools, Leisure Complex and High Rise Residential schemes documented, to Hospitals [6] and Domestic Properties [7].

The issue is not confined to the UK and Ireland, with international cases also well publicised [8]. The reasons for such failings are not clear, but are most likely the result of a combination of factors including; a focus on cost reduction over prioritising quality, inadequate workmanship and flawed inspection processes. In aiming to address the issue there is a possibility that technology, whilst not being a panacea, can play a part. The embracement of technological change within the sector is gaining momentum [9], motivated by near universal Building Information Modelling (BIM) usage and awareness [10] as a result of the 2011 UK BIM mandate [11]. Changing mindsets coupled with rapid technological developments means that there is the potential to explore the use of technology as a vehicle for developing new and innovative inspection processes to assist with delivering more robust quality management on projects.

II Architectural Technology Insight

To gain a better understanding of the inadequacies relating to construction and build quality, and to determine the potential for digital technologies to assist in identifying quality issues during on-site construction operations, an online survey was prepared and sent to a select group of industry professionals. Comiskey *et al.* [12] call for greater insight from professionals involved in the technical design and on-site inspection processes. This study aimed to achieve that objective by working with the Chartered Institute of Architectural Technologists (CIAT). Chartered Members of CIAT were purposively selected to participate in the online survey due to their expertise in technical design, detailing and understanding of on-site practice. In defining the Architectural Technology (AT) discipline CIAT [13] state;

> *"At its core, is the anatomy and physiology of a building or structure, its relation to context, how it is assembled and how it performs through form, function and fabric."*

Additionally, with the AT discipline generally regarded as being a leader in terms of BIM adoption, members were identified as being ideally placed to comment on quality and technological related aspects. Whilst other studies have investigated related areas [5], it was felt necessary to capture the views of those involved from a technical design perspective. Thus, the aim of the study is to examine the experiences of, and gain feedback from, industry professionals involved in technical design and inspection, highlighting the challenges that currently exist in relation to construction deficiencies and identify the potential for technology to assist in this regard.

III Methodology

To realise the identified aim a scoping study methodology was employed. Arksey & O'Malley [14] identify reasons for selecting scoping studies which include their use as an evaluation metric in relation to undertaking a more comprehensive review and for the purpose of gap analysis. As the reasoning aligned with the ambition for the work, it was felt a suitable methodology for adoption. A multi-method approach to data collection was utilised. It should be noted that an evaluation of technologies which could potentially assist with on-site verification was also part of this scoping study but is not reported in detail in this paper.

a) Online Survey

The initial data collection took place via an online survey examining experiences of Chartered Architectural Technologists in relation to general build quality issues that currently exist, both in the UK and internationally. Two separate online surveys were sent, one to Chartered Members of CIAT on the Register of Practices (circa 1405), and one to all Chartered Members in the International Regions (circa 310). CIAT defines the Register of Practices as "*all practices which have CIAT Member(s), MCIAT, as principals, partners, LLP members or directors and are on the Institute's Register of Practices.*" As the Register of Practices is primarily UK centric, inviting Chartered Members in the International Regions to complete the survey was seen as a way of obtaining an international perspective. An online survey was deemed the most appropriate method of data capture as it was to be sent to a sizeable population. Cohen *et al.* [15] outline the benefits of online surveys which include low cost, time saving, convenience and reduction in human error in addition to the ability to access to a larger population. However, this is balanced against the realisation that response rates for online surveys are generally lower than for paper based mail surveys [16] [17].

b) Focus Group

In addition to the online survey four focus group sessions were held, one in the UK and three in Canada. Their purpose was to expand on key themes and gain an in-depth understanding of specific build quality issues resulting from the survey findings. Canada was selected due to its recognition of the Architectural Technology discipline along with its high level of BIM awareness (98%) as evidenced by the NBS International BIM Report [18].

Influenced by the work of Adams [19], a hybrid of two separate approaches was utilised for the focus groups, combining nominal and interacting models with a vignette technique. The vignette used in this study consisted of eight construction defects being presented using visual representations. The participants were required to evaluate each defect based on their professional experience, and, using a scale, record a numeric value for the probability of the defect occurring and its potential severity. These values were multiplied together to establish the risk level. The purpose was to create a benchmark for common construction defects against which technological solutions could be evaluated. Data was collected in the form of a failure mode and effect analysis table [20]. The nominal approach used, a way of subjectively gaining expert evaluation [21], was based on individual analysis prior to a general discussion which resulted in a consensus decision. The interacting approach seen group discussion leading to a consensus. Whilst the nominal group approach is viewed as being superior [21], time and logistical constraints meant that the latter was the most applicable method for the Canadian focus groups. A purposive sampling approach was employed to ensure those participating had they requisite knowledge and expertise to participate in a meaningful manner and to not undermine validity. The focus group design achieved the suggested requirements of Kitzinger & Barbour [22] in relation to sample size and number of participants and was used as a means of data triangulation [23], to corroborate the findings of the initial questionnaire survey.

IV Scoping Study

The online survey was created using Survey Monkey and was live for a period of 16 days. For this study, the response rate is defined as the total number contacted, minus those for which email bounce backs and annual leave out of office notifications were received, divided by the number of respondents. The total sample size recorded for Chartered Members on the CIAT Register of Practices was 1357, with the average question response being 143 (10.54%). The average response rate for the Chartered Members of CIAT in the International Regions was 32 (10.32%).

a) Response Rate

To improve response rates a reminder email was sent out in addition to survey promotion by CIAT. The relatively low response rate could be due to a combination of factors. The timing of the survey coincided with the summer holiday period and whilst some of the population had automated responses to notify of their absence, there is a possibility that others did not and were included in the population sample. In addition, a number of automated responses indicated a date of return immediately prior to the survey closing date, with those individuals less likely to participate. The initial survey link had a technical glitch, and whilst quickly rectified, this could have impacted on response rate. Thirdly, and perhaps most importantly, anecdotal evidence would suggest that due to the survey containing references to BIM and digital technologies, many practitioners applying traditional work practices, which would be the majority of those on the Register of Practices, potentially felt unable or unwilling to complete the survey due to a lack of expert knowledge which could potentially undermine validity. With the realisation that BIM process implementation is still very much the domain of larger firms, there is the possibility that this had a significant impact on the response rate.

a) Response Rate & Study Validity

Morton *et al*. [24] surmise that response rate alone is not indicative of study quality and that there is no specific figure in terms of response rate appropriateness. The same authors [24], citing the work of others, highlight that studies with low response rates (20%) can be more accurate than those with much higher response rates (60-70%). Holbrook *et al*, cited by [24], outline that the level of accuracy for studies with low response rates, some as low as 5%, are often only slightly less accurate than those with higher response rates. In an evaluative analysis undertaken by [16], response rates which would be considered as being low, between 10% and 20%, were recorded in over one third of the studies evaluated. A conclusion can therefore be drawn that a study with a low response rate does not correlate with lower validity. Morton *et al*. [24] argue that a better gauge of validity is to follow the 3D rule of disclosure (information on participants and non-participants), denominator (used to calculate response rate) and detail (on attempts to improve participation) in tandem with the response rate. All of the measures identified have been provided for this study.

V Results & Discussion

The main findings resulting from the online survey are provided in this section, with responses shown from both the Chartered Members on the CIAT Register of Practices (ROP) and Chartered Members of CIAT in the International Regions (International).

The initial question (Table 1) aimed at gaining a better understanding of the perceived performance gap within the sector and the prevalence of on-site practice deviating from the approved technical design. The findings suggest that this is an issue, with close to 80% in both surveys recording such deviation as being either prevalent or extremely prevalent and only 1.4%, combining both survey responses, stating that this occurrence was rare.

Table 1

Emerging research would suggest that there is a performance gap in the construction sector between design building performance and actual performance of constructed buildings. A possible contributing factor is a deviation between what is designed and detailed at the technical design stage and what is actually constructed on-site. How prevalent do you think this practice is in the construction industry?

	ROP	**International**
Extremely Prevalent	17.6%	25.0%
Prevalent	62.0%	53.1%
Unsure	8.5%	15.6%
Not Very	10.6%	6.3%

Prevalent		
Rarely Occurs	1.4%	0.0%

Interestingly, the top ranked building type for which the performance gap was perceived greatest differed, with low-rise residential buildings (ROP) and high-rise multi occupational residential buildings (International) highlighted in the respective surveys.

Experiences of on-site inspection were sought (Table 2), aiming to determine the extent to which work is unable to be inspected due to being encapsulated within the building fabric and concealed from view when the inspection takes place.

Table 2

Whilst visiting a site, have you experience of work being covered up or having progressed to a stage where some details are unable to be fully viewed or inspected?

	ROP	International
Yes	87.7%	90.3%
No	12.3%	9.7%

For those answering Yes, 78.3% (ROP) and 65.5% (International) stated that they considered this as being either prevalent or extremely prevalent.

The potential benefits of a technological solution to assist with inspection and verification of in-situ constructed details was investigated (Table 3). Unsurprisingly, the responses suggest that such a solution would be beneficial. A similar question was asked in relation to hidden in-situ constructed details, with 94.3% (ROP) and 96.9% (International) outlining that a technological solution would either be beneficial, very beneficial or extremely beneficial. Whilst the majority of construction operations are executed in good faith, not deliberately aiming to hide or conceal workmanship or as-constructed elements, inspection is required to ensure the requisite workmanship standards have been achieved.

Table 3

How beneficial would a technological solution be, which could potentially assist with verification of in-situ constructed details?

	ROP	International
Extremely Beneficial	21.8%	34.4%
Very Beneficial	43.0%	40.6%
Beneficial	31.0%	21.9%
Not Very Beneficial	2.8%	0.0%
Of No Benefit	1.4%	3.1%

Poor on-site practice, especially in relation to detailing, was seen as contributing to and having a negative impact on building performance, with 76.7% (ROP) and 83.9% (International) of respondents agreeing this was the case in relation to fire safety, with these figures rising to 96.6% (ROP) and 84.4% (International) for energy efficiency. There was also a consensus that current regulatory inspection processes are inadequate for verification of constructed details (Table 4). This aligns with the assertions made in the Hackitt Report in relation to inadequacies with inspection processes [1] [2].

Table 4

In your professional opinion, do you believe that current regulatory inspection processes, in the country in which you undertake the majority of your work, are adequate for in-situ verification of what has been built, especially in relation to building details?

	ROP	International
Yes	18.6%	21.9%
No	67.6%	65.6%
Unsure	13.8%	15.6%

A series of questions which were identical to those included in a CIOB survey [5], were posed for the purpose of comparison. When asked if current management of quality on construction projects was adequate in terms of supervision, 62.2% (ROP) and 40.6% (International) answered negatively, with the figures at 58.7% and 38.7% respectively when a similar question relating to sign-off was posed. The majority of respondents felt that there were inadequacies in relation to management of quality on construction projects in terms of inspection 66.4% (ROP) and 48.4% (International), workmanship 67.1% (ROP) and 67.7% (International) and verification 63.6% (ROP) and 51.6% (International). The responses to the quality management questions make for uncomfortable reading for anyone affiliated to the construction industry, with workmanship standards identified as being a particular area of concern.

Interestingly, a question asking respondents to rank in order of importance the aspect which has the biggest impact on construction quality, drew identical responses. The biggest factor was seen as poor on-site workmanship (1), followed by deviation from approved details (2), substitution of materials from those specified (3), lack of inspection (4) and lack of third party verification (5).

For both surveys, having an accurate as-built record was viewed as being important, with materials used in the construction recorded. There was a recognition of the potential afforded by digital technologies to assist in relation to data capture and verification (Table 5 and 6). Whilst the notion of capturing and delivering an accurate as-built model is the optimum outcome, the challenge faced in achieving this is significant and not to be underestimated. It requires any and all changes undertaken when building to be recorded, with the final asset information model to be updated to reflect these.

Table 5

Do you see digital technologies assisting in producing an accurate as-built record in addition to current BIM processes?

	ROP	International
Yes	62.8%	78.1%
No	9.7%	9.4%
Unsure	27.6%	15.6%

Table 6

Do you think BIM and wider digital technologies could potentially assist in the verification of building details, easing the reliance on surveyors and certifiers?

	ROP	International
Yes	49.0%	68.8%
No	23.8%	21.9%
Unsure	28.0%	9.4%

The results obtained generally align with the assertions made in the review of literature relating to construction quality deficiencies. They also confirm that inadequacies relating to quality is not solely a UK problem. The particular areas of concern are in relation to the encapsulation of details within the building fabric before inspection can take place, the inspection process itself and the perceived workmanship standard. These findings are especially interesting in light of those responding having a detailed technical knowledge and understanding of detailing. The need for accurate as-built records was also highlighted, including detailed construction makeups, with a feeling that BIM and digital technologies could potentially play a part in improving inspection and verification.

a) Failure Mode and Effect Analysis

To supplement the survey findings, expand on the key themes and obtain a more in-depth understanding of specific build quality and workmanship issues, a series of focus groups were held. The session with UK representatives, ten in total, began with a presentation and discussion surrounding the findings of the survey, with broad agreement to the answers provided. A vignette technique was then used to visually represent eight typical construction defects, with participants individually evaluating each in turn. A group discussion was held before participants had an opportunity to amend their initial rating. The purpose being to create a benchmark for common construction defects against which technological solutions could be evaluated. The failure mode and effect analysis can be seen in Table 7, with the building detail in focus being a ventilated rainscreen wall envelope system. Table 7 states the common defects in turn, followed by the probability of occurrence, likely severity if occurrence happens and the overall risk level based on the following:
Risk Levels 0-8 Low, 9-11 Moderate, 12-14 High, 15 and Greater Unacceptable

Table 7

Material substitution in relation to fire stopping (such as different products from those originally specified being used for vertical and horizontal fire barriers during construction)

Probability (P)	Severity (S)	Risk (P x S)	Level
3.3	4.1	13.53	High

Material substitution in relation to insulation (such as different insulation products from those originally specified being used during construction)

Probability (P)	Severity (S)	Risk (P x S)	Level
3.6	3.6	12.96	High

Material substitution in relation to cladding (such as different cladding products from those originally specified being used during construction)

Probability (P)	Severity (S)	Risk Level (P x S)
2.8	3.6	10.08 Moderate

Gap between fire barriers including the junction between vertical and horizontal members

Probability (P)	Severity (S)	Risk Level (P x S)
3.8	4.7	17.86 Unacceptable

Gap between insulation materials

Probability (P)	Severity (S)	Risk Level (P x S)
3.9	3.6	14.04 High

Incorrect dimensional gap between fire barrier and rear of cladding panel, contravening technical guidance

Probability (P)	Severity (S)	Risk Level (P x S)
3.1	4.1	12.71 High

Missing components (that is any missing components in the envelope assembly ranging from insulation and fire barriers through to fixings for cladding panels)

Probability (P)	Severity (S)	Risk Level (P x S)
3.2	4.7	15.04 Unacceptable

Damaged Components (that is any damaged components, specifically relating to cladding panels, insulation and fire barriers)

Probability (P)	Severity (S)	Risk Level (P x S)
3.2	4.1	13.12 High

Due to the limitations of this paper only a summary of the main risk levels from the Canadian focus groups is presented (Table 8). The focus groups were undertaken with experienced construction professionals from three internationally recognised multidisciplinary practices, one based in Toronto and two based in Vancouver. As outlined in the methodology section, due to time and logistical constraints, an interacting approach was used for the Canadian study, with a group discussion leading to a consensus decision. As with the UK focus group, each session began with a presentation and discussion surrounding the findings of the online survey, with broad agreement to the answers provided. A vignette technique was then used to visually represent eight typical construction defects, with participants individually evaluating each in turn.

Table 8

Material substitution in relation to fire stopping (such as different products from those originally specified being used for vertical and horizontal fire barriers during construction)

Practice 1 Risk Level	Practice 2 Risk Level	Practice 3 Risk Level
Low	Low	Unacceptable

Material substitution in relation to insulation (such as different insulation products from those originally specified being used during construction)

Practice 1 Risk Level	Practice 2 Risk Level	Practice 3 Risk Level
Low	Low	Moderate

Material substitution in relation to cladding (such as different cladding products from those originally specified being used during construction)

Practice 1 Risk Level	Practice 2 Risk Level	Practice 3 Risk Level
Moderate	Low	Low

Gap between fire barriers including the junction between vertical and horizontal members

Practice 1 Risk Level	Practice 2 Risk Level	Practice 3 Risk Level
High	Unacceptable	Unacceptable

Gap between insulation materials

Practice 1 Risk Level	Practice 2 Risk Level	Practice 3 Risk Level
Moderate	Low	Unacceptable

Incorrect dimensional gap between fire barrier and rear of cladding panel, contravening technical guidance

Practice 1 Risk Level	Practice 2 Risk Level	Practice 3 Risk Level
High	Low	Low

Missing components (that is any missing components in the envelope assembly ranging from insulation and fire barriers through to fixings for cladding panels)

Practice 1 Risk Level	Practice 2 Risk Level	Practice 3 Risk Level
Moderate	Low	Unacceptable

Damaged Components (that is any damaged components, specifically relating to cladding panels, insulation and fire barriers)

Practice 1 Risk Level	Practice 2 Risk Level	Practice 3 Risk Level
Moderate	Low	Low

Risk Levels 0-8 Low, 9-11 Moderate, 12-14 High, 15 and Greater Unacceptable

The findings from the UK focus group highlighted that, with the exception of material substitution in relation to cladding materials, the risk level for the other defects presented were either high or unacceptable. The results from the Canadian focus groups differed between practices, but as the questions were subjective and based on personal experience this was not unexpected. As outlined by [24], any discussion presented should be taken in context, considering the response rate of the survey and the robustness of its design. That said, the findings from the online survey demonstrate a general issue with construction quality, with the focus group findings suggesting specific concerns in relation to aspects of passive fire protection associated with materials used and their installation. For the vast majority of the defects presented, the risk level identified by the UK focus group was either high or unacceptable which is noteworthy.

b) The Potential for a Technological Solution

With inadequacies in relation to construction quality highlighted, and common defects shown as posing a risk in relation to both energy performance and life safety, there needs to be a more robust approach to ensuring the veracity of materials and workmanship detailing on-site. Whilst the responses to the online survey suggest that technological solutions can potentially assist, it is worth highlighting that this can only be achieved by having competent professionals working together towards a common goal.

However, technology, aided by BIM processes, is already being used to assist with design in the form of information model development (3D), construction sequencing (4D), cost aspects (5D), sustainability (6D) and facilities or lifecycle management (7D). It is already being widely used on construction sites, with examples including site operatives viewing project Building Information Models on tablet devices and 'marking up' snagging requirements, sharing and assigning these to project team members via the cloud. Laser scanning and point cloud overlay with project Building Information Models for the purposes of progress checking is also now a common occurrence. Technologies such as Quick Response (QR) codes and Radio Frequency Identification (RFID) tags have also gained traction within the industry, used as a means of asset information capture for the purposes of facilities management and to track materials on construction sites. However, it could be argued that there has been a lack of focus on the use of technology for the purpose of improving quality in relation to the construction of critical details from a performance perspective. There has been a focus on construction management as opposed to quality management, with ensuring the correct construction of important building details from both an energy performance and life safety perspective being overlooked. With the industry embracing technological change, the time is right to push the boundaries and investigate technological solutions which have the potential to align with the BIM process to assist with verifying construction quality. For this to happen there needs to be a focus placed on accurate data capture during construction which in turn leads to an accurate asset information model or a digital building twin. This is a challenge, as developing an accurate digital twin requires either a constant site presence to document any and all alterations undertaken whilst building or some sort of technology which can assist, something regarded in the survey as being beneficial. In reality, an optimum solution may be a technological solution which can assist on-site inspectors such as Clerk of Works in performing this task.

A detailed study which evaluates the technologies which could be applied for this specific purpose is required, and which looks at both construction aspects both prior and subsequent to envelope closure.

VI Conclusion

This study has identified that inadequate construction quality is a concern both within the UK and internationally. The area of focus of this paper has been in relation to the implementation of technology to potentially assist with on-site inspection and verification and for the identification of substandard workmanship and defects in built details. However, this must be tackled alongside the need for greater education of those individuals who are constructing said details on-site and improved communication between main contractors and their sub-contracting teams. From professional experience, it is reasonable to suggest that a significant proportion of construction issues occur unintentionally, due to a lack of information, communication or knowledge. Whilst the inspection element is a real concern, the first stage in improving standards must be to address these issues.

Following on from this, with the common defects identified posing a risk in relation to life safety, inspection processes must change to become more robust. Even if communication and workmanship standards do improve, there is always the issue of human error to consider. Traditional manual visual inspection on projects has its limitations, and there is a need to provide assistance to those undertaking inspections on projects to ensure key deficiencies are identified. This is where technology can play a part. The findings from the study have identified the potential for BIM and wider digital technologies to assist in the areas of the creation of as-built records and verification of constructed details. Research must therefore be undertaken in relation to the most appropriate data collection technologies which can be used for this purpose and aligned with a project BIM via a cloud based pathway for the purpose of verification.

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External Memory Solution for Large-Scale Point Cloud Data Processing

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Abstract – Computing and analysing big data on a single computer is a well-known problem. The authors provide insight on a way around this problem through the use of an external memory system for optimised big data management by incorporating the STXXL C++ library into an existing software system. In this paper the authors describe the performance of two different versions of their cloud-based data processing software, one of which incorporates STXXL's intelligent caching system to automatically page data to-and-from a filesystem on-disk. The experiment compares a software architecture without STXXL, to a new one with STXXL integration, in order to establish what benefits exist for using external memory caching versus in-memory processing. The tested software versions perform computations within the authors' cloud infrastructure, utilising sample datasets in ASTM E57 Format for the point cloud(s) and IFC STEP Physical File Format (SPFF) for the building information model(s), and the behaviour of these computations are recorded and analysed. The authors' results show that a robust and performant external memory implementation can increase the affordability and scalability of cloud-based solutions, as the cost of hardware in the cloud is a major expense for maintaining systems of this kind. Results show that while the speed of each individual execution is lowered, a higher level of throughput in a given time period allowed the external memory system to exceed the original software's overall performance, and enabled greater efficiency when handling analyses.

Keywords – Point Cloud, External Memory, Data Processing, Cloud Computing, Construction Software

I. Introduction

When building or using software to analyse big data, the largest obstacle to widespread availability or adoption is the limitations of the computer system running them. This is often a matter of available data storage on a given computer, chiefly its Random Access Memory (RAM). Databases, High Performance Computing (HPC) clusters, and other systems designed for large data sets, provide a way around this problem through the use of distributed computation and "external memory". In contrast to "in-memory" computation, where the entire dataset being operated on is contained within the RAM of the computer, external memory applications use an intelligent caching system to automatically page data to-and-from a filesystem. This allows operating on much larger datasets than what naturally fits into the system.

The authors recently designed, developed, and currently now maintain, a cloud-based Scan-vs-BIM [1] software that analyses and compares Terrestrial Laser Scanning (TLS) data with a Building Information Model (BIM), to find correspondences between the real-world built environment and its digital twin counterpart [2]. The system is currently operational, but costly to run, as the necessary resources to execute analyses is significant in terms of RAM on the cloud-orchestrated virtual machines (VMs).

Taking advantage of the work already done in the field of distributed computing, the authors chose the widely-established STXXL library to modify their analytical software for better resource usage. The authors set out to trial the new software prototype with its external memory implementation against the existing version, which has an RAM-only design, and collect results to compare the two software systems based on their per-execution performance. A potential benefit of doing this is a reduction in cost as less VMs are needed to handle the same number of executions, because more can now be packed into the same amount of RAM with the excess that would normally cause issues to be placed on the hard disk in the temporary cache storage. That method then lends itself to better scalability and wider usage as more users can be supported on the cloud system.

II. Background

a) Big Data & Cloud Computing

Systems designed to process big data that does not fit entirely into a computer's memory have long been a topic of research and development. Nowadays, many technologies in the distributed and HPC domains utilise external memory systems in their operation. Apache Hadoop offers an abstraction over computation of data that may exist in many heterogeneous forms across a cluster, including subsets of the data in RAM or on-disk [3]. Hadoop is generally regarded as the go-to big data processing toolkit, whether in the cloud or on-premises. In the same area of big data, the experimental project Thrill was designed with the goal of presenting a fast low-level batch processing system in C++ that retains all the advantages of higher-level systems such as Hadoop [4]. HPX is a C++ library that is designed for parallel and distributed computing, again addressing a similar need for better memory management of large datasets [5]. As for solutions using other languages, an extension to the statistical programming language R offers external memory algorithms for analysis of large datasets, as the main barrier with big data computation in R is that it is memory-bound [6].

Each of these solutions, and many more active in the computing industry today, all deal with handling large or extremely large amounts of data, and as such have different design considerations compared to traditional in-memory approaches. The time it takes for a hard disk, or solid state drive, to load data is orders of magnitude greater than the time for data to pass from RAM to the CPU registers for processing [7]. In response to this access time concern, external memory algorithms will often utilise a streaming approach , or split the data into "blocks" or partitions [8], some of which are passed into memory for computation while others remain cached until needed. A common application of external memory algorithms that lends itself well to such behaviour is sorting [9][10].

Algorithms designed around external memory are considered an effective equivalent to their in-memory counterparts if they preserve a similar level of performance, or offer predictable run-time performance scaling as their operational dataset increases far beyond the capability of in-memory computation [11]. The Standard Template Library for Extra-Large Datasets (STXXL) is a library designed to maintain high performance with a similar interface to the built-in C++ STL [12]. STXXL handles I/O directly through the application layer, instead of the operating system's virtual memory [13]. The authors employed the STXXL library to change their existing in-memory solution into a new scalable and more cost-effective external memory-based solution. Direct access allows STXXL to handle its own intelligent caching of data between memory and disk, in a more performant manner than relying on the OS to *page* or cache chunks of memory to disk, as this approach is general-purpose and designed to keep everything running, not necessarily to preserve any level of good performance from applications still executing in a memory-exhausted system. However, STXXL uses the same concepts as the OS-level approach, with a special page/swap file controlled by the runtime used as the destination for data expunged from memory, whilst avoiding the bulk of the runtime penalties [12]. STXXL implements the Parallel Disk Model (PDM) , which supports storage using file(s) on a single disk, or multiple via disk striping to reduce efficiency loss [14][15].

b) Testbed & Experiment

The *testbed* utilised for the testing herein is the cloud-based Scan-vs-BIM software BIM & Scan® AutoCorr™. The authors simply refer to this as *the software*. The software was designed to fulfill a need for *as-built* model and Scan-to-BIM validation in the Architecture, Engineering, and Construction (AEC) industries. The acceptable inputs for the software computation are: 1. E57 formatted ordered/structured point clouds, and 2. building information models formatted according to the Industry Foundation Classes schema version 2x3 TC1 Coordination Model View Definition version 2.0 (IFC2X3 TC1 CV 2.0). The point cloud and model are uploaded to the cloud-based software and are executed within a user-specified tolerance.

The software computation yields the results of its analysis as file outputs. Several result file types are made available to the user, which show in text report and visual form, the corresponding and non-corresponding elements on the construction site and in the design coordination model. Output files comprise of a colour-coded "semantic" point cloud in E57 form, and additional reports in CSV and BIM Collaboration Format (BCF) [2]. This software solution typically aids AEC stakeholders in identifying problem areas on the construction site and within their BIMs, i.e. where the design doesn't match the constructed reality. Furthermore, it assists in correcting BIMs providing a novel automated BCF approach for locating and reporting said issues [16].

The *experiment* discussed later in Sections 4, 5, and 6, aims to measure and compare the performance of BIM & Scan® AutoCorr™ v1.2 which has an in-memory implementation, and v1.3 which comprises the new external memory implementation for the point cloud processing aspect of the main algorithm. The hypothesis is that the new implementation will have an effect on the overall cost and speed of the processing. However, it is not evident what these performance differences and possible benefits are, when and where they occur exactly, nor what the impact will be during the scaling of said implementation.

III. Motivation & Benefits

As mentioned previously, the testbed computation is conducted using point clouds that are required to be in the ASTM E57 Format [17]. E57 provides optimised bulk storage of many millions of data points segmented into separate registered scans with associated metadata. The volume of data produced by scanning equipment and therefore stored in an E57 file can be quite large, and once loaded into the software it must keep the entire dataset in-memory for it to be analysed. During said analysis, operations are performed that either alter the existing dataset, or create new dataset(s) derived from the E57 input file. Several common techniques, including sub-sampling and ray-casting, comprise part of the software algorithm. As such, the memory overhead of the testbed introduced when handling large numbers of points from the E57 input file is excessive on ordinary desktop computers, and even more impactful in cloud-based deployments.

Similarly, the same can be said for the BIMs required by the computation. Models can be very large in size as programs parse the tessellated geometry, iterating through each vertex and edge, derving the mesh topology from the IFC STEP Physical File (IFC-SPF). However, the testing herein is focused solely on the point cloud computations when using external memory. The model geometry provides the environment within which the analysis is conducted, however its data is not related to the testing process presented in this paper.

A potential benefit of implementing an external memory paging system is the reduction in cost of both hardware requirements and the cloud-based operation. The authors' software cloud infrastructure is hosted on Microsoft Azure [18], and utilises a container-based orchestration system through Kubernetes [19]. Providing cloud-based software to users globally requires defining the hardware specifications for the VMs upfront. The upfront specification is required for every software execution scheduled to take place in the system. The total cost for this infrastructure is based on the hardware itself, e.g. number of CPU cores, gigabytes of RAM, hard disk space, etc.

Cloud service providers like Microsoft Azure offer the ability to pay-per-use of resources allocated by their clients. Virtual machines, databases, file storage, and other features are requisitioned and paid for in this manner [20]. Also, other payment options such as fixed-fee are available, but it is envisaged that flexible pricing can afford better scaling options as user activity increases. There is little need to spend money maintaining resources that are not being used, and this principle extends to the software as well. If the maximum capacity provided by VMs allocated for running the analyses is not filled by the available executions, then there is a monetary cost incurred from the unused capacity. Choosing to implement an external memory system, and using STXXL's file caching, replaces the expensive RAM requirements with cost-effective hard disk space or specialised data storage, whilst further lowering overall hardware costs.

IV. Design & Implementation

During the STXXL-based implementation, the most value found in adopting an external memory architecture was in the reduction of memory overhead required for executions made by the system. The new design affords a lowering of the required hardware specs of the original software deployment, reciprocally enabling day-to-day cost savings because fewer VMs are needed and more executions can be processed on a single VM. It is for this reason a new design and implementation utilising STXXL was created. In Section 6 we evaluate the efficacy of the new system in terms of cost-effectiveness.

The new software architecture design contains two areas, sub-sampling and ray-casting, that stand to benefit from external memory implementations. The sub-sampling occurs per-scan as they are loaded from E57 and performs a uniform spatial reduction of the dataset, reducing the size of the scan while retaining the shape of surfaces captured by the scanner. As this input could potentially contain millions of points per-scan, the whole scan must be loaded into memory and processed there. The second area of interest, which is ray-casting, creates a stream of rays based on each point in a scan, emanating from the scan origin position towards the given point, and casts them into the 3D virtual environment defined by the model geometry loaded from the IFC input using the IfcOpenShell toolkit [21]. Both areas incur significant RAM penalties when executing and were modified to accommodate STXXL data structures in the new prototype. However, the ray-casting phase of the algorithm is the primary focus of this paper, as it demonstrates the feasibility of changing the system memory architecture in a more straightforward way. Due to the I/O characteristics of STXXL, sequential streaming access to a sequence of data points is faster than random access, and all methods were modified to use this paradigm. Derived geometry from the IFC-SPF remains solely in-memory because is typically smaller than the point cloud, on the order of several hundreds of kilobytes or megabytes, and modifying IfcOpenShell to incorporate STXXL is a complex endeavour beyond the scope of this research. It should also be mentioned that the user-specified tolerance input required to begin execution does not alter the performance of the software during execution, nor does it affect test results in this paper, i.e. results do not change due to different specified tolerances.

To implement the external memory system, the authors modified their existing software, changing the storage of the underlying point cloud and result dataset to use the STXXL vector class, a drop-in replacement for the C++ STL class of the same name [22]. The new algorithm design utilises a buffered ray-casting approach, i.e. a subset of the data is processed and a buffer of fixed maximum size is filled with rays defined from the data subset. The rays are then passed to an Intel Embree environment and cast into the 3D scene using its ray-streaming functionality [23]. Results are processed, and a callback for each valid "hit" in the scene is triggered, which computes additional data about the target point/hit surface relationship before inserting into a result dataset. Results are then passed on to the next phase, which handles output visualisation and reporting.

Figure 1 shows the process used in the external memory implementation. As the ray-casting is performed using the Embree library, the authors kept the same buffering approach as above while changing the input method. Originally the ray buffer was filled by selecting a subset of the in-memory points. The new design uses the STXXL library's high-performance sequential I/O to fill the buffer [24]. Potentially, this approach affords point clouds of any size to be iterated across and analysed by filling the ray buffer as it traverses the cloud sequentially, then when the maximum size of the buffer has been reached, ray-casting of that batch is performed. At the end of each ray-casting, the results are processed and inserted into a STXXL vector representing the output dataset, before allowing the iteration over the point cloud to continue. Both the input and output datasets are stored in an external memory system. This approach allows the bulk of the data to remain on-disk where storage space is less expensive as opposed to in-memory, which is much more costly. The fast sequential I/O allows, in theory, the program to retain its in-memory performance within reason. The authors expected to see execution times comparable to the pre-STXXL version of the software.

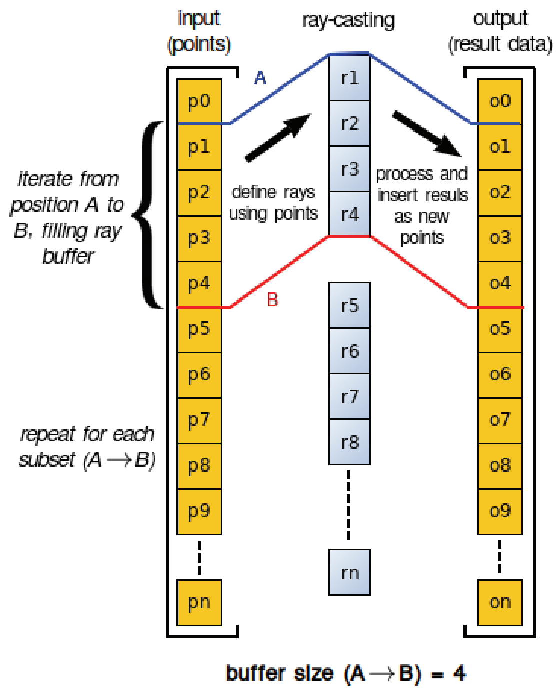

Fig. 1: Simple example of buffered ray-casting. Both versions of the software use the same approach, with the ray buffer filled from a subset of points during iteration over the entire dataset.

STXXL creates a cache file for paging data to-and-from disk. It was necessary to first establish the amount of disk space used during execution, in order to define the temporary storage space allocated to the binary *blob* created by analyses performed in the cloud. A blob in this context represents a binary file created on-disk or in attached file storage. The optimal size was found by recording the total allocation of STXXL operations on-disk, and using that to estimate the maximum possible space required. This blob optimisation enables temporary space within the cloud file storage to be created on-the-fly and disposed of once execution completed. Special consideration was made to the nature of the cloud infrastructure, and that the storage space lies closest to the physical VM hardware, reducing the impact of network file transfer operations from affecting the performance of the overall system.

V. Test Methodology

The authors established a testing methodology using Docker for evaluating the performance characteristics of the in-memory versus external memory design implementations of the software. Docker [25] allows the software to run both locally on a single PC, or in the cloud system developed by the authors. Both PC and cloud-based cases must be tested. As the software is designed for cloud deployment, it runs in a container on a VM managed by Kubernetes as an execution *pod*. A pod in this context is a single execution of the software analysis within a Docker container, with attached storage. Further details on Kubernetes and its orchestration model is available from the Kubernetes authors [19].

Firstly, local testing was performed using Docker on a single PC. Containerisation of the software allowed the authors to sample, at regular intervals, the overall system resource usage of the execution. A script was created that utilised Docker's in-built stats tool to query the executing process every 1 second and pipe the reported data into a CSV file for later use. The resultant CSV was analysed and the relevant columns were selected. These were *Time* in seconds (s) and *Memory Usage* in Gigabytes (Gb). *Memory Usage* was split further into in-memory and external memory metrics for comparing the overall execution(s) of the original and modified software versions.

Secondly, the testing for the cloud-based implementation was performed. This differed from the local testing in that the complexity of the cloud environment made direct querying of data difficult. However, the time taken for executions to complete is the important element for analysing the cost-effectiveness of the external memory implementation. Therefore, the authors recorded the start and end of cloud execution as timestamps and the difference between them was used as the overall execution time.

Finally, *throughput* calculations were conducted to investigate the potential performance overhead of the new implementation versus its memory reduction. Based on the specifications of the cloud hardware, the authors computed the RAM used per-execution of the in-memory and external memory versions of the software, and compared the changes to throughput afforded by the RAM reduction of the new version.

VI. Results

Three datasets used in the testing are described in this paper: 1. a Plant Room (~4.5Gb), 2. an Office Floor (~6.1Gb), and 3. a Hotel (~7.6Gb). They each comprise both an IFC model and E57 point cloud. These inputs were chosen because they lie in the upper bound of allowable inputs into the cloud system, where users are capped to a maximum size of 8Gb for uploaded input files.

As per the methodology set forth in Section 4, both cloud and local testing was conducted. The local testing used a Linux-based PC with Docker installed, which had 96Gb of RAM, two 8-core Intel Xeon 3.4GHz CPUs totalling 32 threads when hyperthreaded, and a 1Tb HDD which stored the inputs and paging cache location. In the cloud, VMs provisioned through Kubernetes on Azure were of type E4 [26], with 4 CPU cores/threads available alongside 32Gb of RAM. Both in-memory and external memory versions of the software were hosted on separate instances of the cloud environment, with identical resources. Individual executions are limited to a maximum RAM size of 8Gb and 2Gb respectively. The 2Gb limit for external memory application was determined by evaluating the local testing behaviour. A temporary file storage space of 25Gb was allocated for the duration of the execution, which acted as a location for the paging cache file.

Figures 2, 3, and 4 show the results for the locally tested datasets. No memory limitation was imposed in order to see how high the in-memory software's RAM usage performed compared to its STXXL-based counterpart. The Plant Room dataset is shown in Figure 2. In this case, the in-memory execution completed in less than half the time of the external memory version, but the RAM consumption spiked to above 3Gb.

Figure 3 shows the same behaviour for the Hotel dataset, where the in-memory version maxed out at ~2.5Gb, however, remaining quite close the external memory RAM utilisation and completing in half the time. Finally, the Office Floor dataset shown in Figure 4 has the starkest difference demonstrating the trade-off external memory offers. The in-memory execution finishes in roughly a quarter of the time the external memory version takes, but it exceeds the external memory RAM usage by a factor of five. Each of these tests show different behaviour, due to the characteristics of the datasets chosen, but the common aspect between them is that the in-memory version is expensive when it comes to using the available RAM.

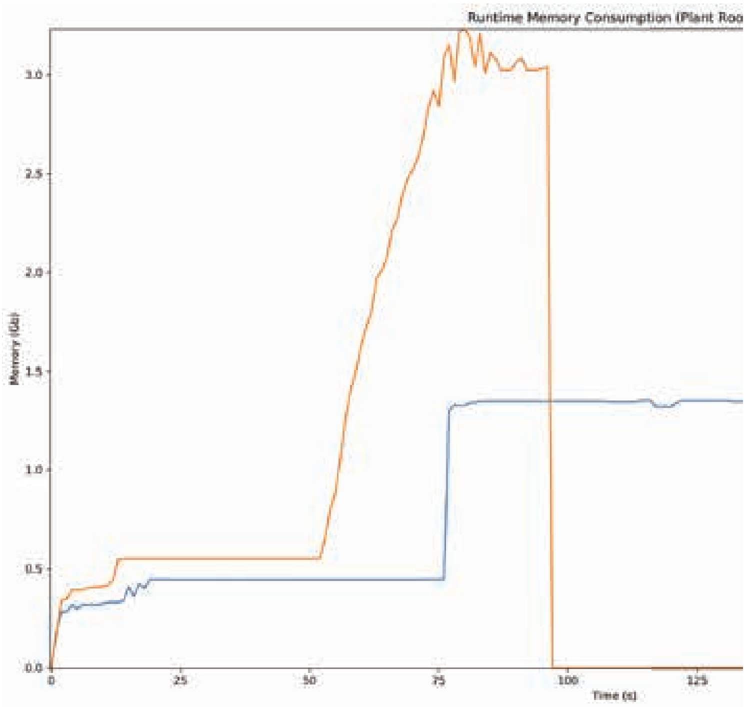

Fig. 2: Plant Room execution memory usage.

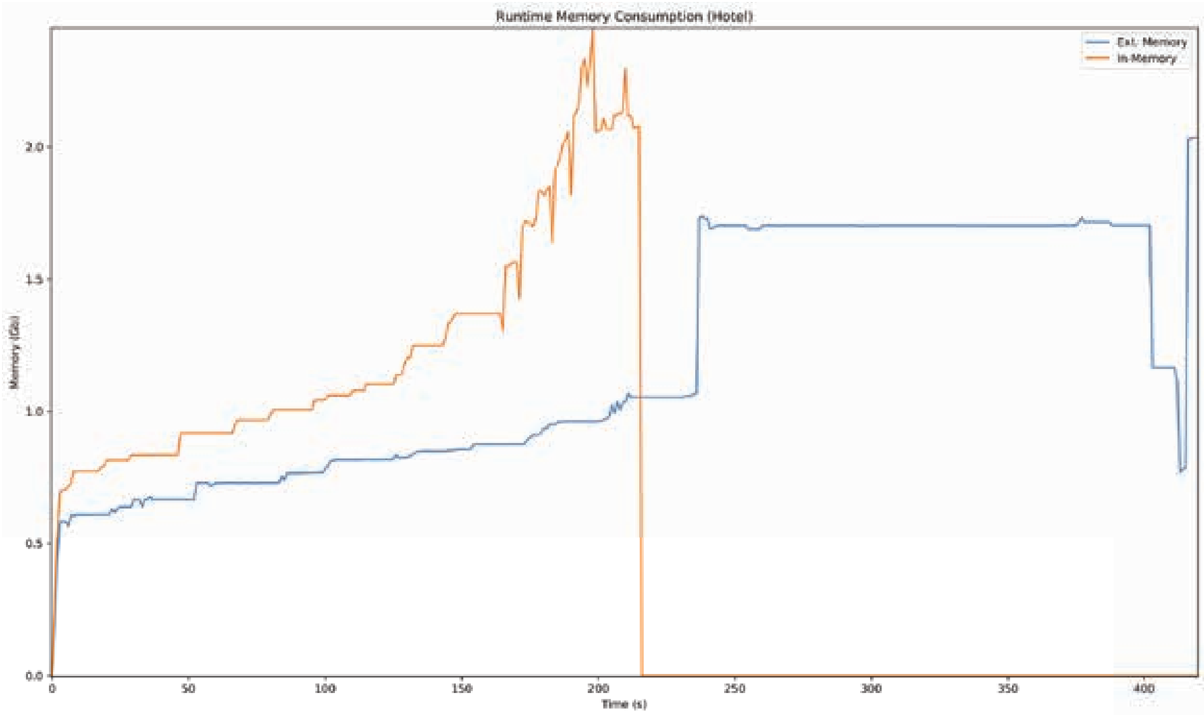

Fig. 3: Hotel execution memory usage.

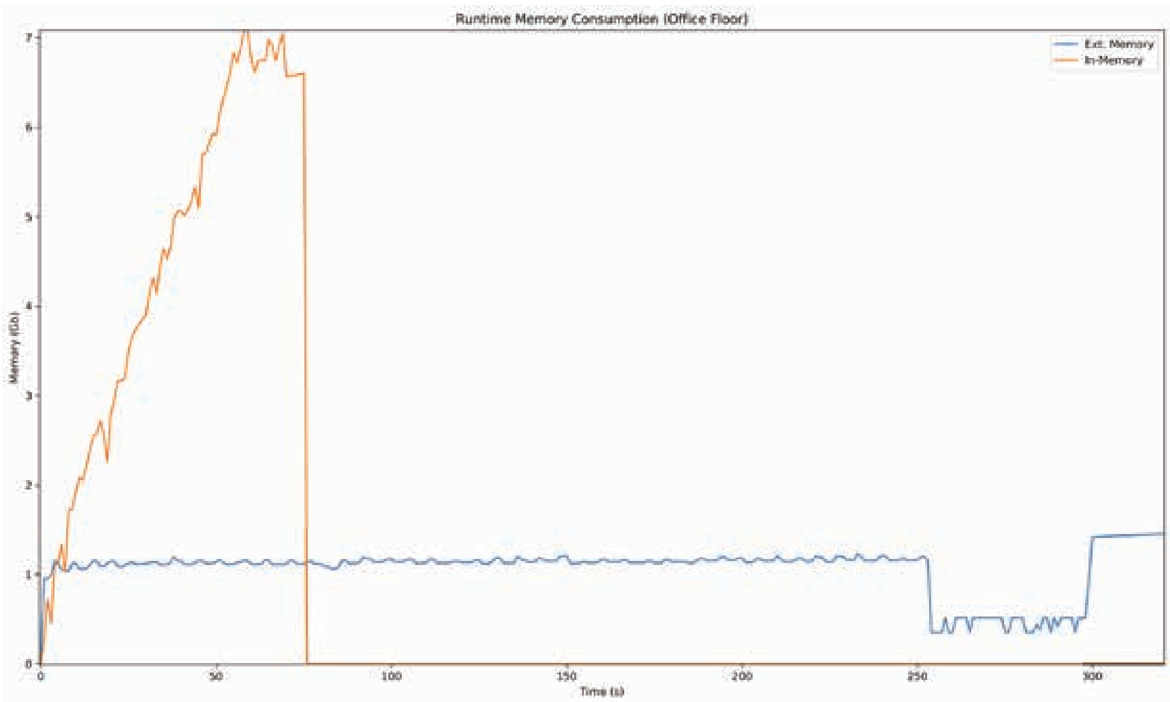

Fig. 4: Office Floor execution memory usage.

Utilising the aforementioned information, the authors moved on to cloud testing, to see if the RAM-limited executions behaved in a similar manner. Each of the three datasets were uploaded and run in both versions of the cloud system, and their time taken in seconds was compared with local testing in Tables 1, 2, 3, and 4. Note that cloud operations took longer in general due to additional layers between initiating the execution and its actual processing.

Table 4 shows that the external memory implementation slowed down the processing time due to I/O complexity introduced by STXXL. This behaviour was different than anticipated, as it was intended that a majority of the performance was preserved after the modifications. At best, the execution ran 50% slower, and at worst 75%. However, execution time was only part of the evaluation.

PLANT ROOM	***In-Memory***	***Ext. Memory***
Cloud	392s	954s
Local	97s	218s

Table 1: Cloud and local timing for the Plant Room dataset.

HOTEL	***In-Memory***	***Ext. Memory***
Cloud	836s	1876s
Local	216s	419s

Table 2: Cloud and local timing for the Hotel dataset.

OFFICE FLOOR	***In-Memory***	***Ext. Memory***
Cloud	793s	1736s
Local	76s	320s

Table 3: Cloud and local timing for the Office Floor dataset.

PERF. TIMING	***Local***	***Cloud***
Plant Room	44.5%	41.1%
Hotel	51.6%	44.6%
Office Floor	23.8%	45.7%

Table 4: Execution time of in-memory version as a percentage of external memory version's duration.

With this information in hand, a throughput estimation was created, based on the current specifications of VMs in the cloud system. The authors used the following formula to compute throughput:

$$T = C / D$$

Where T is throughput, D is execution duration, and C is execution capacity, i.e. the available space on a single VM based on its memory. The Azure E4 VMs used have 32Gb of RAM, which when capped at 2Gb per-execution and leaving room for the OS and other orchestration systems, means a single VM can at most support 15 executions in parallel $C_e = 15$. The previous in-memory version allowed 8Gb of RAM per-execution, meaning it can only support 3 parallel executions $C_i = 3$.

The authors calculated the throughput for in-memory and external memory using the Plant Room data set with $C_i = 3$ and $C_e = 15$, and $D_i = 392$ and $D_e = 954$. Therefore, where units = seconds:

In-Memory: $T_i = 3/392 = 0.0077$

External Memory: $T_e = 15/954 = 0.0157$

Next, T_i and T_e were converted from seconds to minutes: $T_i = 0.462$ and $T_e = 0.942$. The resulting values now represent the executions per minute based on VM capacity. Due to the increase in throughput, moving from in-memory to external memory, more executions in the cloud system will finish before a smaller number of executions in the old system complete. This behaviour shows that a tangible reduction in the hardware cost-per-execution is possible. The throughput results above show that each individual execution takes longer to run while a higher number of parallel executions are allowed. Thus, the external memory software version exceeds the original software's overall performance, in terms of executions completed within a given timeframe, based on the expanded parallel capacity provided by the throughput increase. As a corollary to the increase in parallelism, the scalability of the system is improved as a greater number of users can submit analyses to be executed within the existing VMs. With more processing done on existing hardware, there is less need to deploy additional VMs until the number of user-submitted executions reaches the software's expanded limit.

VII. Conclusion

Big data such as large point clouds in the AEC domains are a frequent concern, and new methods or technologies that alleviate constraints on big data processing are desired. The research shows that when utilising an external memory solution to achieve a lower RAM overhead, cost-effective improvements can be yielded when the throughput is increased. The tradeoff for this improvement is an increase in execution time. Furthermore, the true benefits are revealed as the system with such a solution is scaled up. It is demonstrated, by using throughput calculations, that implementing external memory as the primary method of data storage for processing can improve cloud-based systems, and increasing the capacity for scheduled executions improves robustness and scalability.

VIII. Future Work

The authors intend to continue their investigation into the benefits of using external memory versus current in-memory portions of the overall algorithm. It is anticipated that new system developments will have this technology incorporated into the designs for them from the onset. However, further testing is required, to evaluate the benefits of lower RAM usage provided by external memory on a large scale where it is envisaged that the benefits are most prevalent. The extent of the throughput derived in this paper is to be stress-tested, and the performance across many parallel executions across many VMs in the cloud system are planned to show further benefits of designing software an external memory solution.

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Incentivising multidisciplinary teams with new methods of procurement using BIM + Blockchain

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Abstract– This paper researches a potential method of incentivising AEC industry professionals to design to better than NZEB standards. Analysing the potential of a purposefully designed local microgrid storing excess energy generated by solar technologies embedded within the building envelope; the microgrid excess output is measured and recorded using a (Post Occupancy) "Blockchain" application and measured against the data provided at design stage on a (Predictive) "Blockchain" database. In turn, this creates the potential for "Added Value Networks". The first being a financial incentive for designers to strive for the very best building performance, and the second, a financial incentive for building occupants to conserve energy leaving more energy for sale. This will be the basis for comparing predictive energy use against actual energy output. Actual energy output during occupancy can be recorded using real time sensors matching the number and location of the digital sensors. The information on both databases are secured using the immutable and transparent properties of Blockchain.

Keywords– BIM, Blockchain, Microgrid, Sensors, NZEB, POE.

I Introduction

This paper researches how construction procurement may develop in the future. Provided the Architectural, Engineering and Construction (AEC) industry is ready to adopt new methods. If new methods are to be realised in the future, they will have to adhere to new building standards. Currently, governments are aiming to introduce Net Zero Energy Building (NZEB) standards in the future [1]. NZEB standards are followed when producing a building that is capable of meeting its own energy demand through renewable sources [2]. By signing the Net Zero Carbon Buildings Declaration, some parts of the world such as London, Los Angeles, New York, Paris, Sydney, Tokyo, and Toronto have all pledged to ensure buildings in their cities, new and old, will meet the net-zero carbon standards by the year 2050 [1]. The current culture of construction is very different to this future aspiration. Construction today is fragmented and defensive, participants prepare for battle rather than harmonious collaboration and do not strive to produce buildings that produce more energy than they consume. There is usually a lack of trust and a lack of information between the various parties. This, more often than not, leads to disputes [3]. AEC industry contracts today focus on pushing the risk to either the designer or the contractor and are hampered with excessive bureaucracy. This leaves people in quite a defensive mode throughout the contract; also adding to the tension is the relentless focus on the lowest-cost tender awarding which has numerous repercussions on build quality.

> *"You can pinch a bit here or there in the capital cost, but the outcome of that can result in far-greater costs in the performance of the building.- You are adding to the cost rather than getting to the optimum solution."* [4]

For buildings to be declared self-sustaining it requires a lot of analytical data to be sure that the claim is genuine. Sensors, microgrids, smart meters, and Blockchain technology allows this analysis to be possible. In 2016 the company LO3 Energy, created a real world use-case. It is called 'The Brooklyn Microgrid'. Using a network of community owned solar panels, members of the community in Brooklyn, New York were able to generate and store energy, then sell the excess energy to the neighbours in their community [5]. Microgrids that combine the capabilities of solar panels, smart meters and Blockchain technology have the power to bring small communities together and to turn large building projects into self-sustaining ecosystems [6].

The aim of this research is to explore and answer the question: "If a building can produce more energy than it is consuming, is there an opportunity for the

One specific POE report researched eighteen buildings. The report noted that all eighteen buildings in question missed the target when compared to their design stage predicted performance goal [22], this is not uncommon. The following graph was taken from that paper, reporting on the findings.

Fig. 1: Predicted analysis versus in-use data [22]

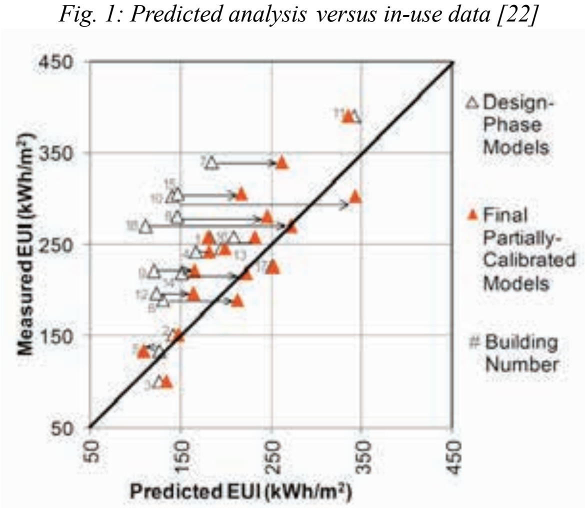

Figure 1 highlights a gap between predicted energy performance and the actual energy performance [22]. The evaluation of building performance and occupant satisfaction in the post-occupancy phase is relatively under-developed compared to evaluation methods applied during a buildings design phase [23].

f) Microgrid

A microgrid can be described as a cluster of loads. Loads are Decentralized Energy Resources (DER) (e.g. PV panels) and Energy Storage Systems (ESS) (e.g. battery), which operate in conjunction to supply electricity reliably. Microgrids can be applied to buildings new and old and are seen as an approach to reduce centralized power distribution by sourcing and sharing renewable energy locally between individuals running microgrids on their buildings in a community [6]. There are real world use-cases, for example, the previously mentioned L03 Energy Brooklyn Microgrid noted in the introduction.

III Methodology

The author has investigated various methodologies and chosen Design Science Research (DSR). DSR is a method of evaluating innovative IT solutions that extend the boundaries of known applications. The core mission of DSR is to develop knowledge that can be understood by professionals and applied in practice [24]. DSR is a systematic form of designing a solution that involves the development and study of "artefacts" [25]. The "artefact" can be a concept developed on an existing platform and used to create new functionalities. The author chose DSR because it applies to researchers who wish to present innovative BIM solutions, evaluating them for real world use-cases. [26]. The "artefact" in this paper is a BIM model equipped with a Blockchain.

f) GDPR

"The EU General Data Protection Regulation (GDPR), along with the new UK Data Protection Act 2018, will govern the processing (holding or using) of personal data in Ireland" [27].

Precaution taken to minimise data risk was to ensure only fictional designs were used when modelling in BIM software applications. This ensured no individually identifiable building design was displayed in screenshots illustrated throughout this paper; Allowing for the following open and candid discussion.

IV Research Testing

Existing research has proven real-world sensors can populate BIM models with real-time information. The author expands on the premise of Digital Twin technology; taking the existing research a step further with Blockchain technology. Using the existing research as a base line the following basic conditions, for the purpose of research testing conditions, are assumed:

- One floor, four walls and no roof.
- A heat sensor on the internal face of each wall receives data from a hypothetical real-world, geometrically identical, building.
- Each 3D virtual sensors in the BIM model displays a reading of 0.32 Kw.

Dynamo was used to develop a script that could be used to log and test BIM model data on a Blockchain ledger. The script is dissected into groups for demonstration purposes. The green phase has one group. The orange phase has three groups and the pink phase has one group. Figure 5 on the following page illustrates this.

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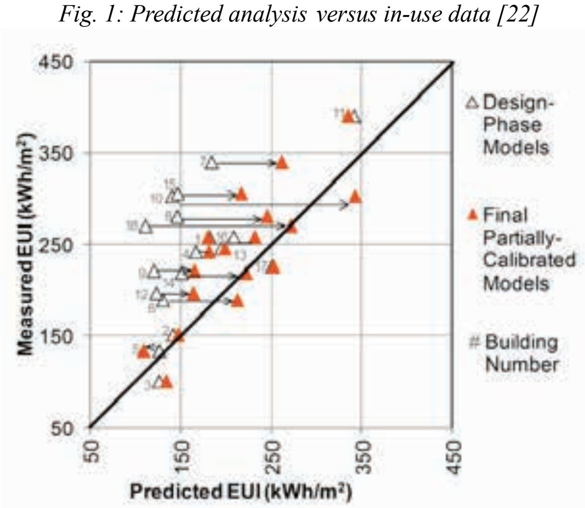

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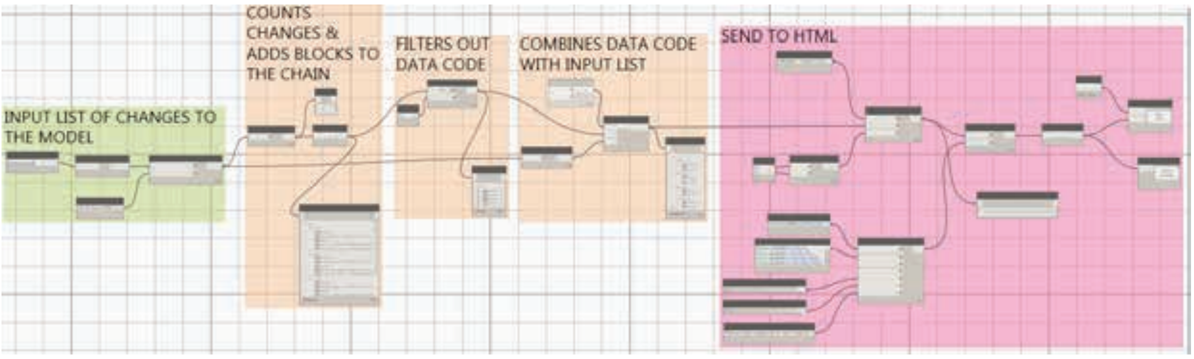

Fig. 2: Screenshot of complete dynamo Script developed by author for primary research testing. Source: Author.

Starting with the Green phase; this group is used at the beginning of the script to focus on a specific category within the BIM model, in this case, data devices (sensors). The node "Family Types" allows the user to choose the category. The sensor category was chosen. The node "All Elements of Family Types" selects every sensor family in the project. The "Code Block" node inputs a search for the term "Read From HTML. This feeds into "Element.GetParameterValueByName". These two nodes combined, find the information within the "Read from HTML" parameter. These four nodes can be seen in Figure 6 below.

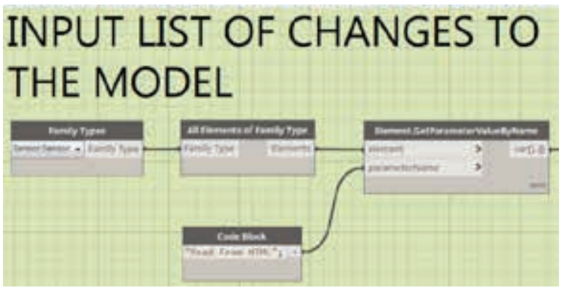

Fig. 3: Green group, get "read from HTML" information. Source: Author.

With the information from the sensors selected, the next step was to progress to the orange phase. The first orange group: Counts changes and adds blocks to the chain. There is a custom node present which is highlighted in Figure 7. The author created a custom node that is essentially a novel Blockchain. (See Figure 7)

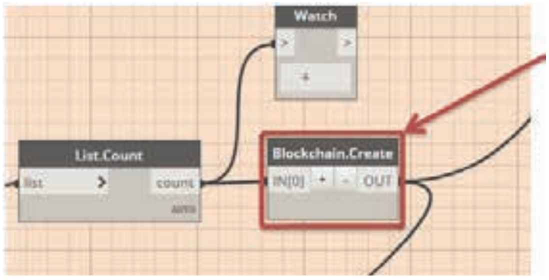

Fig. 4: Custom node (Blockchain)

Inside the highlighted custom node there is custom blockchain code. Figure 7 displays a watch node reporting the number four. Watch nodes only monitor and display information. The true path of the script is progressing from "List.Count" to "Blockchain.Create". The watch node simply confirms that four counts of sensors are fed into the Blockchain. The custom "Blockchain.Create" node creates a genesis block, the first block of the Blockchain. It then continues to timestamp, produce and assign a hash number synonymous with that block. This process is done four times as there are four sensors sent through the Blockchain. Each sensor generates a block. Each block is timestamped, assigned a hash number and connected to the previous block via their individual and unique hash numbers. The information is timestamped and hashed together into an ongoing chain. This is the basic workings of a Blockchain. The output can be seen in Figure 8, an image of the watch node reporting on what transpired on the Blockchain: (See Figure 8)

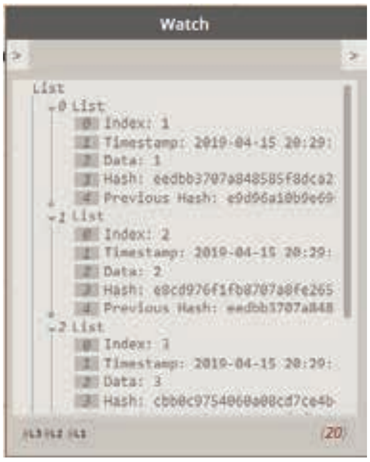

Fig. 5: Output of custom Blockchain node

Moving onto the next group of nodes, filtering out each of the four Blocks was achieved by using the nodes "List.GetItemAtIndex" This node searches through the information seen in Figure 8 and takes the data to be further pushed through the Dynamo script. (See Figure 9)

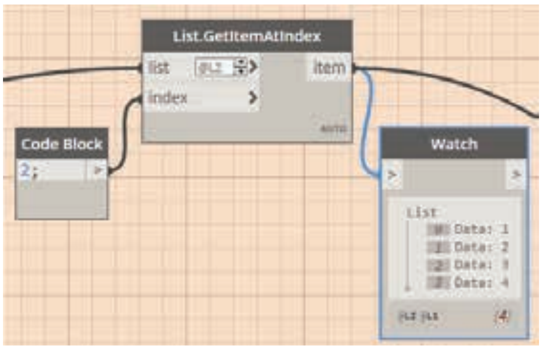

Fig. 6: Filtering out each Block

From there the data from the Blockchain is combined with the energy reading. (See Figure 10)

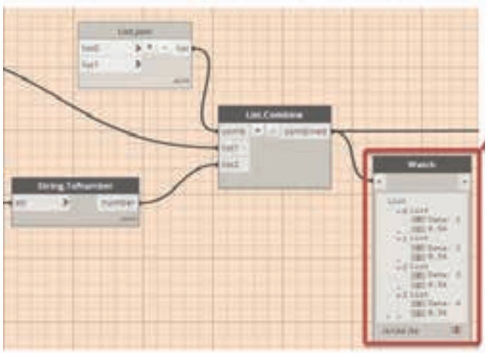

Fig. 7: Screenshot of Blockchain and energy data combination.

The watch node in Figure 10 consists of information that needs to be more universally legible. To represent this data in a more visually pleasing manner it was sent to the next group of nodes combining the information before sending it out into a bar chart for clear visual representation.

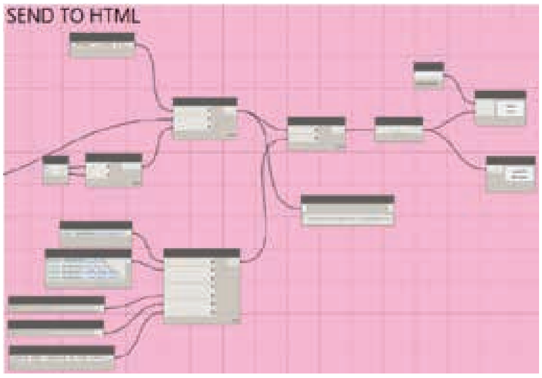

Fig. 8: Send information to HTML format

The next group, the pink phase, seen in Figure 11 is the validation phase. This phase checks nodes to ensure the script executed correctly, outputting monitor-able charts. To generate a chart the aesthetics of the chart must be defined. The majority of the nodes in the pink group are parameter rules that define how the chart is visually output from the dynamo script.

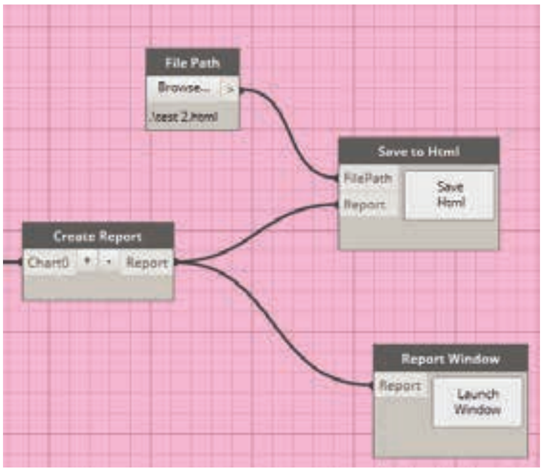

Fig. 9: Final step in the Dynamo script process.

V Findings and Discussion

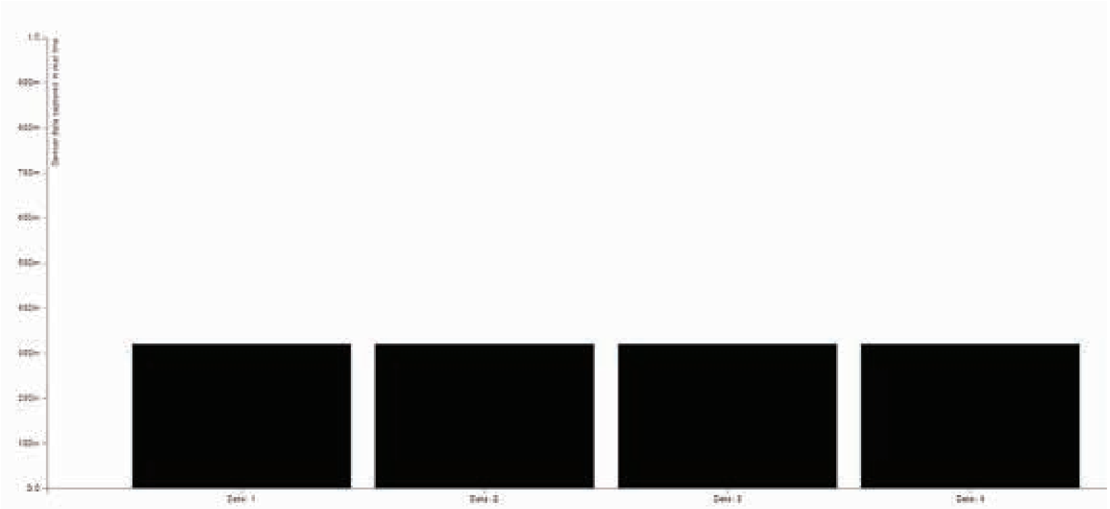

Fig. 10: Chart generated from Dynamo

The graph of Figure 13 was generated when the dynamo script completed. This graph illustrates the successful achievement of recording BIM data on a Blockchain with dynamo. The potential for BIM + Blockchain is great, especially as there is a longing for change in the AEC industry. Schleifer C Thomas highlights the need for change in procurement within the AEC industry. Thomas notes lump-sum 'lowest bid wins' contracts don't work [28].

Clients want their project to move forward as rapidly as possible and want to be sure of the outcomes. However, at each stage of the process, most decision-making information only becomes known after the client has spent most of their money, this usually results in frugal clients [29]. Clients may become more frivolous rather than frugal, at the early stages of a project; if they are assured the property investment will generate not only rental revenue but energy sale commission as well, provided better than NZEB standards are achieved.

The greed seen today from clients who want their built assets built as cheaply as possible to turn over short term profits on their investment is not only ethically questionable but is having profound repercussions on the global environment. Buildings account for the majority of global energy consumption [30]. If the AEC industry can be incentivised to make better than NZEB standard buildings the environment will be spared a great deal. The short sightedness of building quickly and cheaply needs to come to an end, this attitude is throttling the evolution of innovation [29].

VI Conclusion

From this research of qualitative desktop literature studies and quantitative testing methods the author notes the tremendous value of Blockchain, a distributed ledger, when used specifically with a digital twin. All stakeholders will become aware of how much energy is produced by built assets and all stakeholders will know how much energy is consumed by built assets. None of this information can be altered as to do so would result in an obvious deviation from the set rules agreed by the rest of the stakeholders. If a built asset is successful in producing more energy than it consumes, smart contracts can be deployed on the Blockchain to sell the surplus energy back to the public and share the income amongst the design team in a democratised way. Therefore, it is in the financial interest of the design team to strive for better than NZEB standards. Noted in the Literature review:

> *"In the same way that the internet changed information services forever, Blockchain will transform services of value forever. The only question is: What form will this transformation take?" [10].*

The research in this paper highlighted one way this transformation could potentially materialise.

Although the potential here is obvious, it is still difficult to fully realise the power of pairing these two team-oriented technologies without working in a large team. The study of these two distributed and collaborative technologies can be paired for several different applications. These new applications should be further researched by teams of capable industry professionals and academic specialists.

The research question: If a building can produce more energy than it is consuming, is there an opportunity for the building owner and/or design team / building occupants to sell the surplus energy as a commodity? The result of answering this question positively has developed a potential for two "added value networks". The first, an added financial incentive for the design team to strive for the very best building performance, and the second, an incentive toward the building occupiers to conserve energy usage as this will leave more energy to sell and thus building up an "added value network" of people and places.

This outcome was an assumption prior to the completion of testing. Now with proof, the author concludes, Blockchain can indeed present an opportunity to sell a surplus of energy as a commodity and share the income amongst different parties in a democratised way. However, this will be the evolution of the proof of concept, taking the proof of concept from tested theory into practice is the next step for the author.

The barriers are, culture change and education; as Blockchain technology remains misunderstood by the mainstream. The technology will only become a revolutionary advancement when it becomes part of mainstream culture and the potential becomes common knowledge. Blockchain technology will then be adopted globally.

Upon reflection after the completion of each project objective it is clear that the answer to the research question: If a building can produce more energy than it is consuming, is there an opportunity for the building owner and/or design team / building occupants to sell the surplus energy as a commodity: Is, yes. In turn, this results in "Added Value Networks" incentivising designers to provide quality energy producing buildings and incentivising people to conserve energy both for financial reward.

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CitA BIM Gathering **Proceedings**

Leadership in Digital Transition

Overcoming Resistance To BIM: Aligning A Change Management Method With A BIM Implementation Strategy

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Abstract—The adoption of Building Information Modelling (BIM) in the Irish construction industry has risen from 10% in 2011 to over 70% in 2018. Where there is criticism towards BIM concerning its ability to reduce environmental impact, it is not about the ambition to adopt BIM but more so the capacity to embed BIM within the industry. The National BIM Council introduced a Roadmap to Digital Transition for Ireland's Construction Industry 2018-2021, which defines a strategy to transform the construction industry to digital. This research paper explores how small to medium size companies within the Architectural, Engineering, and Construction (AEC) industry in Ireland can respond to both organisational and individual resistance to the implementation of BIM processes in practice. A literature review and stakeholder interviews from organisations at various stages of implementing BIM have demonstrated that to change how the industry works there must be an overall goal to adopt BIM. In order to achieve business goals, it is important to investigate change management processes which can support the reduction of resistance from employees. While it has been found that implementation needs to come from a bottom-up approach, more importantly it is top-down from management that will make BIM practices the norm. As a response to the industry's introduction of BIM and the transition to digital, companies are embarking on organisational change through the review of business structures and operational strategies. To reduce resistance companies have come up with new approaches, such as introducing an implementation team, developing training programmes, and altering the organisational structure with new roles and responsibilities. A BIM adoption roadmap that aligns change management methods with a BIM implementation plan can bridge the gap and ensure that BIM becomes commonplace within an organisation.

Keywords — Building Information Modelling, BIM Adoption, Digital Transition, Change Management, Implementation Roadmap

I Introduction

As the Architectural, Engineering and Construction (AEC) industry in Ireland embarks on the transition to a more digital and collaborative working environment, businesses are being challenged to meet the sophisticated demands of clients [1]. With the rapid adoption of Building Information Modelling (BIM) across the globe, companies are reviewing their organisational structures and changing the way in which they carry out their day to day tasks. It has been identified that one of the largest barriers to overcome is the behavioural resistance to change that is found amongst both client and the construction industry [2].

Within the Irish industry small to medium size companies are defined as having less than 50 employees and an annual turnover not exceeding €10 million [3]. Verheugen [4] describes micro, small and medium-sized enterprises as the engine of the European economy, and that these companies are a vital source of jobs while creating entrepreneurial spirit and innovation within the EU. Table 1 below highlights the size of architectural firms in Ireland recorded from a survey carried out to study the strategic leadership of architectural firms in Ireland [5]. With an astounding 86% of firms in Ireland employing five or less staff, it is essential to assist these firms during such a widespread industry transition to digital, and the welcomed introduction of BIM.

Table 1 Architectural firm size Ireland 2010

Total No. of Employees	2010 (%)
1	45

2	14
3	14
4	8
5	5
6-10	8
11-20	4
21 +	2

Research in the area of BIM tends to focus on finding solutions to technical difficulties with BIM [6]. There has been less research carried out focusing on how BIM implementation influences work practices, and the processes required by an organisation to reach overall goals and employee expectations [6]. Lasting BIM adoption has stalled not because of technology or business, but because of human factors. Managing employee expectations is vital. "BIM doesn't work" [7], that is in many cases true as BIM does not work for those whose expectations are too high. BIM does not work for someone who does not know how to use it, and for someone unwilling to change how they think and work.

With the publication of the NBC Roadmap to Digital Transition for Ireland's Construction Industry 2018-2021, Knoster, T (1991) states *"Without Vision, you will have confusion; without Skills you will foster anxiety; without Incentives you will meet resistance; without Resources you will breed frustration; without a Plan you'll make false starts"[1].* This statement provides insight of the requirements that the management of AEC practices must consider with the introduction of BIM to the Irish construction industry.

II Review of Literature

The literature reviewed for this paper considers the changes that have come with the adoption of BIM from both an industry and a business perspective. The Irish construction industry is growing concerning BIM adoption with 76% of respondents to the Irish BIM study reporting confidence in BIM skills and knowledge. 79% of those also reported an increase in demand for BIM in Ireland [8].

a) Barriers of BIM

The focus of current research looks mostly at the industry, company and project level of BIM adoption. Several obstacles which have been identified include; low awareness, lack of training, dissolution of the industry, difficulties in changing traditional work methods, the introduction of new roles and responsibilities, as well as software interoperability. However there has been one impediment which has not been investigated, and that is the perception of BIM by users [9]. Individual users of information systems react in different ways to new technologies. Users of technologies may; reject it completely, partially use it, resist it, unwillingly accept it, or fully embrace it [10].

The UK National BIM survey 2018 identified that the largest barrier to BIM adoption within organisations that have yet to adopt BIM is the lack of in-house expertise (71%), closely followed by no client demand (69%), lack of training (61%), and cost (50%) [11]. In comparison to the findings from the UK market, within the Irish industry, the top five barriers reported [8] were client awareness, implementation within smaller companies, lack of standardisation and protocols, lack of in-house expertise, and issues regarding data ownership and liability. It is expected that with the growth of BIM, traditional work methods will diminish as more and more clients see the benefits of BIM.

Another significant obstacle affecting BIM adoption may be the demographic of the industry and the enthusiasm to adopt new technology. It has been identified by the Irish Prospects to 2016 [12] that the ageing of the Irish workforce and the availability of new graduates to the industry are key barriers to be overcome. Technology is playing an increasingly more critical role in the construction industry, the most recent trends within the green building and BIM shift in technology implementation. Technology brings many opportunities to workforce development including non-construction audiences. The opinions of Uddin and Khanzode [13] is that BIM is enhancing people's careers both with existing professionals and in creating new career paths for young professionals [14]. It is believed that the Irish construction industry can address skill shortages through the utilisation of BIM, increasing the attractiveness of the construction industry to young professionals according to Construction 2020 [8]. Given the uptake of digital technologies within the industry, this is expected to increase the demand for highly skilled labour [15]. To address skill shortages, it is clear that more needs to be done to reverse the stereotypes associated with the construction industry. It seems, even amongst those working in the construction industry that the perception is comprised of hard hats and hi-vis vests. There is a lack of awareness in terms of careers in construction management, and offsite activities such as design [15].

b) Changes BIM Brings to a Company

A case study in Sweden of how a large public client is initiating BIM implementation within their organisation has identified the changes which occur with BIM implementation and categorises these changes into four areas; BIM management systems, BIM measurements, BIM skills, and BIM education [6].

BIM management systems look at changes such as; defining the lowest level of BIM use within the organisation, the mentoring of BIM, new role descriptions such as BIM coordinator and BIM manager, and the adoption of industry standards. BIM measurements investigate the level of knowledge within an organisation regarding BIM and the attitudes towards BIM, this also includes measurements of BIM such as key performance indicators (KPIs). Meanwhile the BIM skills level looks at competencies and framework agreements for BIM coordinators and BIM managers, as well as BIM education considering BIM training courses [6].

Research which aims to extend the Unified Theory of Acceptance and Use Technology model to understand the perceptions of BIM users resulted that Performance Expectancy does not directly affect Behavioural Intention, thus signifying that BIM is often perceived as an unrewarded addition to traditional work processes [9]. The findings from this survey show the need to redefine organisational strategies, standards, and incentives to advance user acceptance of BIM.

c) Organisational Change

Organisational change is described as a process which is undertaken by a company to change its working methods or aims [16]. Organisational change is categorised into two categories, planned and unplanned change. Planned change is described by Windell L French [17] as a deliberate effort to modify an organisational system to respond to environmental and internal forces.

The evidence of a relationship between BIM and organisational change can be argued as it is suggested in research that BIM is a driver for change [18]. Succar [19] suggests that in order to achieve successful BIM implementation, a company must first make use of the potential benefits and understand the need of how BIM implementation is dependent on changes within an organisation. Froese [20], suggests similarly that for BIM to reach its full potential within a company there is the requirement to alter the skills and work practices of its users. Succar [19] describes within the research framework presenting BIM in a multidimensional setting, that the higher the maturity stage of BIM implementation within a practice, the requirement for larger changes will gradually increase.

Adopting BIM without a plan is described by Deutsch [7] as taking a trip unaware of the baggage that can slow you down, and with regard to BIM these items relate to workflows, learning curves, interoperability, insurance, identity and role, mindset, and communication [7].

d) Individual Resistance

Individual resistance to change resides in the basic human characteristics such as individual's perceptions, personalities and needs. In understanding the importance of change, having the clearest vision or plan is not enough to succeed. There are a number of barriers to implementing change and individual resistance is one of them [21].

Due to the likelihood of employee resistance, change should only be done to accomplish an overall goal and not for the sake of it. Change provokes resistance as people can be afraid of the unknown, do not have an understanding for the need to change, or share the same vision for change [22]. Employees may see change as a threat to their current position within a company and therefore resist the change. This type of change is primarily due to the lack of communication between managers and employees causing rumours and speculation [21].

Change occurs at the individual level and for a company to successfully change all individuals within the organisation must change; therefore it is essential to understand how change affects one person at a time [23]. ADKAR is an acronym that represents the five key milestones an individual must achieve to succeed with an overall goal. These five milestones are; awareness, desire, knowledge, ability, and reinforcement.

Table 2: Change management milestone definitions

ADKAR	Definition
Awareness	Business reason for change
Desire	Desire to engage with change
Knowledge	Having the information to change
Ability	Action planning / implementing change
Reinforcement	Ensuring that change sticks

III Research Description

The objective of this research area is to explore the following:

a) The potential barriers faced by BIM implementation within micro, small, and medium AEC practices in Ireland,

b) The identification of the changes BIM brings to AEC practices and how those changes may transpose into challenges,

c) The effect of changes introduced by BIM implementation on the people within AEC practices,

d) How AEC practices are currently overcoming resistance which has arisen from BIM implementation,

e) Aligning a change management plan with BIM implementation to allow BIM to become common practice within AEC practices in Ireland.

This research was carried out through literature review of currently available published material, and stakeholder interviews with AEC practices at various stages of BIM implementation.

a) Pre-Interview Questionnaire

Participants were chosen from three different levels within AEC companies in Ireland. The three levels defined were;

- General Management,
- BIM Management,
- BIM Users.

A pre-interview questionnaire was completed by each participant to give insight to the research area and to allow for openness and transparency from the interviewees when partaking in the semi-structed face-to-face interviews. The questionnaire was completed by six of the seven interviewees and covered the following topics:

- Background and professional experience.
- Understanding of BIM and BIM maturity levels.
- Understanding of company's vision for BIM.
- The most significant barriers to BIM.

b) Semi-Structured Interviews

Seven individual qualitative interviews were used for the purpose of stakeholder research to collect data from individuals currently working through BIM processes daily. The face-to-face interviews were carried out with a selection of employees from each level within companies in the Irish AEC market. Figure 1 identifies the number of interviewees from each category.

IV Results

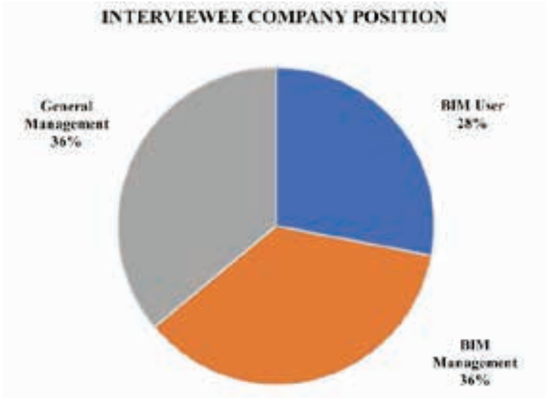

Fig 1: Chart demonstrating company position interviewed

The results discussed are based on deductive analysis of qualitative data collected from semi-structured interviews with individuals from AEC companies currently implementing BIM, along with data collected from the pre-interview questionnaires. Descriptive analysis of interview data was carried out using Excel. All interviews were commented on by the researcher and responses were categorised with general topics discussed.

Table 3: Data source figures

Data Source	Respondents
Pre-interview Questionnaire	6
Semi-structured Interviews	7
Total	13

a) Awareness of BIM

The interviewees were asked a series of questions to determine an understanding of BIM within the office environment. Concerning the company's vision for BIM this was something that most stakeholders found difficult to define. Five of the seven respondents discussed in one way or another that they believed their company's vision for BIM was to deliver all projects within the office through the BIM process. While this was the consensus, many of the interviewees from both a management and employee level felt a clearer vision was something that would benefit the company and individual's understanding of what the company is working towards. Figure 2 below illustrates the results from the pre-interview questionnaire regarding understanding of company vision for BIM.

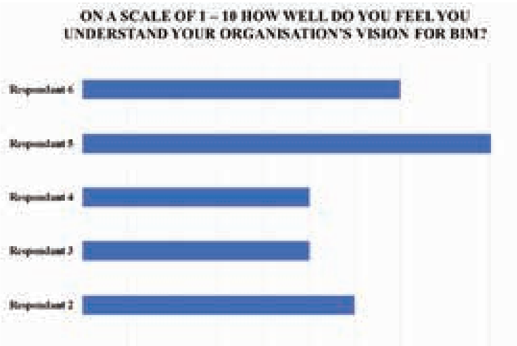

Fig 2: Understanding of company's vision for B

Interviewees were asked to describe why there ould be a need for BIM implementation within the ompany which 57% responded that due to the ganisation's client demand it was necessary. 14% sponded that it would be a requirement due to the ompany working on government contract jobs, hich under the BIM mandate due to be published ter this year it would become necessary to deliver bs through the BIM process. Others felt that ompany size had to do with BIM implementation, nd if BIM wasn't implemented the company would e left behind.

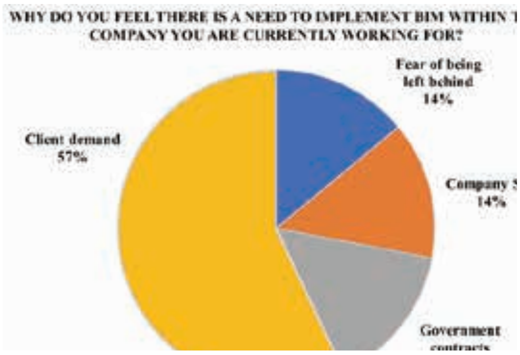

Fig 3: Why there is a need for a company to implement BIM

In understanding the awareness of BIM within e companies, management were asked a series of uestions relating to corporate BIM strategies, the troduction of new roles and responsibilities, and ow these roles are defined within the companies. The sponse to these questions was mixed from dividuals within the same companies. The response as that corporate BIM strategies were in place, but was not something written down and is a broad atement that alters depending on what the client for specific job wants. Concerning new roles and sponsibilities 67% of respondents agreed that the IM process had brought new roles to the companies, hile the new roles are not defined within the ompany's organograms. One interviewee discussed e longevity of these roles and whether these roles would be better assigned to existing roles within the company.

b) Building Desire Within Companies

Building on desire within the companies' employees were asked about the involvement of managers regarding BIM implementation. 50% of the respondents reported that managers were actively and visibly involved, while the remainder respondents said that some of the management were more involved than others but in general everyone was trying to come to terms with the understanding of the BIM process. Respondents felt that management could provide more clarity with a visible BIM implementation plan, standards, and protocols, as well as management having a more meaningful understanding of what goes on regarding the modelling aspect of BIM. A topic which was discussed with all interviewees was personal views regarding openness and transparency during an organisational change such as BIM implementation, and 100% of all respondents felt that this is extremely important to avoid the harvesting of resistance within teams throughout the offices.

When looking at desire from a company management perspective, managers were asked to describe any incentives the companies had considered to aid the implementation of BIM. All mangers who were interviewed spoke about educational assistance as an incentive to employees, while employees were aware of the educational assistance it did not appeal to some as it would involve additional hours outside of work. 67% felt that there needs to be more done to show employees the benefits to their working life with the introduction of BIM processes, and that, that alone is an incentive in itself. Further incentives would be worth considering as there was a general feeling that it would be beneficial in achieving the overall vision for BIM.

c) Learning About Knowledge

The structure around knowledge within the interviews was based on gaining an understanding of in-house standards and protocols, as well as how companies were managing the growth and spread of knowledge within the practices.

Interviewees from the management category within the companies were asked questions regarding in-house standards and protocols of which 66% responded yes that there were standards and protocols in place, but that these were very much a work in progress and not always adhered to by staff. When the employees within the companies were asked a similar question regarding in-house standards and protocols, there was an uncertain response from many of the interviewees. 75% of the respondents were unsure if there were standards and protocols in place, or respondents were aware of some form of standardisation but did not know what this standard was. Interviewees from the employee level were asked if standards and protocols would be beneficial to the day-to-day tasks of the company, of which 100% of respondents agreed some form of structure is required in order to know what should be achieved.

Similarly, both management and employees were asked questions regarding strategies for building knowledge within the companies. Management discussed the availability of educational assistance to staff, as well as a continuous professional development (CPD) program within the offices. While these are in place one interviewee spoke about the need for more formal training as it was very much dependant at the moment on staff being self-driven to want to learn and upskill in the area of BIM. 50% of respondents from the employee level responded that there is an unawareness of any specific training plans regarding BIM, but that there is assistance available if desired. The remainder 50% agreed there was a form of training plan in place for individuals and this was covered within CPDs and within annual KPI reviews.

d) Ability

While looking at the ability section of the interviews, here an analysis of how companies action the previously studied area of knowledge was reviewed. With management the following topics were discussed; BIM implementation plans, change management strategies, provision of time and tools to learn new processes, and any changes in the output of work since the introduction of BIM to the offices. 66% of respondents stated that there was no BIM implementation plan within the office or that it was not something that was used. The mangers felt that this is something that would be beneficial to the company and that it needs to be made visible to all staff. Respondents also felt the implementation plan should cover BIM as a general topic and not just the information model.

In relation to a change management strategy each respondent covered this aspect differently. Respondent one felt that BIM was not a dramatic change to the company and therefore it had not been put through previous change management techniques. Respondent two felt that change management is a challenging aspect for smaller companies due to the need of recourses to manage it. Respondent two also felt that BIM very much introduced a social aspect in a manner whereby it requires the need to interact with others, as well as the cultural change aspect of BIM. There was a general feeling towards cultural change that difficulties are experienced with all aspects of it. The third respondent described change management as a work in progress. The shift from 2D to 3D within the office was a significant change that was probably not managed in the way it should have been, the interviewee felt that this may have been the case due to initial resistance from the management team when first introducing BIM processes.

When reviewing the questions asked at the employee level within the companies, the main focus was on the provision made for people who are changing daily work processes. All respondents at this level felt that the provision of CPD training was available to them, that the managers are aware of the competency level within the office regarding the new software, and that this is something that is taken account for within project planning as well as team structures. Two out of the four respondents often felt that a lot of the focus is about getting the modelling aspect of information right which does not always benefit the project. One respondent in this area felt that previously there was a safety net provided by management within the company, but that this seemed to no longer be evident something that can harvest anxiety within employees trying to learn new information.

e) Reinforcement

Within the reinforcement section of change, management interviewees were asked to identify the barriers which had been exposed within the company during the implementation of BIM. Within the pre-interviewee questionnaire, interviewees were asked to rank a list of identified industry barriers to BIM in order of importance Figure 4 below identifies the results from the pre-interview questionnaire. The most significant barrier identified was differences in expertise (13%), closely followed by no contractual framework for BIM (10%), and cost of implementation (10%).

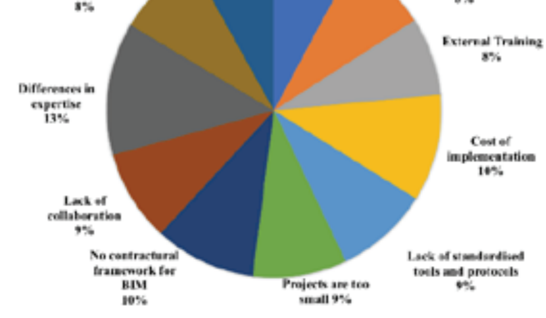

Fig 4: Significant barriers to BIM adoption in the Irish construction industry

Figure 5 highlights the personal barriers interviewees have experienced which were expressed during the interviewing process. The results from these questions have similarities with regard to lack of collaboration and time, but many of the responses highlighted by individuals differs from the barriers the industry is facing. The most significant barrier in this case, is time with 28% of respondents highlighting this as a personal barrier.

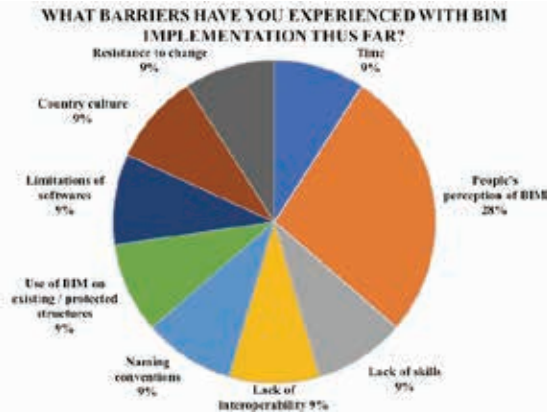

Figure 5: Personal barriers faced during BIM implementation

Interviewees were also asked to describe the valuable lessons which the companies have learnt through the introduction of BIM processes. 57% of respondents felt that the most valuable lesson learnt is the importance of the collaborative work environment which BIM has introduced. A number of interviewees expressed the reluctance to work with other consultants in the future who do not a least provide a 3D information model. 26% of respondents also took valuable lessons learnt from the less linear process concerning BIM. One interviewee described the process as "*everything is happening at once",* while another described the work that is currently going on within the industry as "*we are building at an exaggerating rate which is only made possible by BIM*". Other valuable lessons learnt described by interviewees included; the value in a 3D information model, federated site models and clash detection.

Finally, within reinforcement, it was essential to look at the way people were working on a day to day basis. Interviewees were asked if it was often easier to revert back to traditional work methods before the implementation of BIM when external pressures of time etc. were applied. Figure 6 below illustrates the findings from this, whereby 57% of responded yes, it is often easier to revert to traditional work methods.

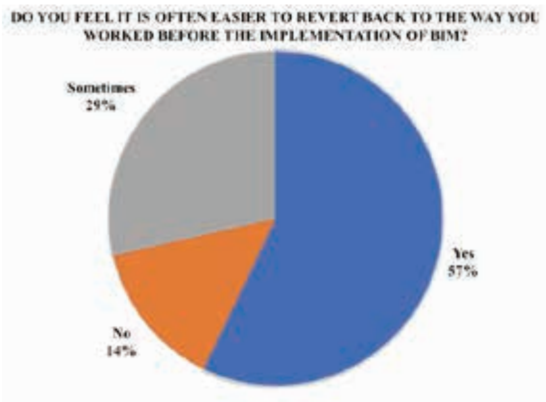

Figure 6: Interviewee likelihood to revert to traditional work methods.

V FINDINGS

Having analysed the findings of the semi-structured interviews and research into the area of change management methods. Figure 7 below represents fourteen key issues identified within twelve BIM implementation plans. These issues have been identified through a comparison study of implementation plans from three categories; software, academic, and AEC industry professionals [24]. Figure 7 also defines the stages covered by the Prosci ADKAR change management model which highlights the five key milestones an individual must achieve for change to be successful [23].

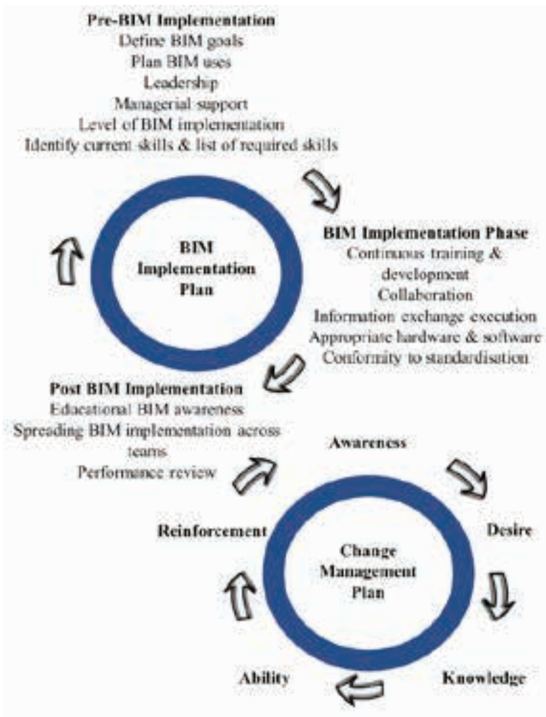

Figure 7: Identified stages of BIM implementation and change management

The findings of this research paper are represented in Figure 8 which represents a BIM adoption roadmap aligning change management methods with a BIM implementation plan.

Figure 8: BIM adoption roadmap aligning change management methods with a BIM implementation plan

VI Conclusions

Comparison between the literature review and the analysed data from the pre-interview questionnaire and semi-structured interviews provided initial direction on how companies are currently managing the implementation on BIM within AEC practices in Ireland. The data collected from the literature review identified some of the barriers to BIM which the industry is facing, and furthermore, the data collected during the interview process identified a different set of obstacles to which SME practices have been exposed. The literature review also identified the changes that BIM brings to a company such as the new roles and responsibilities identified within the BIM process. The interview process with AEC company stakeholders investigates these changes and how companies are managing change within the business. The consensus from the interviewing process resulted that generally, BIM is a significant change to the daily operation of a practice in Ireland and that it is a change that needs to be carefully managed to avoid resistance from both an organisational and individual perspective. Respondents felt that a BIM adoption roadmap that aligns change management methods with a BIM implementation plan could only benefit the transition period, by providing measurable milestones and allow for reflection on change.

Further research into BIM implementation and change management methods is necessary to resolve issues highlighted by the respondents regarding the management of a large-scale change such as BIM. Future work to trial the proposed roadmap will be necessary to show the benefits of delivering BIM with change management.

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A Critical Appraisal of the potential for public works contracts' and design-build Clients in Ireland to leverage benefits from BIM processes

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Abstract— The zeitgeist of the Irish Architecture, Engineering, Construction and Operations (AECO) Industry is digital construction and collaborative processes. However, Clients don't know what they want from BIM, and are confused about how to get what they need. This paper critically appraised the potential for public works contracts' Clients to leverage the benefits from BIM processes. Key stakeholders were interviewed to establish where possible barriers and issues arise in order to enhance Client engagement throughout the capital/ delivery and operations phase of the built asset. A Toolkit, derived from the Literature Review, was investigated by the interviewees. This detailed research resulted in 4 Key Insights: (1) Improved Education & a BIM online portal to be provided by the Government; (2) The urgent revision of GCCC/CWMF Public Works Contracts to include reference to BIM technologies, standards and processes, and include confirmation of Client ownership of the BIM Model; (3). A new role of Client BIM Consultant, to be included in the Mandate from Government; (4) The requirement of a BIM Mandate for Ireland in order to drive engagement. It is proposed that the implementation of the 4 Key Insights will enable Clients to leverage the benefits of BIM would result in better outcomes on Public Works, in the short, medium and long term for all Stakeholders.

Keywords—BIM; Benefits; Client; Engagement; Barriers; Solutions/Toolkit.

I INTRODUCTION

The zeitgeist of the Irish Architecture, Engineering, Construction and Operations (AECO) Industry is digital construction and collaborative processes. This industry has emerged from the worst recession in living memory and is currently undergoing the global transition towards an information revolution. BIM is a structured process which ensures a building is delivered as efficiently as possible and can drastically reduce the detritus prevalent in the Irish AECO Construction industry.

The Winfield Rock Report (Winfield & Rock, 2018) contests that innovation and change are critical to leverage radical efficiencies and improved productivity across the entire asset life-cycle. Building Information Modelling is at the heart of digitisation which is spearheading a transformation of the built environment, enabling the creation of a space where digital and physical assets interact (Philp, 2016.

This research will ascertain how to leverage the benefits of BIM for Clients on Capital Works Management Framework (CWMF) / Government Construction Committee Contract (GCCC) public works contracts and design-build contracts in Ireland. Would better Client engagement in BIM processes on public works and design build contracts in Ireland leverage benefits for the Client, Stakeholders and end-users of the built asset?

In the United Kingdom, despite the legal mandate of BIM Level 2 introduced in April 2016, a recent survey carried out by BIM+/CM found that 'only 38% of centrally-funded government clients made BIM a requirement on all of their projects' one year after the mandate for Level 2 BIM on public-funded projects was introduced (Chevin, 2017).

The major benefit of Building Information Modelling is that it enables us to build the building twice- once virtually, where all the clashes and construction issues can be resolved- and then flawlessly in the real world (Philp, 2016). This ensures cost savings, both in terms of accurate quantities, and projected operational savings. The BIM model can also facilitate enhanced safety during the construction phase and into the operations phase.

This research will critically investigate what barriers exist, if any, to Client engagement with BIM processes, and where and why they occur. Following in-depth analysis of these barriers, a set of solutions, referred to as a Toolkit, will be proposed for discussion with selected stakeholders of the AECO industry in Ireland. It is hoped that the Toolkit could assist with driving the adoption of BIM in Ireland. Due to time-constraints the research could not include longitudinal or cross-sectional analysis, however, previous research by professional bodies/ institutes and other reliable sources has been incorporated.

II & III Research Objectives & Aligned Methodology

- **Objective 1:** Critically appraise the current state of Client engagement with BIM processes on public works and design-build contracts in Ireland.

- **Research methodology:** Qualitative methodology comprising interviews with selected stakeholders of the AEC industry in Ireland including CitA BIM Information Capability Programme (BICP) researchers, in addition to critical assessment of the literature including existing publications and annual surveys by CitA, Engineers Ireland, RIAI and others.

- **Objective 2:** Critically examine the barriers to Client engagement in BIM processes and evaluate why these barriers occur.

- **Research methodology:** Interviews with stakeholders and critical analysis of the literature.

- **Objective 3:** Perform a gap-analysis between BIM process requirements from Clients and Clients current ability to engage, with particular emphasis on the Organisation Information Requirements (OIR) Asset information Requirements (AIR), Employer's Information Requirements (EIR) and BIM Execution Plan (BEP).

- **Research methodology:** Structured interviews with various stakeholders of public works contracts in Ireland: including advocates/ proponents and opponents of BIM technologies on public works and design-build contracts, and synthesis with existing publications and journals.

- **Objective 4:** Propose a definitive set of solutions, or Toolkit, for better Client engagement in BIM processes on public works and design-build contracts in Ireland.

- **Research methodology:** Thorough critical assessment all previous findings.

- **Objective 5:** Evaluate the set of solutions suggested to enable better Client engagement in BIM processes on public works contracts in Ireland to enable the maximum benefits of BIM to be leveraged by the Client.

- **Research methodology:** Evaluate with each of the interviewees the proposed set of solutions, the Toolkit, for leveraging the maximum benefits of BIM for the Client on public works contracts in Ireland.

IV Literature Review

The scope of published research in the area of Client engagement in BIM processes is limited in an Irish context, and research from other countries where BIM is more established will be employed.

Eadie, Browne, Odeyinka, McKeown, & McNiff, (2013) suggest that substantial impacts may be achieved through BIM implementation throughout all stages of the construction process. Murphy (2018) contends that it is only in last 12 or 18 months that there has been any real engagement (by Clients in BIM) "without them fully understanding what it is about". Ghaffarianhoseini et al., (2017) suggest that despite major technical advancements in BIM, it has not been fully adopted and industry stakeholders have not fully capitalised its definitive benefits. The lack of widespread uptake of BIM appears to be linked to risks and challenges that are potentially impeding its effectiveness (Ghaffarianhoseini et al., 2017). These risks and challenges will be discussed in the Barriers section of the paper, and also evaluated in the qualitative analysis section.

Despite the introduction of the Digital Strategy 2021 (2017) Ireland has yet to mandate BIM, and BIM adoption rate in the AEC sector is relatively slow. A Public Sector BIM Adoption Strategy questionnaire was recently circulated to relevant stakeholders in the Irish AEC industry by the Office of Government Procurement. One of the questions posed requested the respondent to outline the obstacles that exist to the successful adoption of BIM in the construction sector. Clients need to be convinced of the benefits of BIM, but Guthrie attests that "clients still do not understand what they are asking for or what BIM is. The majority don't have any idea and basically see BIM as a cost" (Chevin, 2017).

In Ireland, the Digital Roadmap 2021 (Irish Government, 2017) aspires to attain a 20% reduction in the initial cost of construction and the whole life cost of built assets, 20% reduction in the overall project delivery time, 20% increase in construction exports. BIM is an integral part of achieving these goals, and these benefits would apply to Clients on public works contracts in Ireland.

Fig. 1: NBC Digital Roadmap 2021 Key Performance Targets. These indicate the benefits from digital construction and BIM.

Wong & Fan (2013) assert that the pursuit of sustainability has become a mainstream building design objective. Building information modelling (BIM) has the potential to aid designers to select the right type of materials during the early design stage and to make vital decisions that have great impacts on the life cycle of sustainable buildings (Jalaei & Jrade, 2015). In regard to Health and Safety, (Wetzel & Thabet, 2015) suggest a BIM-based framework to support safe maintenance and repair practices during the facility management phase, through safety attribute identification/classification, data processing and rule-based decision making, and a user interface. This is a major benefit to the Client on public works contracts as the necessary parameters for sustainability, energy-rating and lean construction can be embedded in the BIM model, and this ensures compliance with the relevant statutory legislation.

Clients also benefit from early synchronization of designs, synchronization of design with construction, and enhanced building performance through analysis/simulation resulting in the delivery of comprehensive data at project completion. BIM enables improved outcomes to public sector Clients providing buildings better aligned to the Client's needs, and the company's image/brand, which are built quicker and cheaper. However, the most important benefit to the Client is certainty, because collaborative BIM results in reduced risks to the Client (Montague, Slattery, Mockler, & Adlem, 2015). Collaborative working results in minimal re-working, as clashes are identified and resolved within the federated model, saving both time and cost and reducing waste. In addition, integrating the management of information across the longer term activity of asset management with the shorter term activity of asset construction for a portfolio of assets should deliver real savings (BSI, 2014).

Mcauley, Hore, Kane, & Fraser, (2015) suggest that a more collaborative approach to the public works contract in Ireland is required. Roberts, Blundell, Dartnell, & Poynter-Brown, (2016) suggest that collaborative working is not merely a vehicle for cost reduction, but more significantly, a structured means of enhancing team performance and value-added returns from investment in construction. (Eadie et al., 2013) contend that collaboration aspects of BIM produce the highest positive impact, and suggest that the process aspects are more important than the software technology. The federated BIM model becomes an as-built Asset Information Model following handover, which, if maintained, will provide an invaluable tool for the operational phase and throughout the lifecycle of the built asset.

Why then, are Clients not insisting on BIM? (Moore, 2015) contended that education is needed for clients to better know their requirements, and for them to demand that projects are completed to a BIM standard. The Transformative Power of BIM (Gerbert, P., Castagnino, S., Rothballer, C., 2016) identifies the significant savings to be realised from digitisation, and the Boston Consulting Group Report (2016) identifies that full-scale digitisation of construction projects could lead to cost savings of 13-21% in the design, engineering and construction phase, and 10-17% in the operations phase. However, a possible barrier to Client engagement in BIM may be that there is no clarification of who is making these savings? Is it the Client, the contractor, the design Team or the end-users? The Client ultimately wants to know how he/she will directly benefit by employing digital construction and BIM.

Another barrier may be that Client does not adequately identify what they are looking for in the OIR, AIR, EIR and BEP. The Organisation Information Requirements (OIR) relate to the entire portfolio a large Client may have, and is a document which should set out what is required at a strategic level for all of the assets e.g. sustainability, LEED rating, carbon footprint etc. The Asset information Requirements (AIR) relate to the specific single building or asset the Client wants to build, and will include the design brief. Both of these documents are incorporated into the Employer's Information Requirements (EIR), which then informs the BIM Execution Plan (BEP). The EIR is a very important document, and Clients need professional advice to draft this document to ensure all their requirements are met. Montague (2017) asserts that the independent and impartial advice of a BIM consultant on a project, can significantly assist client organisations who do not have the knowledge and skills to properly ask for BIM, to defend or counter any reasons they are given not to use BIM, or to know that what they are receiving is a proper BIM service. (Wallbank, 2015) contends that the appointment of an Information Manager should take place on all Level 2 BIM contracts, and this appointment is often taken as an additional responsibility for an existing contributor (usually the Lead Designer or Architect) rather than a separate consultant. (Mathews, 2015) suggests that additional roles for the BIM process may be required, and this Capstone will ascertain whether a new BIM Information Consultant role, directly appointed by the Client, working exclusively on behalf of the Client and independent from the design team, will enhance the BIM process and drive significant improved outcomes for the Client on a large public works contract in Ireland.

The GCCC CWMF Public Works Contracts

There are ten forms of Contract for Public Works, each for different purposes: PW-CF1 up to PW-CF10 (*Capital Works Management Framework Guidance Note Introduction to the Capital Works Management Framework GN 1.0 2 Introduction to the Capital Works Management Framework Document*, 2009). These contracts are prepared by the Government Contracts Committee for Construction (GCCC). PW-CF1 relates to Building Works designed by the Employer, and uses the Traditional Contract type. PW-CF2 relates to Building Works designed by the Contractor, and uses the Design-Build Contract type. These are the contracts pertinent to this Paper.

The development of the Construction Works Management Framework (CWMF) was introduced expressly to reform construction procurement in the public sector. The strategic objectives of that decision were: Greater cost certainty at contract award; Value for money; More efficient delivery of projects; To ensure as far as practicable that the accepted tender prices and the final outturn costs are the same; and to allocate risk so that there is optimal transfer of risk to the Contractor. The public works contracts are fixed price contracts, where the risks of added costs (e.g. inflation, costs of materials or labour etc.) is borne by the Contractor. In Design/Build & PPP projects, BIM will help support early contractor engagement to help influence the long-term asset management, through better information and analysis.

The Public Works Contracts make no reference to BIM. The Public Works Contracts are structured in a way that means they cannot be amended at all, and nothing can be added to them. In practice, the CIC BIM Protocol is attached to the Public Works Contracts for projects requiring Level 2 BIM, but there is no direct reference to BIM in any of the actual contract documents. The Office of Government Procurement is currently reviewing the contracts in relation to their BIM Strategy, however, they have not made any announcements or publications in this regard.

The Digital Strategy was written to inform the Irish Government but has not yet been officially adopted as yet by any Department, which means that it has not been funded. Therefore, the target actions set out in the plan have not been achieved.

V QUALITATIVE ANALYSIS & SYNTHESIS OF INTERVIEW FINDINGS

In order to ascertain the current 'real world' situation, a number of structured one-to-one interviews were completed. These interviews included clients, architects, main contractors, and stakeholders specifically chosen to obtain a 'fully rounded' picture of client engagement in BIM processes on various PPP and design-build projects. Many of the interviewees worked together on the same projects but in different roles, and were specifically chosen so that the findings would reflect different perspectives of BIM on the same project. In this way a 'rounded' investigation of the barriers, gaps and issues were explored, and the Toolkit, or set of proposed solutions, which had been derived from the Literature Review could be evaluated and interrogated by each interviewee. In this way the final proposed Toolkit would propose tangible solutions for leveraging the benefit of BIM for Clients on public works and design-build contracts. All interviewees were anonymised in order to protect both their identity and confidentiality. Each interviewee was presented with the same questions relating to the objectives of the research, and some additional questions tailored specifically to each interviewee. The proposed Toolkit, which had been derived from the Literature Review, was also provided in advance of the interviews to allow the interviewee to prepare and with the intention of garnering valuable insight into current commercial practices. Fourth generation analysis (Guba & Lincoln, 1989) was also employed with all interviewees asked to comment on pertinent findings (anonymous) from previous interviews.

The interviewees were as follows:

1. BIM Manager 1: A BIM Manager and Project Architect at one of the leading main contractors that actively uses BIM on projects.
2. Architect 1: A Company Associate Architect and Software Developer at a major design office that actively uses BIM.
3. BIM Manager 2: A BIM/ Information Manager at major Government Mixed Use Development Agency.
4. Solicitor 1: A senior solicitor specialising in Irish Construction Law.
5. Client 1: A Sector Head & Development Director, PPP Programme Manager at a Government Development Agency.
6. Client 2: Head of Capital Projects & Planning of a Major Government Campus.
7. FM Consultant 1: A Director of Property and Facilities Management Agency.
8. Architect 2: An experienced architect from a city Local Authority.
9. BIM Manager 3: Digital Construction Manager at a Tier 1 main contractor that actively use BIM.

In addition, David Philp was interviewed in order to gain insight into what Ireland can learn from the British experience of BIM implementation and engagement. David Philp is Global BIM/IM Director of Construction Institute of Building (CIOB) and a high-profile advocate of BIM.

It proved a Sisyphean task to get responses from the proposed interviewees for a ‘negative’ perspective i.e. a client who does not want, or refuses, to engage in BIM processes. The author has been told anecdotally that there is resistance, but found no-one willing to speak against the corporate stance of ‘we are a progressive company/body engaging in modern digital procurement processes’.

As outlined in the Literature Review, Architect 1, Client 1, BIM Manager 1 and Client 2 identified the fact that the Public Works Contracts make no reference to BIM. In practice, the CIC BIM Protocol is attached to the Public Works Contracts for projects requiring Level 2 BIM. However, Architect 1, Client 1, BIM Manager 1, and Client 2, agreed that this issue should be addressed, and that all the Public Works Contracts should be revised immediately to include refences to BIM technologies, processes and standards.

a) Barriers: BIM Term & Definition.

BIM Manager 3, a Digital Construction Manager at a Tier 1 main contractor that actively use BIM, asserted that “the biggest single mistake was the inclusion of the term Building Information Modelling in terms of the PAS, because this has misled people. If I was walking around, waving that document and it didn’t mention Building Information Modelling, people might realise that this is about documentation”. The Mayfield Rock Report (Winfield & Rock, 2018) contends that all the BIM experts interviewed gave a different definition of BIM, and no two people gave the same response. This means there is still no standardised definition of BIM Level 2, and definitions can vary from project to project. However, one can define the 9 pillars of BIM Level 2:

1. PAS 1192-2
2. PAS 1192-3
3. BS 1192-4
4. PAS 1192-5
5. PAS 1192-6
6. Government Soft Landings
7. Digital Plan of Work
8. Classification (Uniclass 2015)
9. CIC BIM Protocol

Packham (2018) suggests that BIM as meaning ‘Building Information Management’ or ‘Better Information Management’ is a better definition for what the “true purpose of BIM” actually is. In a recent UK report, British Institute of Facilities Management (BIFM) ‘Awareness of BIM’ survey (August 2017), two-thirds of respondents reported that they had either none, or very little knowledge or involvement, in BIM.

BIM Manager 3 asserts that “BIM is how you deal with your information- The Holy Trinity: the graphical model, the non-graphical model, and documentation”.

b) Barriers: Clients are not clear in defining what they need from the process.

BIM Manager 3 contended that it is only in last 12 or 18 months that there has been any real engagement (by Clients) “without them fully understanding what it is about”. FM Consultant 1 concurred suggesting “We are definitely seeing more clients ask for it [BIM]: some are closer to it; other have it as almost a tick-box requirement and may outsource the delivery of it to others. And that has its challenges". He also advised "as with anything that is new, there is an element of resistance to change; lack of understanding; a hesitancy".

Although it is widely purported that BIM technologies and processes ensure greater certainty and reduced risk to the Client (Montague et al, 2015), FM Consultant 1 suggested that many Clients query who is making that saving: "Who is making those savings? [through using BIM processes]? In the construction phase, if there is a 10% saving, who is making that? Is it being shared among the participants, including the Client?" He further contended that Clients ultimately ask "What's in it for me?". In relation to the significant savings from full-scale digitisation (Gerbert, P., Castagnino, S., Rothballer, C., 2016), FM Consultant 1 questioned "In the post-construction/ operations phase, if there is a 10-15% saving, who is making that? Usually, the saving will be derived by the occupiers, [and] it is not a direct benefit to the client".

Packman, P. (2018), Client 2, and BIM Manager 3, concur that BIM provides us with the opportunity to define the Asset information requirements from the outset, so that the required information is available in the prescribed format immediately on moving to the operational phase.

BIM Manager 3 also asserts that Clients have yet to understand how to get the most out of the AIM. He also asserted that what Clients are looking for when requesting BIM is quite "ambiguous" and "in terms of asset handover, it is still very vague". He then explained that the FM team were "very concerned in best maintaining these [educational] buildings for 25 years, whilst working within the contract, which had some very specific [financial] penalties in it….There would be very severe financial penalties for every hour that that [teaching] room is unavailable".

In order to resolve this, and with agreement of the Client, BIM Manager 3 suggested how their FM team approached how the information in the BIM Model would be identified and tagged in order to prevent penalties accruing: "We started grading assets, using the principles of Part 3 [PAS 1192-3]. A Category 1 asset would be something that could cause a cluster of rooms to be unavailable. Category 2 would apply to lesser assets, and so on".

Client 2 contended that clients only care about the operations phase of the building, and need their information formatted in terms of (i) repairability, (ii) replaceability and (iii) upgradability. Client 2 further asserts that this is where a major 'gap' exists, because design teams are concerned with gathering the COBie information in the models, whereas, the information required for operations is currently stored in a way that is not useful.

In terms of the supply chain, Philp (D., Philp, personal communication, 19th September 2018) attests that product manufacturers have a major role to play in removing one of the barriers to the adoption of BIM by providing digital representation for their products with classification to facilitate providing the "right object, with the right level of detail at the right time". The Construction Products Association is driving this agenda by setting up BIM for Manufacturers to enhance engagement in that sector (Philp, 2018).

Client 2 attested that BIM was demystified by the UK Government strategy in driving BIM adoption because "it was approached from a cultural and not a technical perspective; there was an understanding that a 'cultural' change was required". It is suggested that Irish Government need to adopt a similar approach in driving the Roadmap to Digital Transition 2018-2021 (NBC, 2018).

It was suggested by Client 2, that many contracting authorities who do not fully appreciate the benefits of BIM, and there is little empirical evidence to show these benefits either. He further contended that "All we [contracting authorities] can do is say that it 'must surely' be beneficial. This makes the argument weak, and I think the communication [of the benefits of BIM processes] is already poor, making the argument even weaker"

Other Benefits of BIM:

Montague et al (2015), BIM Manager 1, BIM Manager 2, BIM Manager 3, Client2 and Architect 1 propound clash detection as one of the major benefits of BIM. Architect 1 purported: "In terms of clash detection, we had little or no clashes (at construction phase), and that is the experience we are getting from other projects".

The use of 3D modelling within BIM processes enables efficient and effective exploitation of the full benefits of the information measured in a point cloud survey. Architect 1, affirmed that a point cloud survey of the site was completed, including "the buildings adjacent to the new build we were doing, and the existing buildings to be demolished (surveyed) to a certain level of detail…more than sufficient to generate sections, elevations that were very accurate for planning".

The Client & the BIM Model- contractor benefit

Solicitor 1 contended that a number of main contractors sell the BIM model to their clients as a value-add in order to give them a competitive advantage at Tender Stage. BIM Manager 1, concurred that many contractors generate a BIM model even when not required on a project, because of the all the benefits of BIM- clash detection, quantification, sequencing etc.

Architect 2 revealed what can happen when clients do not use BIM on public works contracts. He cited examples of where the main contractor took the tender drawings and, either in-house or using external specialists, generated a BIM model of the proposed development specifically to identify where the clashes would be so that additional extras could be claimed during the project.

The advantage of having the BIM model generated also allows the contractor to derive accurate quantities and enables an accurate tender price to be furnished, or one which allows a significant profit margin. The contractor also can use the BIM model to schedule work packages and site logistics, again major advantages on fixed price contract. BIM Manager 1, BIM Manager 3 and Architect 2 all attested to this.

Architect 1 purported that “contractors are claiming for everything they can on public works contracts”. The GCCC Contracts assume everything is designed when the project goes to Tender. Client-led changes after Tender are easy targets for claims, in addition to unforeseen delays due to unforeseen site conditions, and delays in the programme which the contractor cannot control, all enable the contractor to submit financial claims. Errors or omissions in information can be curtailed if the client’s designers can provide information in a timely manner as part of the standardised RFI process.

VI Toolkit/ Set of Solutions

a) Toolkit Suggestion 1: Clarification that Client owns the BIM model throughout the entire process

The first Toolkit proposal is that written contractual clarification that the Client owns the BIM model be included in the contract documents. This would be subject to Copyright law, throughout the entire process of design, tender, construction, and consultancy procurement, and continue through the operations phase for the entire lifecycle of the building. Current practice means that the Client gets access to the models at Data-drop stages, but direct access can prove challenging between these stages. This is a situation that the author, who is Project Information Manager and BIM Manager on a large design-build multi-use headquarters for a semi-state body, personally experienced during a lengthy construction phase.

The literature analysis states that the Client owns the model and Solicitor 1 asserted that, subject to usual copyright, this is already the case in terms of the legal perspective. Solicitor 1 also contended that the copyright issue remains the same for traditional processes as for BIM processes. However, the author has experienced instances where members of the design team refuse to share the .RVT BIM model with the Fit-out design team. This lead to protracted delays using the incompatible .IFC model, and subsequently resulted in the .RVT model being shared, subject to onerous caveats. This situation would have been avoided if this was clearly identified as a separate clause in the contract documents.

Both BIM Manager 2, and Client 2, contended that difficulties exist in accessing specific details of a (BIM) building from the design team model originators. BIM Manager 1 and Client 2, discussed multiple instances where members of the design team refused to share BIM building details when requested to do so by the Client during the operations phase, claiming that these details were subject to copyright. Client 2 also cited an example of where a Client wanted to extend a building, and employed a different architect to design the new extension using the previous BIM model. He then required waterproofing details that were employed for the first phase in order to ensure consistency of construction. However, the previous architect refused to share the details, claiming it is subject to copyright. Client 2 also cited an example of where a Client wanted to insert a new door in an existing wall, and wanted to employ the same architectural details for the architrave and shadow gap, however, the architect claimed this was their ‘signature’ trademark design detail, and subject to copyright, and would not provide the pertaining details.

In an attempt to overcome this obstacle, or barrier to the BIM process, BIM Manager 2, now inserts a specific clause in the public works contract forms specifically to ensure that the Client ‘owns’ the model and all associated details, and the associated copyright. Client 2 also employs a similar clause in contract documents following previous difficulties with the design team refusing to share details claiming copyright constraints.

One of the reasons often mooted by the Design Team is the issue of copyright of the models. One of the changes in the revised (April 2018) CIC BIM Protocol (*Construction Industry Council,* 2018) relates to the copyright provisions, which are now more flexible. It states in Clauses 6.2-6.4 that the Project Team member retains copyright ownership and grants a licence, and that this only applies if the Agreement contains no provisions regarding intellectual property; if the Agreement contains such provisions, they will apply to the Material. This means that the Protocol can be used (unamended) even if the Project Team Member will not retain ownership of its intellectual property, because it will be transferred to the Employer. If ownership of the intellectual property in the Specified Information is being transferred to the Employer, the Agreement should make clear if there is any "background intellectual property" which the Project Team Member will retain ownership of (e.g. information model objects).

Solicitor 1 advised, in response to anonymous feedback from another interviewee, that the principle that the author, or originator of a piece of information (such as a model of drawing), is responsible and liable for that content and quality still applies (Ref: EU BIM Task Group page 74). Solicitor 1 contended that there have always been disputes as to who is responsible for inaccurate information. It is to be hoped that the more widespread use of digital tools in the future will make it clearer and easier to identify the responsible party.

In terms of Collaboration, and how the design team share information and models, Client 1, suggested "It is all about digitisation, the flow of information, but what is really difficult to crack, when the Design Team are working together, is the collaboration piece". Collaborative working is a fundamental part of BIM processes and workflows on projects. Solicitor 1 asserted that it is imperative that each party signs the CIC BIM Protocol individually. He also contended that it is not "safe" to "assume that by agreeing to comply with the EIR and BEP that any party could be taken to have signed up to the CIC BIM Protocol". He suggested that this is because the CIC BIM Protocol sets out important clauses in relation to how the parties are to work together, and the safest course is to ask each of the parties to sign the CIC BIM Protocol at the same time as the Agreement. Current practice suggests that the separate signing of the BIM Protocol does not always occur, particularly when sub-contractors are appointed. This should be mandatory and should be expressly stated in the contract documents.

There are numerous references in the literature to the term 'Building Information Modelling' itself being a barrier to BIM adoption. This contention was supported by the interviewees. Client 2 and BIM Manager 3 concurred with Packham. (2018) who suggests that BIM as meaning 'Building Information Management' or 'Better Information Management' is a better definition for what the "true purpose of BIM" actually is. In a recent UK report, BIFM 'Awareness of BIM' survey (August 2017), two-thirds of respondents reported that they had either none, or very little knowledge or involvement in BIM.

Packman (2018), Client 2, and BIM Manager 3, concur that BIM provides us with the opportunity to define the Asset information requirements from the outset, so that the required information is available in the prescribed format immediately on moving to the operational phase.

Philp (2018) attests that product manufacturers also have a major role to play in removing one of the barriers to the adoption of BIM by providing digital representation for their products with classification to facilitate providing the "right object, with the right level of detail at the right time". Philp (2018) contended that the Construction Products Association is driving this agenda by setting up BIM for Manufacturers to enhance engagement in that sector.

b) Toolkit Suggestion 2: Better Education including on-line portal

The second Toolkit suggestion is for better education of the benefits of BIM for Clients through an online portal similar to the UK's Digital Built Britain or Scotland's Scottish Futures Trust. In addition, easily-accessible information, backed up with real-life BIM exemplars, showing how the BIM model reduced cost, waste and improved processes throughout the construction/ life-cycle, in addition to showing ROIs and reduction in waste etc.

BIM Manager 3 asserted that a major barrier is the lack of education, "Clients don't yet understand what BIM is".

Architect 1, a senior architect at a major design office that actively uses BIM, attested that "Education for Clients is the biggest barrier at the moment- it's the same in the UK. Some are up to speed, some are not. The Client has to define the rules at the beginning (for the project) to stay on track", and proports that lack of education "stops the Client getting what they want from BIM, at the end of the day".

Client 1 purported that the [AECO] industry and client groups need to converge on a best practice way to do BIM. He further attested that "When you stand back and look at things from the client's viewpoint, they want the service from the industry, [to provide] the school, the hospital or whatever, and BIM is really how the industry should be organising itself. To me [client] this is a supply-side process. It is about using digital processes and collaborating more together".

Client 2 suggested that "one of the 'barriers' to Client engagement is the language used in the EIR, which is over-complicated, and needs to be simplified using 'plain english' and simplified technological terms". However, as the EIR is project specific, this Client may be referring to an EIR produced by the Lead Designer or contractor. Thus, this perception that EIRs included difficult terminology may be misguided, and better BIM education for this Client may resolve this issue, or the new role of Client BIM Consultant who would ensure that the Client was getting what he/she requires in the EIR.

Philp (2018) "totally" concurs that the lack of education is a major barrier, and purports that education is required for new entrants, with upskilling for those embedded within the construction industry. Philp (2018) asserts that the focus should be on information management and data science before developing skills around the tools, and contends that academia has been slow to reshape undergraduate courses, which should "respond better to industry needs", but, conceded that MSc and post-graduate courses are "good".

c) Toolkit Suggestion 3: new role of Client BIM Consultant

This Toolkit suggestion involves the establishment of a new specialised Client BIM Consultant, appointed by the Client, and working solely for the Client, to ensure that BIM processes and standards are applied correctly throughout the project, and on into the Operations phase of a building. Matthews (2015) suggests that new roles will be required for BIM technologies and processes, and are constantly evolving as digital construction develops. Mady (2017) suggests a new role of a Life Cycle Engineer for the operations phase, as digital technologies and BIM drive changes in the Operations and Facility management phase. Client 1 suggested that "When you talk about BIM, the Client should really only be saying I want the output at the end". Clients, especially large corporate clients with multiple portfolios do not have the time to get involved in gaining a detailed insight into how BIM procurement works, and want to leave this to the Design Team and the other professionals they have appointed. Client 1 also maintained "I do not want to tell an Architect or other professional how to do his/her job". BIM Manager 3, who works for a leading main contractor actively using BIM, contended that it is only in last 12 or 18 months that there has been any real engagement (by Clients) "without them fully understanding what it is about". He further suggested that when a Client engages professions for the Design Team "Should a Client not have an expectation that you [as an architect] will deliver the best building in the best way humanly possible now [using BIM]?". The new role of Client BIM Consultant would work only for the Client and independently of the Design Team. This role would ensure representation of the Client throughout the process, and ensure that what the Client needs to be getting from the BIM Model will be met.

BIM Manager 3, concurred with this proposed new role, describing it as "absolutely necessary", and suggested that this role could also be carried out by the Employer's Representative (ER), but agreed that currently that role is "generally conflicted. Clients think that making the ER part of the design team is good for them, but it is actually not".

Architect 1, an architect at a major design practice actively using BIM, contended that a specialised Client BIM Consultant would be very beneficial "someone who is independent, who can spend a couple of hours initially advising them and then reviewing the information say to them this is what that means, so that they can tailor it to suit their (client) needs... Also, for checking (the information) throughout the project". He further suggested "If I was a client, I would get the advice (of a BIM Consultant) in the beginning to help me set up the information (required), and then keep that company on board to assess the information that is being provided". Client 2, who works for a university estates management department, and BIM Manager 1, who works for a leading main contractor actively using BIM, also concurred that this new role is required.

BIM Manager 3 asserted that what Clients are looking for when requesting BIM is quite "ambiguous" and "in terms of asset handover, it is still very vague". Client 1 suggested that "The client should only be involved at the Output [Handover] stage, and not have to get involved in COBie, Data-Drops etc". However, as the Client needs to be involved to approve the information at the Data-drop stages, this can be resolved by the Toolkit suggestion of a proposed new role of Client BIM Consultant. This will ensure that the information provided by the design team is correct, and that the Level of Definition (Level of Model Detail and Level of Information) is correct for that stage. It will ensure the Client is being represented throughout the process, and will get the information he/she requires, in the correct format and at the right time for the Operations phase of the building.

Client 2 suggested that "one of the 'barriers' to Client engagement is the language used in the EIR, which is over-complicated, and needs to be simplified using 'plain english' and simplified technological terms". However, as the EIR is project specific, this Client may be referring to an EIR produced by the Lead Designer or contractor, and therefore, it is proposed that this Client would benefit from having a Client BIM Consultant who would explain what is required, and act of their behalf throughout the entire procurement of the building.

BIM Manager 3 also suggested that the Professional Institutes are not tackling this [lack of education] properly should be providing education in BIM similarly to how they dealt with BCAR. The Professional Institutes (Royal Institute of Architects of Ireland, Institute of Engineers of Ireland, and Society of Chartered Surveyors of Ireland etc.) will need to provide new CPD courses to upskill existing professionals to take on the new role of Client BIM Consultant.

c) Toolkit Suggestion 4: Is an Irish BIM Mandate required?

Whilst the Irish Government Roadmap to Digital Strategy 2018-2021 stops short of being a mandate, Philp (2018) suggests that the provision of a mandate in the UK, "helped accelerate industry adoption and build an apposite pipeline for industry to respond to and invest in" e.g. BIM technologies and training.

Philp (2018) asserts that a strong policy level would "focus client engagement" along with the creation of communities of client practice: UK Public Sector working group, and Scotland Procurers BIM working group. Similar working groups should be established in Ireland to drive Client BIM engagement. Philp (2018) purports that simple KPIs to measure BIM readiness amongst clients would be another measure that Ireland should adopt from the UK experience.

Client 2 attested that BIM was demystified by the UK Government strategy in driving BIM adoption because "it was approached from a cultural and not a technical perspective; there was an understanding that a 'cultural' change was required". It is suggested that Irish Government need to adopt a similar approach in driving the Roadmap to Digital Transition 2018-2021 (NBC, 2018).

VII CONCLUSIONS & RECOMMENDATIONS

In conclusion, and on reflection of synthesis of the outcomes of the Qualitative Analysis and the findings of the Literature Review, a number of Insights/Recommendations were derived and are hereby proposed:

Insight No.1: GCCC CWMF Contracts need to be revised to refer to BIM and to include clarification of Client ownership of the Model

The GCCC CWMF Contracts need to be revised to include reference to BIM technologies, standards and processes, and to confirm BIM Model ownership by the Client. This is required because of the difficulties the Client often has in accessing BIM Models mid-stage (e.g. construction stage which is a lengthy phase between Data Drops). It is also required because of difficulties Client 1, who works for a national government development agency, and BIM Manager 1, who works for a university development agency actively using BIM, expressed in accessing the BIM Model when subsequent extensions or alterations to the building were being carried out, and the authors of the BIM Model claimed copyright of the details, and refused access. Although, the revised CIC BIM Protocol has improved the copyright position, however, this has not been fully tested legally, and as the GCCC and CWMF Contracts make no reference to BIM, the legal position may be open to interpretation.

Insight No.2: Helping Clients get what they want from BIM – BIM Online Portal

Insight No. 1 is that Clients need better education, through the Toolkit suggestion of the dedicated BIM Online Portal. It is critical that this BIM Online Portal is engaging and easy to use and provides Key Performance Indicators (KPIs) and real-life examples of cost efficiencies garnered through the use of BIM technologies, processes and standards. On reflection, it is essential that this is multi-disciplinary, and is hosted by an Irish Government Agency, as from the findings the Government needs to drive BIM as an efficient method of digital construction procurement (refer also to Insight No.4).

Insight No.3: Helping Clients get what they need from BIM- New Client BIM Consultant Role

This new role of Client BIM Consultant will assist the Client in obtaining what they need from the BIM process in term of outputs. The Client BIM Consultant will be an independent appointment, separate to the Design Team, to assist the Client to create the EIR and BEP, and will ensure the Client is being represented throughout the process, and will get the correct information, at the right time and in the right format throughout the entire procurement of the building, at handover, and into the Operations phase of the building. Clients are very busy, as attested to by Clients 1 and 2, and BIM Managers 1 and 3, and expect their Design Team to deliver the building to the best of their professional ability. The Client BIM Consultant will have the deep sectoral knowledge to provide an 'overview' checking of the information being provided by the Design Team, ensure that the correct BIM standards and processes are being followed, and ensure that the correct information is in the models, at the correct time, and in a manner that the Client and End-user want. This information varies from project to project. This new role could be attached to the BIM Mandate, issued from the Office of Government Procurement (refer Insight No.4).

Insight No.4: A BIM Mandate for Ireland is required

Whilst the Irish Government Roadmap to Digital Strategy 2018-2021 stops short of being a mandate, Philp (2018) suggests that the provision of a mandate in the UK, "helped accelerate industry adoption and build an apposite pipeline for industry to respond to and invest in e.g. BIM technologies and training. Philp (2018) also suggests that the lack of an Irish mandate "will create different tiers in the industry and the building of capability will be slower". The Digital Strategy 2021 is not on programme. A BIM Mandate for Ireland would greatly assist in driving engagement in BIM.

In terms of future work, additional legal investigation should be completed regarding the use of the existing CIC BIM Protocol with revised Irish Public Works contracts, and whether a separate Irish BIM Protocol should be drafted. The professional bodies, (RIAI, IEI, SCSI etc.) should investigate how they can assist the sector with BIM engagement, and upskilling of existing professionals. Additional investigation is required of how adjustments can be made to the requirement for full design information at tender stage, which is often then subject to client-led changes resulting in abortive work.

In conclusion, following the critical appraisal of the potential for public works contracts', and design-build Clients to leverage the benefits from BIM processes, it is proposed that the implementation of these 4 Insights would result in better outcomes on Public Works, in the short, medium and long term.

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An investigation into current procurement strategies that promote collaboration through early contractor involvement with regards to their suitability for Irish public work projects

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Abstract – Previous research has established that multi-disciplinary collaboration will benefit a construction project throughout its lifecycle. While Lean Construction, Building Information Modelling (BIM), and Integrated Project Delivery (IPD) can all be viewed as separate processes which add independent value to a project, they are more effective when used in partnership with each other. In order to ensure the high levels of collaboration expected for these processes to work in unison, the early involvement of the Contractor is paramount. Early contractor involvement within the design process can ensure a more focused integrated project team, improvement of both constructability and cost certainty, as well as better risk management. This approach has only been used occasionally on Irish public works projects. Competitive tendering has resulted in creating a culture of claims and adversity, not conducive to collaboration and therefore raising the question, is the traditional procurement format representing value for money for the Irish State.

This paper will investigate current procurement strategies that promote early contractor involvement and their suitability for Irish public works projects. The research will primarily focus on contracts that are best aligned to the Capital Works Management Framework (CWMF) strategic objectives of ensuring greater cost certainty, better value for money and more efficient end-user delivery. To achieve this an initial literature review was undertaken exploring award criteria for early Contractor involvement both within the International and Irish public and private sectors. This research focused on establishing and examining the potential barriers for implementation. The analysed data from this process was interrogated through Stakeholders interviews that aimed to understand the current state of the public work project procurement process and if government agencies would endorse a move away from the "lowest bid win" criteria for contractor selection. A case study was also carried out showcasing a form of IPD used in Ireland. The findings from this paper suggest that early contractor involvement in partnership with IPD can provide a more advantageous solution for the Irish State while also promoting both BIM and Lean Construction processes.

Keywords – Early Contractor Involvement (ECI), Building Information Modelling (BIM), Lean Construction, Integrated Project Delivery (IPD), Public Work Contracts, Procurement.

I Introduction

Reports such as the National BIM Council Roadmap to Digital Transition for Ireland's Construction Industry 2018-2021 warns about the risk of the digital transition stalling if more collaborative ways of working together are not found [1]. Collaboration is fundamental to the BIM process and the fragmentation and adversarial nature of the industry must end if the potential of BIM is to be fully realised [2, 3]

Current procurement methods are seen as one of the barriers to collaborative working [1]. Calls for changes to the procurement process, as well as an increase in collaboration, have been ongoing for years [4]. Clients, both in the public and private sectors, unhappy with traditional procurement routes, are also demanding changes [5]. The Irish Government and the European Union recognise the benefits of BIM to the public sector to generate better value for money [1, 6]. They must provide leadership and remove legal, regulatory, procurement and policy barriers [6].

Although there is no one best procurement method for all projects, the selection of the appropriate one can shape the success of a project

[3] with some methods better than others at promoting collaboration [4]. Early Contractor Involvement (ECI) and more integrated procurement methods contribute to the better buildability of the design and reduce risks [3]. However, the traditional "Design-Bid-Build" procurement method is still predominantly used [4]. Contractors are being appointed on the lowest bid win basis. But this selection method rarely equates to value for money for the client [3]. The industry needs to move away from this "lowest price wins downward spiral" [1].

A fundamental change of attitude and organisational structure is required [3] but implementing ECI represents a significant challenge to public sector clients since public regulation imposes the use of competitive and transparent selection processes [7].

This paper will investigate current procurement strategies that promote early contractor involvement and their suitability for Irish public works projects. The research will primarily focus on contracts that are best aligned to the Capital Works Management Framework (CWMF) strategic objectives of ensuring greater cost certainty, better value for money and more efficient end-user delivery.

This research concentrates on projects where the design is by the employer and therefore, excludes Design & Build and Public Private Partnership.

II Literature review

Collaboration will result in better project outcomes and is essential to the success of the BIM process [8, 9]. Eastman et al. [10] suggest that for BIM to reach its maximum potential, a collaborative, procurement route must be used and contractors should be selected based on best value as opposed to lowest cost [11]. Collaborative contracts aim to '*overcome the misalignment of commercial incentives associated with conventional fixed-price contracts'* [12].

The 1994 Latham report recommended the use of partnering to promote co-operation [13]. However, partnering is non-binding [12, 14], only expresses the intent to collaborate [15] and does not guarantee that each project stakeholder will benefit equally from the relationship [16]. Hayford [12] suggests the methods that best promote collaboration are Project Alliancing and Integrated Project Delivery (IPD). Early Contractor Involvement (ECI) is a feature of both these methods.

a) Early Contractor Involvement

The traditional Design-Bid-Build procurement method generally excludes contractors from the design development process as their appointment can only happen when the design is well advanced [11, 17]. More buildable or sustainable solutions can be overlooked [17]. This method can be a barrier to innovative change [18] and is viewed by some as a hindrance to the proper implementation of Lean and BIM [19]. Early Contractor Involvement is seen as key to the successful use of BIM [20]. According to Wondimu et al. [7], the main advantages of ECI are to improve relationship and collaboration between parties. Other vital benefits from ECI include increased buildability, reduced risks, early completion of projects, savings on projects costs, reduced change orders and overall better value for money [3, 7].

However, implementing ECI is difficult [12]. The selection method "defies established standards" [7] and is a challenge for public procurement authorities regulated by EU Procurement Laws [20]. It requires a "fundamental change of attitude and organizational culture" [3] and the implementation of new procurement methods such as two-stage tendering [21] with a selection focused on qualitative criteria and not the lowest bid [7, 22]. The main drawback of two-stage tendering is the absence of competition during the second stage, where the contractor may view it as an opportunity to increase his price [11].

ECI is deemed more suited to complex projects and different models need to be developed depending on the need of the project [7]. Compensation also needs to be put in place for the contractor's input [21] and it could lead to the perception it will increase costs [22]. However, Lahdenpera [23] argues that minor additional investment in design costs will not increase total project cost significantly and may result in improved efficiency and reduced construction costs.

Roberts et al. [24] report that contractors believe their contribution to a project would be more effective if they were involved earlier, a point also made by the Construction Industry Federation (CIF) in Ireland in their Medium-Term Strategy for the Amendment of the Public Works Contracts [25]. Roberts et al. suggest the publication of new collaborative contracts in the UK is evidence of the importance of ECI [20].

b) Public Work Procurement in Ireland

The department of public expenditure and reform provides through the CWMF the necessary policies and contracts for the procurement of general work in Ireland [5]. The objectives for the CWMF are to ensure greater cost certainty at the award stage, better value for money at all stages and more efficient end-user delivery [26]. McAuley et al. [2, 27] argue that they do not provide value for money and that due to incomplete design at tender stage, they also do not provide cost certainty. The guidance notes highlight that value for money should be considered in the context of whole life cycle cost, not just capital cost [28].

The procurement procedures must adhere to Irish and EU procurement regulations. They should be "open, objective and transparent" and allow the best value for money being assessed through competitive tendering [28].

Before starting a project, the contracting authority should select the right contract type according to figure 1 and match it to the correct procurement strategy [28].

Nature of Works	Contract Type	Code	Form of Contract
Building Works	Traditional	PW-CF1	Public Works Contract for Building Works designed by the Employer
	Design and Build	PW-CF2	Public Works Contract for Building Works designed by the Contractor
Civil Engineering Works	Traditional	PW-CF3	Public Works Contract for Civil Engineering Works designed by the Employer
	Design and Build	PW-CF4	Public Works Contract for Civil Engineering Works designed by the Contractor
Minor Works, Building and Civil Engineering	Traditional	PW-CF5	Public Works Contract for Minor Building and Civil Engineering works designed by the Employer
Short Form, Building and Civil Engineering	Traditional	PW-CF6	Public Works Short Form of Contract for Public Building and Civil Engineering Works
Investigation, Building and Civil Engineering	Traditional	PW-CF7	Public Works Investigation Contract
	Traditional	PW-CF8	Public Works Investigation Short Form of Contract
Framework Agreement		PW-CF9	Public Works Framework Agreement
Large projects (e.g. over €100 million), or technically complex projects on which Contractor input is required at an early stage PW-CF10 Public Works Contract for EARLY COLLABORATION		PW-CF10	Public Works Contract for EARLY COLLABORATION
Urgent maintenance requirements or where certain types of planned maintenance and refurbishment are envisaged		PW-CF11	Public Works Term Maintenance and Refurbishment Works Contract

Figure 1: Forms of Contract for Public Works [28]

Under EU and national procurement rules, procurement procedures may be one of the following [28]:

- Open procedure (open to any individual or company who wishes to participate. Evaluation first based on suitability assessment than under tender evaluation criteria)
- Restricted procedure (Two stages: Pre-Qualification Questionnaire then Tender issued to a short list of qualified candidates)
- Innovation partnership (to be used when 'there is a need for the development of an innovative product or service or innovative works and the subsequent purchase of the resulting supplies, services or works cannot be met by solutions already available on the market'[29]).
- Competitive procedure with negotiation (used when 'prior negotiations are necessary due to nature, complexity or risk profile and when open or restricted procedures are unlikely to lead to a satisfactory outcome'[30])
- Competitive dialogue (used in exceptional circumstances, such as very complex projects that demand more flexibility in the procurement process than in either the restricted or open procedure – for example, those that involve public-private partnerships.)
- Negotiated procedure (may only be used in exceptional circumstances set out in Article 32 of 2014/24/EU, which must be documented comprehensively).

EU and national procurement rules state that winning tenders should be chosen as Most Economically Advantageous Tender (MEAT) or best price-quality ratio, and awarded based on objective criteria to ensure transparency, non-discrimination and equal treatment [31]. MEAT combines price and quality for the assessment of the tender [7]. MEAT is required on all project exceeding €2m in value [17]. It is assessed through technical, management and commercial criteria [28]. It is argued that tenderers often achieve similar scores on the quality assessment resulting in the price being the deciding factor [32]. The CIF [25] questions whether MEAT award is even a "real exercise" and warns that if the criteria are not objective and consistent, the award decision could be challenged [25].

The guidance notes acknowledge the limits of the current procedure by stating that the experts involved in a project are not part of a single integrated team with design and construction working independently of each other [28]. The public forms of contract have been criticised for not encouraging collaboration [2, 33]. The separation between design and construction operations cultivates an 'us and them' attitude [17].

As part of their submission to the report on the review of the Public Works Contracts, Ireland's professional bodies asked for the introduction of collaborative working. The report outlined how to implement co-operation measures, to improve existing contract forms. [32].

The PW-CF10 Public Works Contract for Early Collaboration (for large projects over €100m only) was introduced in 2011 and is effectively a two-stage tender process which facilitates ECI [17]. The contractors are paid an early service fee to take the design to a stage where they can offer a Guaranteed Maximum Price (GMP) for the work. The GMP should be lower than the Target Price tendered during the first stage, and this contract introduces the concept of Initial Saving Share (percentage of the difference between the agreed Guaranteed Price and the tendered Target Price for a Task) [28]. ECI was implemented on the National Children's Hospital project [34] and on the public sector Cashel to Mitchelstown motorway project which was successfully delivered ahead of a challenging schedule [25].

In March 2019, the Minister for Finance and Public Expenditure and Reform launched a review of procurement policy for public works projects [35]. However, some of the recommendations from the previous report on the review of public works contracts published in 2014 have yet to be implemented [25, 32, 33].

The Government Contracts Committee for Construction (GCCC) acknowledged that its suite of contracts was not suited to all construction projects and they were open to considering UK and international alternatives [32]. The Construction Industry Federation (CIF) supported this proposition and added that because Ireland and UK were both subject to EU Procurement Directives, it would be rational to use recognised contracts in this jurisdiction [25].

c) Public Work Procurement in the UK

In its 2018 National Construction Contracts and Law Report [4], the NBS revealed that traditional procurement is still the most used in the UK (46% of projects). They also reported that more than a third of all projects started in 2017 didn't adopt any collaboration techniques. Respondents commented that single stage tendering is still prevalent but that two-stage tendering and negotiation are on the rise.

Two-Stage Open Book tendering is one of the UK Government's recommended procurement models and comprises of Cost-Led Procurement and Integrated Project Insurance [36]. The objectives of these three new models of procurement were to reduce cost, improve programme certainty, reduce risk, encourage innovation, improve the relationship and provide value for money even if it didn't deliver the cheapest construction project [37]. This process is compliant with EU Procurement rules and enables ECI. Bidders are being chosen based on their capacity, capability, stability, experience, and strength of their supply chain plus their profit/fees/overheads and their other costed proposals as appropriate [38]. The contractor selection process for these three methods is detailed in figure 2.

Mosey [38] claims up to 20% savings were achieved on trial projects using the Two-Stage Open Book method. Significant savings were made using a collaborative approach for the London 2012 Velodrome [39]. However, resistance to change from client and industry is seen as a barrier to more widespread adoption [40]. Farmer [40] argue that a levy for clients who procure in a 'short-term or irresponsible manner,' could be the solution to increase the use of collaborative contracts.

Three forms of collaborative contracts were endorsed as part of the UK Government Construction Strategy to support these new procurement methods, namely the ACA Partnering Contract PPC2000, the JCT Constructing Excellence Contract and the NEC3 contract [21]. The NEC has since published the NEC4 Alliance contract at the end of 2017 [8]. It includes multiparty collaboration at its core and is designed for use on major projects or where a number of smaller projects can be combined to create a programme of work [41]. Roberts et al. [24] claim Alliances are considered to be the 'ultimate form of collaborative project and programme delivery' in the UK and elsewhere.

	Cost Led Procurement	Integrated Project Insurance	Two Stage Open Book
Early Contractor Involvement	Yes	Yes	Yes
Contractor Selection Process	2 or 3 integrated framework supply teams (pre-selected by the client) bid for project. If no team can deliver the Target Cost, the project can either be offered to suppliers outside the framework or abandonned or the budget/specification can be revised.	Client holds a competition to appoint the members of an integrated project team. Scoring may include elements assessing competence, capability, proven track record, maturity of behaviours, proposals for removing waste and inefficiency, and fee declaration	Based on an outline brief and cost benchmark. Contractors compete for the contract in a first stage with bidders being chosen based on their capacity, capability, stability, experience, strength of their supply chain, and fee (profit plus company overhead). As a second stage, the successful contractor are appointed to work up a proposal on the basis of an open book cost.
Selection Criteria	selection on basis of tender price and design	selection on ability to deliver and open book accounting	selection on ability to deliver and open book accounting
Design Development	2-3 designs worked up during mini competition	Single design worked up following 1st stage selection	Single design worked up following 1st stage selection
Allocation of Risks	Defined by contractual arrangements / "Joint Risk Pot"	"No blame" integrated project insurance product throughout with predetermined sharing of capped benefit and risk	"No blame" integrated project insurance product throughout with predetermined sharing of capped benefit and risk
Form of Contract	Collaborative Forms (JCT, NEC, PPC)	Alliancing Forms (Bespoke Multi Party, JCT/CE, Amended PPC)	Alliancing Forms (PPC, JCT/NEC with preconstruction agreement)

Figure 2: UK New Procurement Methods (By Author)

d) Project Alliance and Integrated Project Delivery

The use of Project Alliancing is increasing with Australia one of the country's leading the way [42]. Alliance was introduced there in the 1990s on oil and gas projects [43], subsequently developed and in 2015, the Australian Government reported that $30bn worth of public sector projects had been completed or were planned using alliances [14]. Three collaborative procurement methods in use by the public sector allow for the early involvement of contractors namely the Early Contractor Involvement (ECI), Early Tender Involvement (ETI) and Managing Contractor [44].

The guide to Alliance Contracting [14] explains that the selection of the Non-Owner Participants (NOPs) is based on non-price and price elements. As detailed in figure 3, non-price criteria include capability, experience or financial capacities. The price elements will include reimbursable costs, corporate overhead and profit margin. By having a fixed margin (as opposed to a percentage), the contractor has no commercial motive to oppose cost-saving design solutions [23].

Model feature	ECI	ETI	Managing Contractor*
Project phase by model	EOI, RFP and ECI Phase	EOI, RFP and ETI Phase	EOI, RFP and D&C Phase
Project characteristics suited to the model	• Complex • High Risk • Project risks or design elements best understood by Client • Some design unknowns • Benefit from Client's 'insider knowledge' • Price certainty is paramount • Time is restricted • Scarcity of available resources • Opportunity for innovation • Risk of not obtaining competitive tenders using other procurement models	• Complex • Client has mature design • Benefit from value engineering / innovation	• Complex program of works over years • Can be broken into work packages such as site and forward works • Project risks or design elements can be best understood and managed during delivery • Scarcity of Client project management resources • Client cannot provide tender documentation with clarity on scope, risks and other constraints
Design maturity pre-tender	Mature / Limited	Mature	Mature
Project elements requiring collaboration	• Design • Construction Method • Program • Risk Allocation	• No Design • Construction Method • Program • Risk Allocation	• Design • Construction Method • Program • Risk Allocation
Procurement resource impacts	Senior Client resources required to collaborate	Senior Client resources required to collaborate	Senior Client resources required to collaborate
Selection criteria[10]	EOI and ECI Phase: • Capability • Experience • Personnel • Systems • Direct Cost Rates • Indirect Cost Rates • Program • Company Financials • Fixed fee	EOI and ETI Phase • Capability • Experience • Personnel • Systems • Direct Cost Rates • Indirect Cost Rates • Program • Company Financials • Fixed fee	EOI and RFP Phase • Capability • Experience • Personnel • Systems • Direct Cost Rates • Indirect Cost Rates D&C Phase: • Above plus Programme, Lump Sum Management Fee, Risk Allocation, Scope Changes
Payment for Collaboration Phase	Fixed fee (suggested 50% of estimated costs)	Fixed fee (suggested 50% of estimated costs)	Fixed fee (suggested 50% of estimated costs) or Schedule of Rates
Form of Construction Phase contract	• Risk allocated, lump sum	• Risk allocated, lump sum •	• Lump sum with Management Fee • Actual reimbursable costs to sub-contractors • Generally a Guaranteed Maximum Price (GMP)
Risk allocation for Construction Phase	N/A	N/A	Supplier generally takes some delivery risk warranting quality and completion date

Figure 3: Key differences between ECI, ETI & Managing Contractor[44]

Depending on the maturity of the design and urgency to appoint or start a project, NOPs can be selected based on a full price, partial price, or non-price basis. Non-price selection is carried out through written submissions or interviews, but the guide states it is rare that some form of price competition isn't used during the process [14]. Compliance with EU Procurement Laws would be difficult with a non-price selection process as legislation dictates that price should be part of the criteria [45]. Figure 4 compares these three selection methods with the traditional design & construct (D&C) method.

The success of an Alliance project is based on teams integrating, working together and not 'reverting to their old mentality' when things go wrong [42]. It requires strong client leadership as collaboration will not happen just because it is written in the contract [18, 20, 44].

The project alliance model has been successfully implemented in the American construction industry, where it is called Integrated Project Delivery (IPD) [12]. The AIA defines IPD as "a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction" [46].

One of the challenges to implementing IPD is how to select a project team that will collaborate effectively as it deviates from standard methods [7, 9]. The participants are selected based on qualitative non-price criteria [12] as opposed to the traditional lowest priced or most economically advantageous tender. This is necessary as the team is formed at the earliest possible time in the project timeline before the design is even started [46]. With the need for transparency and fairness in the procurement process, the difficulty of choosing contractors on a non-price basis, such as interviews is challenging for public organisations [47]. Proving value for money is difficult when there is no price competition and this could lead to a lack of public support for the method [45].

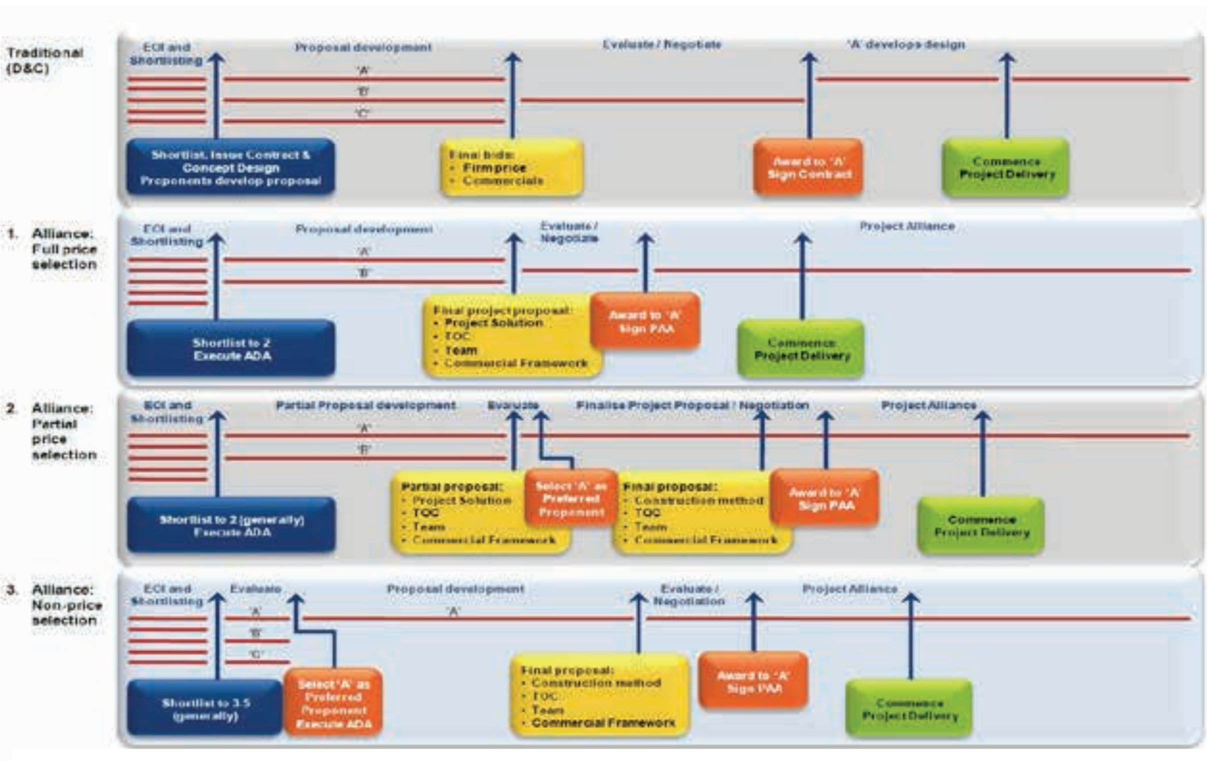

Figure 4: Comparison of procurement activities andmilestones in selection processes [14]

Unlike traditionally procured projects, redesign and value engineering are replaced by a target value design process where the budget is continuously monitored [46]. This budget or target price is set collectively by the project team, and potential conflict of interests are dealt with by open book estimating and use of independent consultants [46].

One of the IPD team selection process is described by Townes et al. [9] in figure 5. “Self-selected teams” (similar to a Joint Venture) composed of the architect, construction manager, engineers, commissioning agent, and potentially the mechanical, electrical and plumbing (MEP) trade contractors developed a proposal. The owner’s screening committee established a “long list” of qualified teams. These teams were then invited to a site visit and to submit a technical proposal. A short list was then established and the remaining teams we invited to workshops. Design concept proposals were developed, and a final interview took place to select the winning team.

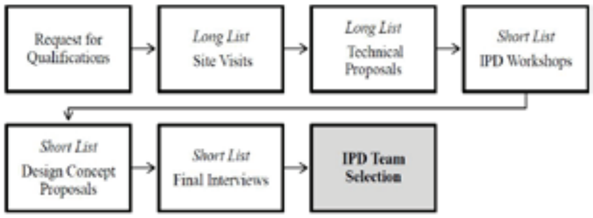

Figure 5: Sequential representation of the case study team selection process [9]

III Methodology

This paper used a qualitative research methodology. It started with an extensive literature review of academic papers, industry and government guidelines and reports from Ireland and abroad. The main objectives were to:

- critically evaluate the current public work procurement processes in Ireland
- critically evaluate collaborative procurement processes in use in both private and public sector abroad.
- critically assess which method (if any) could be implemented in the public sector in Ireland to promote early contractor involvement and improve collaboration.

Semi-structured interviews were then carried out to get an up to date assessment of the public work procurement process in Ireland and test some of the recommendations established during the literature review. The participants selected were all working in a senior position in their organisation with experience and expertise in public work procurement and/or collaborative procurement methods. They were also chosen for their involvement in professional bodies in Ireland and knowledge of the BIM process and the importance of procurement for its successful implementation.

Name	Company	Role
Participant A	Public Procurement Agency	Senior Architect - BIM Champion
Participant B	Public Procurement Agency	Senior Engineer Estate Management
Participant C	Sollicitor	Procurement & Construction Law, Public Work Contracts
Participant D	Tier 1 Contractor	CEO
Participant E	Tier 1 Contractor	Director

Finally, a case study was carried out on the implementation of IPD on a project for a confidential client in Ireland. One of the key people responsible for procurement was interviewed. The objective of this study was to understand the contractor selection process, ascertain the barriers to implementation, review the lesson learned and tie in with the results of the literature review and interviews.

IV Results

a) Evaluation of collaboration and public works contracts in Ireland

The adversarial nature of the construction industry and the need for more collaboration is frequently discussed in industry reports and research papers. All participants in this study confirmed this but there was no consensus on whether the increased use of BIM tools in the last few years had improved collaboration: none felt it got worse and only one felt it got better with the caveat that *“BIM shouldn’t be sold as the answer to all the industry’s issues”*. One contributor commented that if all professional bodies were invested in promoting BIM, there was a lack of joined up thinking, contradicting the idea of collaboration, an issue also raised in the UK context [40].

The participants were asked for their assessment of the public work procurement process and if they felt it promoted collaboration. All but one answered that current contracts failed to encourage collaboration. It was remarked that the word collaboration is not mentioned once in the contracts or guidance notes and that when the word co-operation was mentioned, it was merely aspirational. One contributor stated the 2007 PWC reform had set the industry back many years, failing to follow the international trend for more collaboration. Recurring issues with overspending on public projects proved that it hadn’t delivered on its objectives of better cost certainty and value for taxpayer money and that the sometimes-unfair allocation of risks to the contractors had seen many building firms refuse to tender for public works. The interviewee did, however, comment that many public sector procurers understood the benefit of collaboration and were *"going out of their way to make it work"*.

Most participants mentioned the lack of resources or expertise in the public sector leading to a reliance on external private consultants. They commented that when *'things went wrong'* on a project, the public authority and contractors were generally taking the blame and that they should be held accountable. However, the consultants, who were hired by the public sector to provide this expertise, seemed to escape any blame and contractual liability when they were given poor advice on procurement, BIM, design, M&E services or budget.

b) MEAT & Selection Criteria

The CWMF strategic objectives are to ensure greater cost certainty, better value for money and more efficient end-user delivery [26]. The participants were asked if they felt this was or could be achieved when the selection of the contractor was based on the lowest bid or Most Economically Advantageous Tender basis (MEAT). All participants mentioned the difficulty of implementing a fair, transparent and robust assessment of pre-qualification and MEAT criteria. They all recognised that if the scoring system was open to any interpretation, the award of a tender could be challenged by losing bidders. In this context, awarding the project to the lowest bidder was the easiest and less risky approach despite most participants confirming the evidence gathered in the literature review that the lowest bid didn't necessarily represent the best value for money for the client. Three of them felt that the pre-qualification process should eliminate poor quality contractors, so the only remaining selection criteria left was price.

EU Procurement Laws allow public clients to prohibit or restrict the use of price only when assessing MEAT, but tender cannot be awarded on non-cost criteria only. However, award can be based using a Life Cycle Costing (LCC) approach [31]. Four out of five participants felt more emphasis should be placed on LCC because as one interview stated: *"it makes absolute sense."* Unlike many private projects, where the goal is a quick commercial return or the urgency to place a product on the market, national and local public authorities will be responsible for their assets for the long term. One interviewee stated *"the government should drive this as they will always be around*" while another felt there was growing awareness about the importance of LCC in the public sector and both procurement authority representatives confirmed this. However, many barriers or issues were cited. The assessment of Life Cycle in the context of the contractor selection was difficult due to a lack of expertise in this area, the sometimes *"speculative"* nature of LCC due to fast-evolving technologies and the fact that clients were driving the design, limiting what contractor could propose.

LCC is essential in the context of sustainability by selecting energy-efficient equipment, for example and in the context of cost savings for the client [48]. Another approach encompassing these goals is Lean Construction which promotes the elimination or reduction of waste. Four out of five interviewees felt Lean, but also offsite construction should be a consideration whether at pre-qualification stage or for qualitative tender assessment. One contributor argued that *"ultimately, waste is paid by the client"* and therefore Lean Construction should be implemented. However, they again stated that it would be a challenge to score it: *"how do you measure commitment to reduction of waste?"* The remaining participant argued that smaller contractors working on tight margins across the country were doing Lean without maybe realising it as a matter of survival for their business. He also indicated that if the reduction of waste was so critical for the public sector, reforming the *"broken apprenticeship system"* and teaching new entrants in the industry how to work leaner and how to use modern technologies would yield more results in the long term.

c) Early Contractor Involvement and Collaborative Procurement Methods

Except for the PW-CF10 form of contract (which only applies to projects over €100m), the standard types of contract for employer designed projects in the public sector in Ireland do not allow for Early Contractor Involvement. Therefore, unsurprisingly, the representants of the public procurement authorities, confirmed they didn't have experience of ECI on previous projects. On the other hand, the three private sector interviewees, who had ECI experience, would like to see it extended in the public sector and confirmed many of the benefits previously discussed in the literature review including better value for client and contractor, improved buildability or better teamwork. One contributor commented that offsite fabrication was difficult, if not impossible, without ECI. Industry research shows that client fears a loss of competition and potential cost increase when the contractors are involved before the project is fully designed. One of the contractors confirmed that some contractors might see ECI as a way of *"making more money"* and that trust and honesty were required from both clients and contractors to make it work. However, it was noted that if the client has the necessary expertise to implement two-stage tendering, the risks of increased cost are minimal. Another interviewee estimated that on traditional projects, variations and arbitration/adjudication could cost between 5 or 10 percent of the final expenses. He argued that setting aside 2 or 3 percent of the budget for ECI could eliminate most variations and disputes and therefore save the client money.

A two-stage tender process was adopted for the procurement of the National Children's Hospital project. Some contributors commented that this process was being used very successfully in the UK. They feared that the well-publicised failure of its implementation on the NCH would see procuring authorities revert back to single stage tendering and set back the move towards more collaborative procurement methods and forms of contract.

The UK, Australia or the US have all developed collaborative procurement methods and contracts such as project alliance and IPD. All these approaches have multi-party contract, early contractor involvement and a form of shared risk and reward scheme in common. In the case of the AIA IPD, the contractor selection is often based on qualitative criteria only. The five participants are all senior members of public organisations or professional bodies and they all stated that, to their knowledge, there was no such method being currently developed in the public sector in Ireland. They cited many barriers to their implementation. Unlike the private sector, the public sector has an obligation of transparent, fair and unchallengeable competition which makes qualitative selection difficult. The lack of resources and expertise in public agencies and the lack of support from top decision maker was also mentioned. One interviewee commented on the *"glacial speed"* of the reform of the PWC and that there was a tendency to re-write contracts and guidance documents instead of re-using what had been done elsewhere confirming some of the comments made by the CIF and RIAI previously [25, 33]. Another barrier mentioned was the general lack of trust between stakeholders and that it would require a "change of mindset" to implement new procurement methods.

Synergies between Lean, BIM and IPD are indisputable, but there is currently no contract that facilitates an IPD relationship in Ireland [5]. Nonetheless, the Office of Public Works (OPW) introduced a two-stage procurement system and IPD framework for their lift replacement programme in 2017 [49]. This initiative followed the Lean principles of reducing wastes and repetition from processes and proved to be a success for all the parties involved. One participant commented that the lift industry has few actors in Ireland and this type of framework would be difficult to implement and administer on public construction projects due to the number of contractors bidding for public works. However, this case study did show a willingness to innovate in the public sector and that a *"version of IPD"* can be implemented and improve outcomes.

d) Analysis

The interviews revealed several key concerns:

1. More collaboration is needed to improve project outcomes, but it is not reflected in the current suite of public work contracts.
2. There is a knowledge, experience and expertise gap in the industry and public sector about ECI and other collaborative procurement methods.
3. Assessing qualitative criteria in a fair, transparent and consistent manner is challenging a move away from the price as being the main selection criteria.
4. The need to comply with local and EU procurement rules and getting value for money by price competition will challenge the creation and implementation of an IPD public form of contract.

To further investigates the findings of the literature review and the results of the interviews, a case study of a private IPD project in Ireland was carried out. Although the contractor selection process for a private client doesn't have the same constraint as the one used in the public sector, this project involved many actors who are routinely engaged in public work projects in Ireland (Design team, consultants and contractors). Therefore, it is deemed relevant to the potential application of this particular form of collaborative procurement in public works projects.

V Case study

This case study examines the procurement process and implementation of IPD on a large size project located in Ireland. The client appointed a construction management firm to oversee the construction of a new plant. The findings of this case study are based on the interview of the commercial and procurement manager of this firm.

Based on the brief and an outline design (approximatively 30 percent complete), an approximate bill of quantities was produced and sent out to eight contractors for pricing. Due to the size of the project and the completion deadline, the scope was divided into site geographical areas and it was decided to appoint multiple contractors to work alongside each other on a framework.

The selection of the preferred bidders was made on capability and price. Only two contractors had the capacity (workforce and financial) to carry out some of the most extensive packages and were appointed on the framework. To ensure competitive pricing, three other contractors were also appointed for some of the smaller packages.

Prior to appointment, they had to agree to work in an IPD framework agreement. The contract management firm and all the contractors would all work together to achieve the target cost of the project. This target cost was set lower than the total of all the tendered packages and all parties agreed it was achievable if they worked together. Savings would be shared, but so would over-runs.

Contractors had to declare their profit margin and would be reimbursed their costs.

Some of the critical attributes of IPD were applied to this project: Collaboration, efficient co-location or project dashboards [50]. The IPDA [50] states that for the client to reap the reward of collaboration, it must also be collaborative. Daily meetings were organised, including the client, contract management firm and the contractors, where decision were made in common. Each stakeholder had one vote. Decisions were made quicker than on a traditional project.

Contractors had an incentive to work together and provide savings. Some of these were achieved through Lean processes. Waste were identified, and measures were taken to reduce or eliminate them. Off-site fabrication was a feature of the project, but several other ideas were implemented. For example, it was found that the site canteen was 15minutes away from the job site resulting in loss of productive time. The decision was made to move the canteen closer to the job site and savings amounted to approximatively four times the cost of the relocation. It was also found that there was no need for each contractor to have their own safety officer on site, so a decision was made to pool resources together and appoint a safety team for the whole project.

Although the client didn't report any savings on the original target cost, variations were virtually eliminated (other than changes to the original client brief). As profit was declared from the onset of the project, there was no incentive for contractors to claim for some of the minor changes due to co-ordination or delays. The cost of raising and administrating these change orders would be more than the profits they would generate and would eat into the shared profit pool. Traditionally, if a contractor is late finishing an area, the contractor who is delayed would claim against the client or contractor. Here, any delay was discussed at the daily meetings, the other parties would ask how they could help resolve the issue and put the project back on track. This could mean a contractor "loaning" some of his resources to another contractor.

The main difficulty was to get people on board with the concept of IPD and collaboration at the start of the project. It was a change of culture for contractors who would have been used to a particular way of working for many years. There is traditionally a lack of trust between parties and this framework would involve companies usually competing against each other. For this reason, the client appointed an IPD and collaboration specialist to explain and guide the contractors. After some initial teething problem, the collaboration process was deemed a success by the contract management company.

This case study tackles a number of the issues raised in the literature review and interviews. It offers practical solutions to these issues that could be implemented on public works projects without updating the current suite of contracts. The contractors were selected on qualitative and price criteria, not dissimilar to the two-stage process used on the National Children's Hospital project. The IPD framework was implemented after the contractors were selected, allowing them to contribute to bringing the design to 100% and implement Lean solutions. During the interviews, one of participants mentioned that the Office of Public Works (OPW) owned and maintain a wide range of building including offices and car parks. In the case of city centre projects for example, the use of these facilities could provide the space for collocation and reduce some of the contractor's costs associated with site offices and parking. In the case study, the early involvement of contractors allowed the use of off-site fabrication, reducing on-site waste and helping achieve tight deadlines.

The shared risk and reward scheme is a feature of the PW-CF10 form of contract. If contractors were to declare their margin at the end of the second stage of tender (GMP) in a similar manner as this project, it would create an incentive to provide savings as their project margin would be secure regardless of their reimbursable costs. Any cost savings solution such a pulling resources together for health and safety would benefit all parties by increasing their share of the saving pool.

Neither consultants nor contractors had experience of IPD before this project. The knowledge and experience gap was plugged by the appointment of a collaboration specialist. The cost of this appointment was negligible compared to the benefits better collaboration brought to the project. Public projects are plagued with claims and disputes and many of these issues can be tackled by collaborative working as proven in this case study.

VI Recommendations

a) Education & Training

E.D. Love et al. [22] talked about a "fear of the unknown and desire to avoid criticism" to explain the public sector's reluctance to adopt new procurement methods. The lack of awareness and understanding has also been mentioned [51]. Early Contractor Involvement has been proven to work in the UK and other markets. However, it is relatively new in Ireland and both public and private sector actors would need to understand its benefits and how to successfully implement it to rid procurers of this fear of the unknown. Education and Training is one of the four recommendations made by the National BIM Council in its Roadmap to Digital Transition for Ireland's Construction Industry 2018-2021 [1]. Collaborative procurement methods and contracts should be considered an integral part of any reform or improvement of college construction courses. Quantity Surveyors, under the umbrella of the Society of Chartered Surveyors Ireland (SCSI), regularly provide procurement advice to public procuring authorities, and would be best placed to lead the upskilling of the current workforce through CPDs.

b) Contractor Prequalification/Tender Evaluation

The results from this research paper support some of the recommendations made by the CIF and RIAI [25, 33]. BIM, Lean or Life Cycle Costing are integral features of construction and their assessment should form part of the tender evaluation process, whether as part of the prequalification process or the MEAT process. To ensure a fair, transparent and consistent assessment, new selection criteria assessment guidance documents should be developed to help the procuring authorities and bidders.

The cost and burden of carrying out this assessment for the client and of prequalifying for consultancy and construction firms cannot be ignored. Standardising prequalification between public procurement authorities and introducing a framework, in which firms would pre-qualify for public works as opposed to a single public project, would go a long way to alleviate this burden.

Part of this assessment should include previous performance on public construction project. This would require the development of Key Performance Indicators (KPIs) for all the parties involved in the project.

c) Develop collaborative working for public works

As demonstrated in the case study, collaboration can be improved even when using a traditional procurement method. It is argued that collaboration will fail if it's not clearly described in the contracts [4]. However, despite the traditional adversarial nature of the construction industry, the research has shown that most stakeholders in the industry want change. Re-writing existing contracts or developing new contracts takes time but in the interim, collaborative charters or protocols could be developed alongside collaboration guidance documents (Code of good conduct, colocation, KPIs, lessons learnt, etc…).

d) Develop Early Contractor Involvement

The PW-CF10 form of contract has a threshold of €100 million and requires advance permission of the GCCC. This limits its use to occasional large-scale projects. However, ECI could also be implemented on intricate projects (in Healthcare or Infrastructure for example) by lowering this threshold.

VII Conclusions

Previous research has established that for BIM and Lean to reach their full potential, multidisciplinary collaboration is required, and Early Contractor Involvement is essential to achieve it. The aim is of this paper was to establish the barriers to implementing collaborative procurement methods on public works projects in Ireland by assessing the current processes in Ireland and review best practice abroad.

This research has shown that if the US model of Integrated Project Delivery provides one of the best collaborative platforms to enable BIM and Lean to thrive, its implementation would be challenging in the current public works context. However, the case study has shown that other forms of IPD are possible using traditional procurement methods. The current forms of contract suite enable two-stage tendering which is a prerequisite for ECI. The current threshold restricts its use to large scale projects but could be lowered to extend its adoption.

Concerns have been raised that two-stage tendering allowing Early Contractor Involvement could be abandoned in the light of the much-publicised budget issues of the National Children's Hospital[34]. While lessons must be learned from this project to ensure the same errors are not made again, reverting to traditional procurement must be resisted as it would go against the international trend of the development of more collaborative procurement methods and contracts.

VIII Limitations

While every effort was made to include representation of all stakeholders involved in the procurement of public projects, time constraints and scheduling issues meant that the author couldn't get the input from all the national and local procurement agencies and a Cost Consultant.

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BIM in Ireland 2019: A Study of BIM Maturity and Diffusion in Ireland

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Abstract−In 2017, the BIM Innovation Capability Programme team applied five macro BIM maturity conceptual models to capture the capability of the Irish construction industry and assess its BIM maturity. The results found that while Ireland is mature for modelling processes, it is less developed with regards to collaboration processes and policies. Ireland also ranked poorly when it came to regulatory frameworks, measurements and benchmarks compared to a number of countries which also applied the same conceptual models. At the time, the findings highlighted that Ireland's diffusion dynamic was middle out, meaning that larger organisations or industry associations were pushing the BIM agenda and not the government, which had primarily chosen a passive approach with little or no assertive activities. The results also showed that the educational institutes had a much higher BIM diffusion compared to policymakers. Since the initial findings of the macro BIM maturity study, the Irish government has endorsed many initiatives, such as the announcement of a strategy to increase the use of digital technology in crucial public works projects, as well as contributing to the Digital Construction Transition Roadmap 2018-2021. As a result of Ireland's growing market for BIM and the recent public sector requirements, it was decided to reapply the five macro BIM maturity conceptual models to investigate if this has impacted on Ireland's BIM diffusion dynamic and levels. The results will be complemented through a selection of research initiatives which the researchers have undertaken to further establish Ireland's BIM maturity in 2019. It is hoped that the results from this exercise will inform the Irish government and AEC sector of the key requirements to ensure wider adoption of BIM in Ireland.

Keywords − Building Information Modelling, Ireland, Maturity, Leadership, Education, Standards,

I INTRODUCTION

The 2017 Macro BIM Adoption in Ireland Study [1, 2] at the time provided crucial information in highlighting areas that were required to be addressed if Ireland was to continue the momentum in promoting BIM within the industry. The BIM macro maturity models developed by Succar and Kassem [3] are part of the BIMe Initiative Macro Adoption Project. This framework consists of five conceptual models that have been utilised to measure macro BIM adoption across the world (Figure 1). The research conducted in 2017 strongly indicated that clients were struggling to understand the actual benefits of BIM. At the time there was a strong requirement for the development and dissemination of national guidelines to create and implement a collaborative environment that would foster BIM use for particular professions [1 - 4]. The macro BIM adoption study results were used in the Roadmap to Digital Transition for Ireland's Construction Industry 2018 – 2021 to help guide the industry [5].

Figure 1: Macro BIM adoption models [3]

Since the publication of the roadmap in 2017, the Irish government announced its strategy to increase the use of digital technology in particular categories of public works projects over a 4-year timeframe ending in 2021 [6]. This statement of intent from the Irish government demonstrated an acute awareness of the importance of BIM and how it brings together technology, process improvements and digital information to radically improve project outcomes and asset operations [6]. These initiatives have been encouraged by the ongoing revival of the construction industry with the sector expected to grow by 20% in 2019, totalling €24 billion [7].

Given that the roadmap and government's strategy to increase digital technology had been in effect for two years, along with a continued surge in construction sector output, it was decided by the authors to reapply the macro BIM maturity conceptual models to investigate if Ireland's BIM diffusion dynamic and levels have been impacted. Also, as the roadmap is industry-led and the government's digital strategy for the construction sector had not provided any clear guidance to-date, it was agreed that the macro BIM maturity model would assist in understanding any limitations that a lack of funding has had on the adoption of BIM.

II METHODOLOGY

The BIM Innovation Capability Programme (BICP) between 2016 – 2017 captured the Irish construction industry's and the Higher Education Institutes' (HEI's) response to the increased requirement for BIM on Irish construction and engineering projects [8].

At the beginning of 2019, the Construction IT Alliance (CitA), in consultation with academics from the Technological University Dublin (TU Dublin) and Trinity College Dublin (TCD), commissioned an exploration of a selection of BICP initiatives that could be used to provide further guidance for the Irish AEC Sector. The overall goal of this initiative is to publish a BIM in Ireland 2019 report, similar to that produced in 2017 [9].

This paper will explore an extension to the macro BIM maturity study, which was a BICP initiative in 2017. This framework consisted of five conceptual models that have been utilised to measure macro BIM adoption across the world. These models can be used for:

- Assessing a country's current BIM adoption policy.
- Comparing the BIM maturity of different countries.
- Applying models in developing a national BIM roadmap.

Data for the Irish macro maturity study was collated through a survey tool developed by members of the BIMe Initiative and hosted on BIMexcellence.org [10]. The maturity study in this research, as similar to 2017, focused on "markets" and not projects, teams, organisations or individuals. Specifically, the study undertook to investigate the levels of "adoption and diffusion" of BIM in Ireland. A selection of complementary research initiatives was used to triangulate the data.

III IRELAND'S MACRO MATURITY MODEL 2019

The same 19 persons from 2017 were targeted to complete the macro adoption study, along with 7 new respondents who are actively involved in BIM. A total of 13 persons completed the study. While responses were lower than 2019, they were still well above the threshold required to produce functional data for interrogation from the macro adoption models. This section will explore the results and compare them with the findings from 2017.

Model A: BIM diffusion areas

The macro-adoption model clarifies how BIM field types (technology, process, and policy) interact with BIM capability stages (modelling, collaboration, and integration) to generate nine areas for targeted BIM diffusion analysis and planning. The 2017 results showed that Ireland was mature for modelling processes and model workflows, but it was weak in regard to collaboration processes and policies. Table 1 details the results from 2019 in comparison to 2017.

The BIM diffusion model for 2019 (Figure 2) determines that Ireland has experienced a steady increase in both collaboration and integration for process and policies. The improvement in policy and processes in regard to the BIM collaboration fields can be partially attributed to the roadmap and government's digital strategy.

However, a more significant initiative which has helped in this context is the introduction of ISO 19650. The ISO 19650 documents provide a standardised approach to using BIM for the delivery phase of assets [11]. The Irish BIM community previously reported that it was comfortable working with the requirements of BS 1192 and the PAS 1192 suite of standards [1].

As these documents have influenced the new suite of ISO 19650 standards, it has resulted in a smooth transition for the Irish BIM community, which has contributed to the increase of this diffusion model.

This maturity model should exhibit further growth in the coming years as the National Standards Authority of Ireland (NSAI) now offers third-party certification to IS EN ISO 19650 part 2. The certification scheme caters for three main categories of organisations - employers, designers and contractors. Other certification bodies, such as BRE, have developed a certification pathway scheme that offers BIM certification and is now focusing on the Irish market due to the uptake of BIM within the sector.

	Techno-logy (%)		**Process (%)**		**Policy (%)**	
	17	**19**	**17**	**19**	**17**	**19**
Integration	42	58	21	37	13	25
Collaboration	58	65	35	44	23	27
Modelling	76	77	45	46	27	35

Table 1: BIM diffusion 2017 vs. 2019

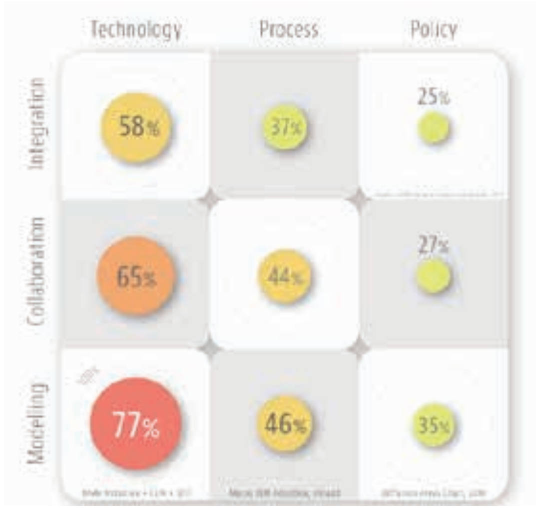

Figure 2: BIM diffusion areas model for Ireland 2019

Model B: Macro Maturity Components model

The macro maturity components model identifies eight complementary components for establishing and measuring the BIM maturity of countries and other macro organisational scales. The components are: Objectives, stages, and milestones; Champions and drivers; Regulatory framework; Noteworthy publications; Learning and education; Measurements and benchmarks; Standardised parts and deliverables; and Technology infrastructure. Table 2 details the results from 2017 in comparison to 2019. Figure 3 illustrates Ireland's current maturity within each area.

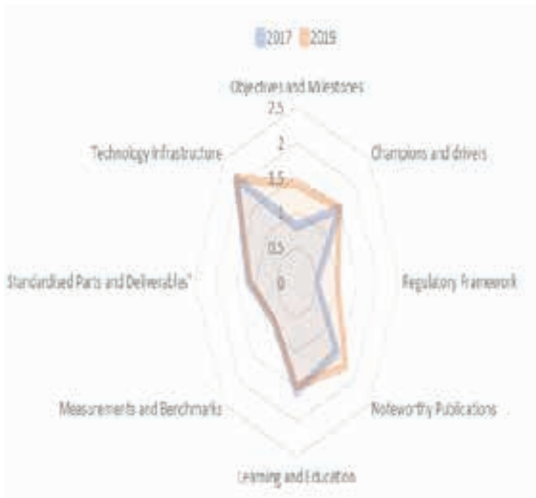

Figure 3. Model B macro maturity components model for Ireland

Compared to 2017, Ireland has seen moderate growth in the majority of components. The largest growth has come within the objectives and milestones, regulatory framework and noteworthy publications. In 2017 concerns were raised that unless a regulatory requirement for BIM is promoted from within the government, then these critical areas would stagnate or regress. The roadmap, government's digital strategy and ISO publications have all played a part in elevating these figures.

	2017	2019
Objectives, Stages, and Milestones	0.8	1.4
Champions and Drivers	1.5	1.5
Regulatory Framework	0.5	1
Noteworthy Publications	1.4	1.7
Learning and Education	1.6	1.7
Measurements and Benchmarks	0.8	0.8
Standardised Parts and Deliverables	1.2	1.2
Technology and Infrastructure	2.1	2.1

Table 2: BIM diffusion 2017 vs. 2019

While other figures have not significantly grown, they remain stable. Ireland's technology and infrastructure continues to attract foreign investment with Project Ireland 2040 firmly placed to support businesses and communities across all of Ireland in realising their potential [12]. Learning and education remain strong with ongoing commitments to digital construction evident within leading third level educational bodies. This commitment is fundamental as the Irish construction industry now faces an unprecedented skills shortage that could potentially impact on the proposed Project Ireland 2040 targets, with 86% of contractors identifying staff shortages as a major concern [13, 14].

Model C: Macro Diffusion Dynamics Model

This model assesses and compares the directional pressures and mechanisms affecting how diffusion unfolds within a population. The model includes three diffusion dynamics: top-down; middle-out, and bottom-up. The model is also augmented by three pressure mechanisms: downwards, upwards and horizontal. Results are similar to those of 2017, which suggest again that that Ireland's diffusion dynamic is still middle-out, meaning that larger organisations or industry associations are pushing the BIM agenda within the industry and not the government.

As the government has not provided strategic funding to-date or guidance documents to assist with BIM implementation, this has resulted in this model remaining static. This is concerning considering that unless adequate funding is provided to support the government's digital strategy, it may risk further alienating SMEs within an already demanding and extremely competitive sector [15].

Model D: Policy Actions Model

This model identifies, assesses and compares the actions which policymakers take (or can take) to facilitate market-wide adoption. The model includes three policy approaches, namely: passive; active and assertive. These approaches are, in turn, mapped against three policy activities: make aware, encourage, and observe. Table 3 details the results from 2019 in comparison to 2017. Figure 4 illustrates Ireland's current maturity within each area.

	Passive (%)		Active (%)		Asserti-ve (%)	
	17	**19**	**17**	**19**	**17**	**19**
Communicate	68	55	32	45	0	0
Engage	74	73	21	18	5	9
Monitor	95	82	5	18	0	0

Table 3: BIM policy actions 2017 vs. 2019

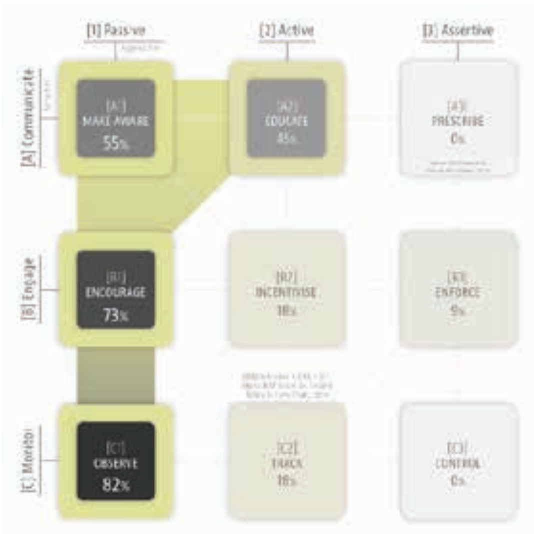

Figure 4: Macro diffusion dynamics model

In 2017 the policymakers in Ireland were mostly passive, with some evidence of active approaches and with little or no assertive activities. While results are similar in 2019, it is encouraging to observe that the Irish government is now seen as taking a more active approach when it comes to communication. This is evident by recent initiatives, such as the establishment of the Construction Sector Group (CSG), which ensures that regular and open dialogue between government and industry takes place on how best to achieve and maintain a sustainable and innovative construction sector positioned to deliver on the commitments in Project Ireland 2040. A part of the CSG's remit is to advise on BIM and other digital innovations and processes. The CSG reports to the

Minister of the Department of Public Expenditure and Reform (DPER) [16]. The Public BIM Sector Group has also played a valuable role in educating members of the public sector through workshops and Hackathons.

While results have improved in comparison to 2017, there is a slight reduction in incentivisation despite an increase in training. These figures would be predicted to decrease or stagnate if the government fails to provide the industry with more encouragement and support to adopt BIM.

Model E: Macro-diffusion responsibilities

This macro adoption model analyses BIM diffusion through the roles played by industry stakeholders as a network of actors. It first identifies nine BIM player groups (stakeholders) distributed across three BIM fields (technology, process, and policy) as defined within the BIM framework. The nine-player groups are policy makers, educational institutions, construction organisations, individual practitioners, technology developers, technology service providers, industry associations, communities of practice, and technology advocates. Table 4 details the results from 2019 in comparison to 2017.

	2017	2019
Policy Makers	1.2	0.5
Educational Institutions	2.7	2.7
Construction Organisations	2.4	2.4
Technology Developers	2.9	3.1
Technology Service Providers	2.6	3.2
Industry Associations	2.2	2.1
Communities of Practice	2.4	2.1
Technology Advocates	2.7	3.2

Table 4: BIM diffusion 2017 vs. 2019

In 2017 the technology developers were seen as the most influential technology players. However, the developers, service providers and advocates are now seen as co-leaders in this space (within the accuracy of the data). For the policymakers, the educational institutes continue to have much higher BIM diffusion compared to policy makers. On a concerning note, the survey shows a significant drop for policy makers within this area which indicates that, despite an increase in objectives and milestones, regulatory frameworks and a move toward an active communication strategy, industry in overall are not satisfied with the government's leadership and support. Educational institutes have responded in kind to this, as seen through the growing number of undergraduate and postgraduate BIM courses, such as the 2019 Irish Construction Excellence Postgraduate winning Masters in Applied BIM and Management at TU Dublin. There has also been a marked improvement in BIM-related research projects, such as the Horizon 2020 BIMcert project, Limerick Institute of Technologies BIMeED project, Galway Mayo Institute of Technology BIM Futures project, TU Dublin/TCD BIM Frameworks, etc. [17 – 19].

The construction organisations are seen as the key process players. However, industry associations and communities of practice are also ranked highly. The BIM in Ireland Umbrella Forum, co-ordinated by CitA, was launched in January 2019 and provided an additional neutral and holistic environment for the sharing of information for review or comment between the different professional institutes digital construction / BIM subcommittees. The Forum has provided updates to the Irish AEC industry on work being performed by the individual professional institutes with regards to digital construction [20]. Some key milestone within 2019 includes the launch of the Construction Industry Federation's BIM Starter Pack, NSAI's ongoing work on a National Annex for ISO 19650 and the CitA BIM Regions continued dissemination and educational workshops on digital construction. Perhaps the most significant development has been the launching of the Royal Institute of Architects (RIAI) BIM Guidance Pack which has provided industry-ready templates, such as, Employer Information Requirements, BIM Execution Plan, etc. Other forum members included BIM subgroups from the Society of Chartered Surveyors (SCSI), Association of Consulting Engineers (ACEI), Women in BIM (WIB), Irish Public Sector BIM Group, Institute of Engineering Surveyors and Transport Infrastructure Ireland (TII), who all continue to do crucial work in promoting BIM within their respective organisations, as well as communicating amongst each other to ensure ongoing conversations are happening.

IV Digital Transition for Ireland's Construction Industry 2018 – 2021

The National BIM Council (NBC) of Ireland roadmap to digital transition for Ireland's construction industry 2018 – 2021 advocates more productive ways of working that improve competitiveness at home and overseas. The roadmap was divided into four key pillars; leadership, standards, education and training, and procurement. This section will explore how the results from the macro maturity models have provided an insight into the current state of the roadmap.

a) Leadership

The leadership section of the roadmap requests that strong, consistent leadership is at the very centre and that it is essential that a platform is created and supported with the resources to sustain the change process. While government has not provided the leadership required, as of yet, there is still evidence that the industry continues to mature.

In the recent NBS CitA survey it was reported that 76% of respondents had adopted BIM. According to the macro maturity models, leadership is presented by construction organisations, professional institutes, and the 3rd level educational sector. Despite no strategic funding being provided to-date from the government, some public sector organisations, such as, the Grangegorman Development Agency, Dublin City Council, Transport Infrastructure Ireland, Office Public Works, Office of Government Procurement, National Development Finance Agency, amongst others, all continue to push BIM. The NBS CitA survey also reports that BIM is being used more often on public sector projects, such as health projects [20].

One of the key recommendations within the leadership pillar in the roadmap was the establishment of a National BIM Centre of Excellence with a focus on driving the digital transformation of the sector. A collective consortium of industry bodies has presented their findings to the CSG on a roadmap for what services the Centre of Excellence should offer and how it should be funded. The paper by Hore et al. [21] also provides supportive information on a proposed framework for a BIM Centre of Excellence and how it could be managed. This funded Digital Centre of Excellence could support the roll-out of digital tools and processes in Ireland while in the short term it could provide a platform for the digital transformation programme envisaged by the NBC in 2017 [22].

b) Standards

One of the key recommendations within the standards pillar was to specify training, educational and certification support initiatives to develop the core BIM capabilities of the industry. The roadmap suggested that government, NSAI and other recognised institutes, develop industry training and certification programs on current best practice standards. In response, as suggested within the roadmap, NSAI has now developed a BIM certification program. This is aligned with the publication of IS EN ISO 19650 part 2, which provides an internationally recognised standard for BIM. Along with the development of the National Annex and the ongoing release of templates and guidance documents, such as the RIAI BIM Pack, continued progress is expected in this area.

Other targets within the standards pillar include support for Ireland's involvement in international and European standards development and aligning planning, building control and public asset information with standards. These aims are both being managed, with three Irish BIM experts attending CEN meetings and, for example, funding being made available for a Postdoctoral Scholar at Dublin City University to investigate how Industry Foundation Classes can be used for digital planning and building regulation control submissions. The development of online tools and supports to help implement "National Tools" has yet to be progressed.

c) Education and Training

The third level education sector continues to be seen as the primary entity for upskilling. Professional institutes also continue to upskill internally by offering workshops and documentation regarding BIM. Organisations, such as CitA, continue to provide guidance to both large enterprises and SMEs within the sector through workshops, discounted training, conferences, research publications, etc.

The roadmap outlines a series of recommendations to deliver a broad awareness and upskilling learning framework for both educators and industry through a National BIM Education Taskforce within the educational and training pillar. A necessary action for the taskforce is the inclusion of digital design and construction in second-level curricula. To target the skills shortage at its core, it is recommended by the authors to explore exemplary international initiatives, such as Class of Your Own and BeIMCraft [23-24]. A condensed focus on pupils before they finish secondary school can assist in presenting them with a broad and diverse range of career choice opportunities within the construction sector. The platform of BIM and other digital technologies can be used to demonstrate the attractiveness of the industry in meeting the aspirations of future generations. At present, the National BIM Education Taskforce has not been established.

To-date, the development of an online BIM self-assessment tool for companies and a base level of learning outcomes targeted at alternative National Framework of Qualifications (NFQ) levels have not been progressed.

c) Procurement

The procurement process of a phased BIM mandate for public works projects is on schedule to commence in Q2 2019. However, as of yet, there are no online supports or reviews of the suitability or provisions made for developing government construction contracts. Concerning the maturity, despite rising in this area, benchmarks and processes may stagnate unless clear direction is provided. The absence of significant developments in these latter areas since 2017 is a cause of concern and addressing these deficiencies should be the focus of the various stakeholders in the next two years.

V CONCLUSIONS

Ireland has shown a steady increase in some aspects of its BIM maturity since 2017. The Irish AEC Sector has, by default, led in the execution of parts of the roadmap and, in doing so, achieved a number of significant targets. However, as evident from the findings from the maturity models, there are still many vital objectives outstanding that will need funding if the key aims of the roadmap are to be achieved. Importantly, these include the establishment of a Digital Centre of Excellence, online tools and support and a BIM self-assessment tool. The AEC sector now finds itself at a crossroads with a push from government required to advance the BIM maturity within the industry. Without this incentive, the industry's digital transition may stagnate, as evident from the comparison of the 2017 and 2019 macro maturity models presented here, where a number of vital outcomes remained the same. The industry cannot afford to stay static and must advance in line with other global jurisdictions to maintain its competitiveness.

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Digital Transformation & BIM Implementation for Small Medium Enterprise (SME)

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Abstract: Construction professionals in the AEC industry are considering the implications of adopting new international standards – which fundamentally affect how practices operate today. Small and medium architectural practices are now asking themselves how they might achieve a proficient and effective working BIM environment.

Ireland is late in adopting BIM processes due to its smaller market and lower, single project and capital budgets. There is now a growing emphasis of effective scheduling and information management in construction projects to increase productivity and performance. This has led to a rise in the use of BIM across the Irish Construction Sector. We recognise the importance and many advantages of BIM and are committed to using innovative processes of managing and modelling building information during a project lifecycle - for a larger number of smaller developments.

We would like to share our own insights into the key detail components that result in the incorporation of digital workflows and processes. These are standards that can't be ignored during such a significant overhaul in workflow processes and information management for small-medium enterprises. As SMEs generally do not have the necessary resources to implement BIM therefore, we also would like to share the problems faced – and the solutions achieved.

As an SME architectural practice, we recognise the importance and need of this transformation.

BIM implementation is archivable in a manner that is structured and accessible for the whole AEC industry, not just the largest players.

Keywords – Standardisation, Implementation, SME Process, Technology, Workflow.

DESCRIPTION

The purpose of this paper and associated presentation is to illustrate the steps an SME Architectural practice have taken in their move to BIM related processes and the challenges and responses that have been required. The scope of the paper is to place the adoption of digital transformation in the context of small practice – that client group, construction group and consultant group.

The paper will illustrate aspects of BIM implementation that are most relevant to smaller consultancies and aims to share the benefit of this experience with practices of a similar scale.

INTRODUCTION

OBFA was formed in late 2012 at the end of an extended recession period that had decimated the sector. The business comprised of the two directors and a one room office. All equipment, software's and methods had to start from the beginning – not by choice but by circumstance. Both parties had come from a legacy practice no longer trading but with projects half finished, with differing datasets and stages of completion.

In 2019, the practice has grown to 12 person strong business with a healthy turnover and multiple medium to large projects from design to site stages.

None of these have yet been delivered through BIM level 2 …

The difference is that now we know how to do it if we are asked.

This paper is structured in three phases – Past Present and Future. In each section we want to illustrate the nature of the digital transformation and how it manifested.

PHASE 1 – 2012 – 2016

It is pertinent to describe the context of architectural practice in 2013. Work was only beginning to pick up. The simplest solution was to maintain the status quo. A CAD environment existed that could have been maintained – and this would have allowed projects to pick up pretty quickly where things had left off. The practice had two projects that had propagated and required immediate consultancy.

However the practice did have to repurchase new hardware and was aware that the drawing environment was changing. The expenditure of social welfare redundancy had to be done wisely and the practice decided to ride the wave without really knowing how to surf yet.

We were aware of a skill gap, but also know that it was narrow. The broader training is generally solid - Architects and Technologists are well trained people and generalists by nature. So this was really just about starting to relearn how to draw again. This was not the first time for a fundamental change as both directors had been originally trained in Pen and Ink.

Platform Commitment / Formalised Training

- Decision to proceed with the Autodesk AEC platform.
- Decision made because the platform appeared to have committed to Ireland where others had stepped back.
- Decision made due to realisation of the need for close correlation with partner engineering consultants.
- Decision made because there was an option that was cheap.

Both Directors took explicit formal training – and were fortunate to have supportive teachers in ArcDox.

There was a generosity in sharing of knowledge here which led to trust and this led to a closer multi year relationship.

The practice had 6 months of work that were hours learning by doing. This is a necessary exercise and may be expected. It was mitigated by a still slowly recovering industry. The business had time.

Very rapidly the practice realised the potential of designing in 3D and designing with data rather than lines and circles. We had put in place the environment where we had no choice. This was now the ONLY way we could deliver a normal architectural service. This is a combination that leads to focused progress.

What we did - which didn't work –

We decided to work with an outside BIM consultant to immediately set down our structures and processes.

Why did that not work

- It was too formal, too fast.
- It was trying to shape large process methods on a small project environment.
- It was not telling us how to do anything – just how we should be thinking about doing things.

What we did which worked –

We were aware that some third level courses had been training Technologists through Autodesk Revit and those initial graduates were coming on stream.

The practice recruited a new graduate who needed professional knowledge which the practice could provide.

The benefit was – he knew how to do stuff and could show us.

Lesson Learned –

Practices must have confidence in the students and graduates coming through. While they have gaps in particular knowledge – they have been working in what was then a new environment for 4 years. With active mentoring they could get work done.

The practice found that it was of exceptional important to instill the necessity for rigor, for responsibility and the impact of decisions. In reliance that confidence and specific competence it is critical to transition from a student to a professional environment

It is necessary for smaller practices to realise who their client base is – and are going to be. It is only at this stage that the practice determined to fit the method with the expectation of the employer.

The practice did need to consider a more formal BIM Implementation Plan. Initial drawings and documents prepared by the practice only alluded to a BIM process but did not apply this with rigor. (Fig 1.)

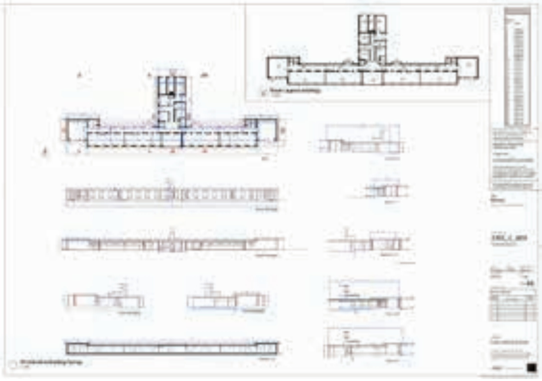

Figure 1 – OBFA – Early modelling outside formalised BIM execution plan.

Figure out your business strategy before you invest anything.

Businesses that aim to enhance organizational performance through the use of digital technologies often have a specific tool in mind. *"Our organization needs a machine learning strategy,"* perhaps. But digital transformation should be guided by the broader business strategy.

Our practice has not found a single 'technology' that can deliver a reliable and definable solution as such. In our experience, we find a combination of technology best suits our daily operations, and this varies between organizations.

Leverage insiders

Businesses that seek transformations (digital and otherwise) frequently bring in an army of outside consultants who tend to apply one-size-fits-all solutions in the name of "best practice." (Behnam 2019). In our experience, transforming our practice needed to rely instead on insiders — staff who have a deep knowledge about what works and what doesn't in their daily operations. It is the responsibility of business owners hear to resource this knowledge

Recognize employees fear of being replaced.
When employees perceive that digital transformation could threaten their jobs, they may consciously or unconsciously resist the changes. If the digital transformation then turns out to be ineffective, management will eventually abandon the effort and their jobs will be saved (or so the thinking goes). It is critical for leaders to recognize those fears and to emphasize that the digital transformation process is an opportunity for employees to upgrade their expertise to suit the marketplace of the future.

PHASE 2 – 2017 – 2019

The practice was growing, and the sector was recovering and trying to catch up on 10 years of low activity. As well as the core business of design, small practice has to manage a large number of processes. These are only increasing in number and complexity. They are also – by and large, universal to both small projects and large ones which means they become resource hungry. The most notable of these between 2014 and 2018 is BCAR.

Any small practice will want to hold onto a core design ethos – and it is easy for this to be lost within all of these processes competing for time and resource. BIM implementation is at risk here of being left behind. Its demands are broad, fundamental – but not legal or regulatory.

The practice was now familiar with the software we were using and by 2016 was a practice of 6. In each case, architects and technologists who joined the practice undertook prompt formal training on the basics.

We had begun to make modelling and information more consistent, but nothing was formalised. We were alluding to standards such as PAS 1192 that gave guidance and structure, but we never had a project large enough to apply it with rigor.

Processes were maturing but by 2016 so was the wider environment. CITA was very active, Government was sitting up and taking notice, Departments were starting to trial methods of data for new buildings – led in part by OPW. The practice took some assurance that the environment of BIM and modelled data was robust and more relevant to the Irish market. This would affect our ability to broaden our client base.

A telling moment was when Fingal Co. Council issued an initial tender for architectural services where the deliverable was to be structured in a BIM L2 environment. OBFA submitted and were in good company in losing. For a simple housing project, the winner was UK based and had won the project based on a detailed knowledge of a process – a process we could not apply with confidence.

Our client base both public and private entities had heard about BIM, but the depth of the process change was not appreciated. BIM was a 3D render - for free.

The practice needed to have someone in the practice whose partial duty was to put manners on the whole practice in terms of structure and standards.

We were able to offer a good working environment and room for someone to grow. This is good business and can be applied at the smallest of scales.

Yeu came to the practice in 2017 and was assisting remotely before then. He was coming from a much larger practice structure working on larger projects and in a mature BIM environment. He also has the interest, the knowledge and a willingness to try something.

The practices job is to nurture that and resource it. As such OBFA undertook basic formalization of standards for all projects in the practice.

1. Information Management & Standardisation

The practice utilises a simple and typical CDE function before issuing any content to external parties by creating a three step approval process within. This is essential before we issuing any contents to external parties.

First step: Review by Project BIM Manager
Review of the project by the project BIM manager to ensure all the model/drawings have met the office standard.

- Model Quality Checklist (QAQC Checklist)
- Modelling accordance to In House Model Development Specification
- Model Checker

Second Step: Review by Lead Architects (Design Review)
Review by lead architect that the drawing and model are accordance to design intent. This is done either digital or paper markup.

Final Step: Approval required by director before issue
Approval is required by directors before issue any drawings/model to external parties. This is a three step process that requires review by all levels of the practice. (Fig 2.)

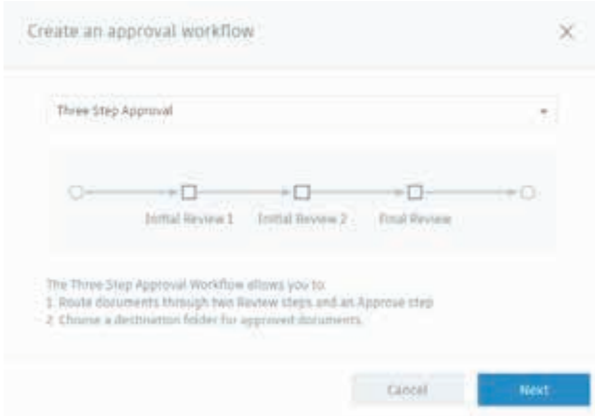

Figure 2 - OBFA Adopted approval process for projects

Note: Not all information is uploaded to the cloud or third-party cloud solution.

Standardization

Without standards, the practice is not able to have effective and efficient way to manage information. At the start, we have a vision that certain standard needed to be introduce within the practice wide.

BIM Execution Plan / Model Development Specification

2. Model Structure Process

A Project is set up as a series of models dependent on the brief, stakeholders and perceived deliverables. The overall project model(s) is federated to allow separate site/building and consolidated modelling data which allows for an easily understood series of datasets. This somewhat duplicates embedded software systems in some BIM modelling platforms, however is more accessible and usable by small practices making the transition from traditional CAD drawing structures. These are exemplified below (Fig 3., Fig 4.)

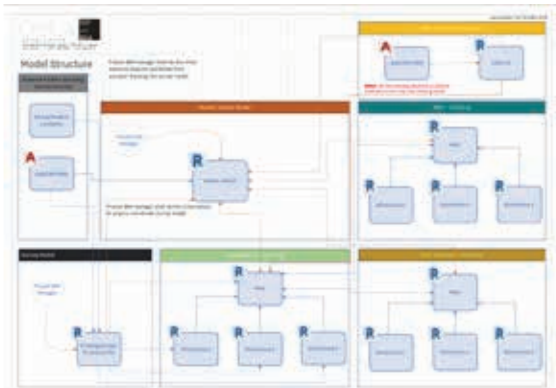

Figure 3 - Sample Model Folder Structure Map

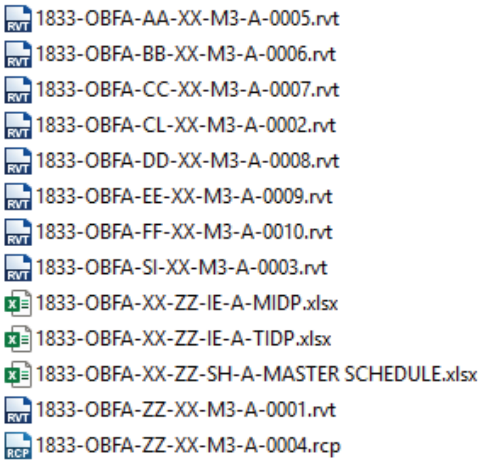

Figure 4 - Example File naming for models

2. ETI – Early Technologist Involvement

The Technologist has an expanded role in the earliest part of project inception.

From the very start of the project there is an information gathering and assembly of the model environment. This involves the technologist input significantly and provides the base against which accurate design can happen. The role is to set up the information environment from the beginning and to take ownership of it.

We refined and overhauled our model structures to suit the project and the number of people working on it.

This is a new process within our practice by involving the technologists early in the project brief. In our experience, this has a positive effect on how the practice structures the way it works. We have introduced two new sub-process that integrated with the project:

Project Kick-off Session:
When a project coms to the practice which will involve design and drawing preparation it is included in a group meeting where the data environment is part of the discussion.

Stand up Meeting:
The practice is starting to introduce a "Stand-Up Meeting". The Stand-up meeting concept originates from IT programming industry. In our case, we adopted the concept by keeping our project meeting short and this happen on daily basic, so that enable the lead architect can track and task necessary to individual team members. Meeting content is recorded in OneNote, and all practice members have access to the discussion.

Dual Process here – Architects are encouraged not to jump into modelling to soon. The sketch roll is still in use and aids in setting out the ideas and forms.

At the same time, the technologist is prepping the 'vessel' into which the information will develop. The architect briefs the technologist on the nature scope and deliverable of the project and the technologist then takes ownership and responsibility for the consistent preparation of the future BIM/Modeling environment.

Lessons Learned

- A consistent repeatable file and folder structure.
- A logic based file and folder naming convention that everyone must use.
- A clear process for managing and using different types of information (Models / Drawings / Graphics / Documents / Photographs)
- Centralised resources
- Maximising use of legitimate software purchasing.
- Technology and Process must be combined in order to work.
- Process review is iterative – Every 6 months be prepared to take a hard look at what is not working.
- There are no "standard" processes that will fit everyone.
- You will need to explore together within the team/practice to achieve the best processes that work for you.
- Avoid the BIM consultants at the beginning.
- Do the basic implementation, then invite external consultants to review
- Over planning or 'Completion Planning' can lead to problems.

When you have achieved a level of comfort in the process, apply rigor promptly. Don't wait.

Give the authority and resource to the person charged with implementing it – don't hamstring them.

PHASE 3 – 2019 - 2024

Leverage the information.

BIM Maturity
The practice has started to review some of the

metrics on progress. We utilise free tools to measure our BIM maturity. This is to give us guidance on our weaknesses and illustrates areas requiring focus. Comparative readiness is illustrated in Fig 5. and Fig 6.

Figure 52 – OBFA self-assessed maturity in 2016

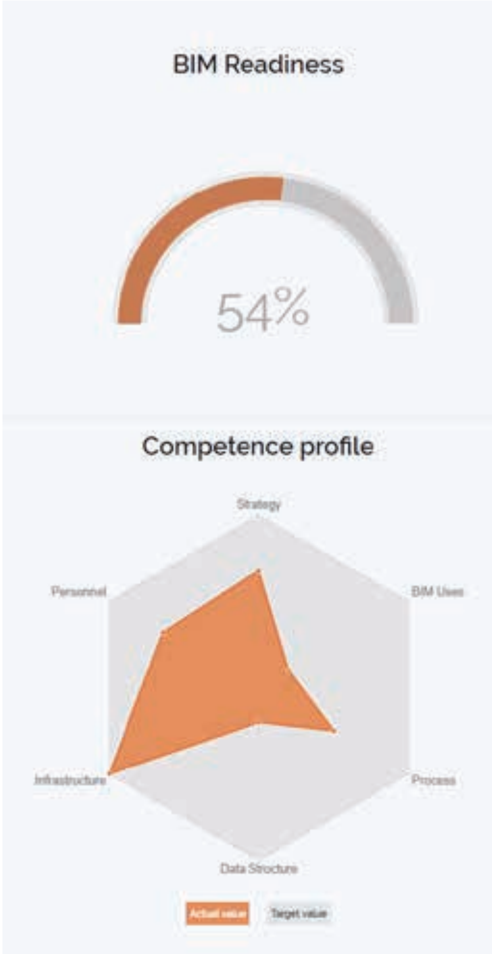

Figure 6 – OBFA self-assessed maturity in 2019

In examination to the figures above, we can clearly identify where we should focus our resources and energy. For OBFA, weaknesses today are -

1. Data Structure: IFC data, Uniclass information .

2. BIM Uses

A BIM use is defined as method of applying Building Information Modelling during a facility's lifecycle to archive one or more specific objectives. BIM uses has general definition and capabilities, such as clash detection between building elements or extract data for facility management use.

We have yet to find ourselves in a scenario where this is required.

Future Practice

What is next for us? What is our future goal in terms of Digital transformation & further BIM implementation? We are going to focuses on 2 areas:

1. Robustness of Process

Our intentions are to refine and smooth the manner in which BIM processes are used on a daily basis in the practice. The act of undertaking tasks on a regular basis under the controls of a defined process allows them to be come familiar and normal. This in turn identifies flaws, gaps and loopholes. The response is to correct, enhance and make normal the correct process and method as part of normal activity.

The practice expects this to be an ongoing iterative process over the medium term.

2. Analytics of Data

Every day, the practice generates a large amount of data through BIM modelling and associated processes. A large part of this information lies in the background, unseen and not overtly of use.

We are exploring how we extract meaning from this data and to analyze this to to improve our day to day workflow.

Example 1: We extracted model data from our BIM software and imported this into Microsoft Power BI (Business intelligence) to enable the raw data to have a visual representation: such as room areas with different zonings, colours and occupancies. This is a useful tool to provide metrics to a non-specialist party or client. This is illustrated in Fig 7.

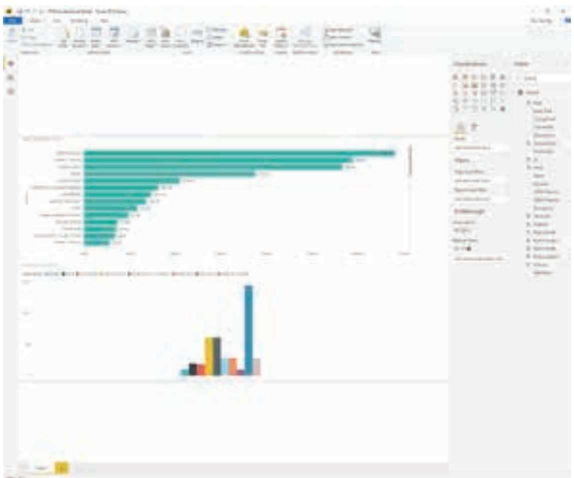

Figure 7 - Power BI data analysis

Example 2: We are seeking to analyze data via BIM 360 which we are using as our primary CDE. All users (including external design team members) are accessing project contents via BIM 360 to do mark ups and raise design issues. This data can be extracted from BIM 360 via Autodesk Forge and transposed to Power BI to show how many issues were raised, their nature and from which discipline. This process helps OBFA to identify genuine design issues or flag simple modelling/drawing errors. It also identifies in each discipline what kind of primary information they are looking for so that we can integrate this knowledge in any future project.

Summary Thoughts

We have listed 5 steps applicable to small practice for those who would like to commence some degree of BIM implementation and digital transformation. None of these will hugely interfere with a business's ongoing ability to deliver services.

1. Reorganize how information is stored and compiled. Revamp folder structures, centralize resources.

2. Focuses on people: broaden the roles of those who have an interest and a commitment. Let the graduates show you what they can do and then apply a firm professional ethic to that ability.

3. Look at what processes are already in place and start to align them with the standards. Do this iteratively. Don't bring in 3rd party consultation until you know what you are asking from them. If you don't understand the question, how can you understand the answer?

4. Work with a familiar design team to implement a shadow BIM environment. Workshop, find a small project to trial, don't rely on an employer direction.

5. Leverage the professional institutes: RIAI has released a comprehensive BIM Pack which contains advice notes and templates. This resource is only going to improve.

Conclusions

This is the most common misconception about BIM. You should not expect miracles simply by changing your tools from 2D CAD to 3D models and expect everything will align automatically.

BIM is not a thing or a component that one can just deploy with one or two statements in a contract.

Small practice needs to absorb BIM processes in a smart way. Start with the simple changes in process, engage committed people in order to get the most benefit out of BIM and be very sure of what you declare you can do.

'Digital transformation is not about technology. According to a recent survey, 70% of all digital transformation initiatives do not reach their goals. 1.3 trillion dollars was spent on digital transformation in year 2018, and it was estimated 900 billion went to waste.' (Behnam 2019)

Any small practice in the SME sector can compete to win larger more complex projects. It is stated RIAI policy to assist smaller practices to do so. It is to our advantage that this scale of practice has access to a wider base of smaller clients on one side and larger clients on the other.

This type of practice will be undertaking the health centres, small infill schemes, urban repair, housing projects around the country.

There is a large body of work here and its much more economic for the SME sector to undertake it – professionally and profitably.

A concern will be if a data-based standard is imposed that applies a mandatory level of complexity to ALL projects, where this simply is not required or desired by the people who will own and operate such buildings. There remain large skillset gaps in Local and Central government and there does not appear to be an impetus to address this. Here lies a role for the SME professional services practice.

So, the goal is to ensure that the data deliverable is appropriate to the building and its user while aligning itself to a consistent and industry understood set of standards.

Internally, this means that architects, engineers and technologists will continue to need assistance and guidance in applying robust work methods to the various stages of scheme development.

On reflection, OBFA can attest that the adoption of BIM processes and methods have been successful. The practice has seen efficiencies. Architects undertake less 'drudge work' with schedules and lists. Architects can produce internally; drawings as design tools that we could not avail of in 2012 – efficiently and cost effectively.

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From Roadmap to Implementation: Lessons for Ireland's Digital Construction Programme

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Abstract ─ As part of their Future of Construction initiative in 2018 the World Economic Forum published an action plan to accelerate Building Information Modelling adoption. The WEF report highlighted actions that companies, industry organisations and governments are advised to implement to accelerate BIM adoption and better capitalise on delivering better project outcomes. According the authors of the report BIM is seen as the centrepiece of the construction industry's digital transformation, however they acknowledged that BIM adoption globally remain slow. Anecdotal experience would suggest that BIM usage in Ireland is also very low and that a similar initiative or an adaptation of the WEF BIM Adoption Circle would be applicable to driving the digital transition programme in the Irish construction industry. This paper highlights the actions that companies, industry organisations and governments are advised to implement in order to contribute to the acceleration of BIM adoption. The authors document the results of a consultative survey of representative stakeholders in Ireland in mid 2019. This survey was designed to investigate the relevance of some twenty seven specific actions identified by the WEF to drive digital transition in the Irish construction industry.

Keywords ─ Building Information Modelling, acceleration, adoption.

I INTRODUCTION

Building Information Modelling (BIM) has been a source of considerable debate throughout the world in recent years. Whilst the World Economic Forum (WEF) recognises the relevance of BIM as an important first step for the construction industry to embrace the benefits for digitisation, the adoption throughout the world has been relatively slow [1] [2].

Despite the slow speed of adoption, globally BIM is gaining considerable traction in recent years with governments across the world mandating it use on public work projects [3]. There is also increased evidence that tier 1 companies are increasingly adopting a 'model first' approach when seeking out increased productivity and efficiency benefits. However, the debate has broadened in more recent years 'beyond BIM' with the industry seeking out further productivity benefits by using an array of innovative digital enabled solutions.

The authors concur with the WEF and remain resolute that BIM is a logical first step that must be adopted more widely in the Irish construction industry if the benefits that are widely reported can be fully realised and experienced.

The complexity of construction requires a focal point where all the design elements of a project are coordinated into a single digital design record prior to a commitment to build. This concept of model creation and co-ordination has more recently been developed into the concept of a 'digital twin' [4].

In this paper the authors present the WEF vision in respect to successful BIM adoption by investigating the applicability of adopting the WEF 2018 BIM Adoption Circle of actions designed to accelerate the adoption of BIM in international markets [1].

The findings of a structured consultation study in Ireland with relevant stakeholders is presented in this paper. It is clear from the findings that while there was much support for the WEF adoption accelerators there remains a lack of understanding as to the precise meaning of 'BIM Adoption' and that there would need to be an adaptation of the WEF model for it to have direct relevance in Ireland.

As part of their 'Shaping the Future of Construction' series the WEF described BIM as a

'collaborative process in which all parties involved in a project use three-dimensional design applications, which can include additional information about assets' scheduling, cost, sustainability, operations and maintenance to ensure information is shared accurately and consistently throughout total assets' lifecycles'.

Whilst this explanation is helpful, evidence would suggest that there are relatively few projects where all parties routinely use three-dimensional design applications.

What is clear from the authors' findings is that an order needs to be brought to supporting the industry to transition towards BIM with companies, industry representatives and government all playing a part in the delivery of a digital concept that will lead to improved projects outcomes for all concerned.

This order will be helped by the funding of the National BIM Council (NBC) Roadmap to Digital Transition 2018-2021 [5] but also by the introduction of an implementation plan of actions, such as, envisaged by the WEF in 2018.

This implementation plan will help in motivating, fostering greater collaboration and enabling the industry to adapt to a future where BIM will become business-as-usual leading to a more productive and less adversarial industry in the future.

II BIM IN IRELAND

In Ireland the first formal reference to BIM was included in a 2013 Forfás report which focused on Ireland's Construction Sector [6]. Specific mention was made of BIM in the report as an advanced technology that will ensure increased competitiveness and innovation in the sector. This was followed in 2014 by the Construction 2020 Strategy which aimed at restoring a properly functioning, sustainable and dynamic construction sector, operating at an appropriate level for the size of the economy. The report outlined two specific actions which included implementing a BIM staged development programme to support companies advancing to level 2 BIM capability, which subsequently led to the development of the *BIM Enable* and *BIM Implement* support programmes for Enterprise Ireland clients [7].

In January 2017 the Government launched its *Action Plan for Jobs 2017* [8]. A particular action flowing from the Action Plan for Jobs 2017 included a requirement for the Office of Government Procurement and Enterprise Ireland to prepare a strategy for the adoption of BIM across the public capital programme and to mandate the manner in which it is to be adopted across the public sector.

Following consultation with public bodies engaged in public works projects, the government Construction Contracts Committee (GCCC) prepared a position paper in 2017 for the purposes of inviting responses from industry. Titled *A Public Sector BIM Adoption Strategy,* it outlined the context and rationale for the adoption of BIM on Irish public works projects and put forward a proposed timeline for adoption, ranging from 12 - 48 months, for projects to adopt BIM. These projects range from Band 1, which are of low complexity, such as low density housing projects, to Band 5, which are complex projects with a specialist operation and maintenance regime, such as acute hospitals [9].

In December 2017 Ireland's National BIM Council published the Roadmap to Digital Transition for Ireland's Construction Industry 2018-2021 [5]. The Roadmap consists of the four parallel pillars of leadership, standards, education and procurement with particular milestones to be achieved for each of the pillars during the programme period 2018-2021. Unfortunately, at the time of writing this paper, no funding has been secured from the Irish government for the implementation of the first three pillars. The procurement process of introducing on a phased basis a BIM mandate for public works projects is on schedule to commence in Q2 2019.

The increased level of interest in BIM in Ireland has been driven primarily by Construction IT Alliance (CitA) in the delivery of specific monthly BIM events, a CitA BIM Gathering International conference in 2013, 2015, 2017 and 2019, and its successful CitA Skillnet training funded programme. In early 2016, CitA secured funding for the BIM Innovation Capability Programme for Ireland to capture the current state of readiness of the Irish construction industry to work with BIM. In late 2017 CITA published a BIM in Ireland report [10] which provided a detailed account of the various initiatives and communities of practice advancing BIM in Ireland. An updated version of the report is due to be published by CitA in Q3 2019.

In February 2018 the Government of Ireland published the Project Ireland 2040 report which took a radically different approach to future planning (2018-2017) in Ireland. The initiative involved the formation of a Construction Sector Group (CSG) that would report directly to the Project Ireland 2040 steering group [11].

The CSG was established in order to ensure regular and open dialogue between Government and the construction sector. The CSG formed a Growth and Productivity Sub-Group to look at a wide-ranging analysis of productivity to inform new industry approaches for improvement. Their remit also included taking forward proposals from the BIM Roadmap.

III WORLD ECONOMIC FORUM BIM ADOPTION CIRCLE

The World Economic Forum's Future of Construction Initiative in collaboration with The Boston Consulting Group developed the *BIM Adoption Cycle* [1].

The implementation framework is shown in Figure 1.

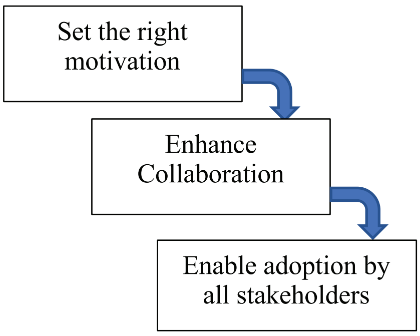

Figure 1 –WEF Implementation Framework

The authors of the WEF report suggested that '*increasing BIM adoption requires greater collaboration and that stakeholders should be motivated and given the right capabilities'*.

In addition they stated that

'Successful BIM adoption requires a high level of collaboration among stakeholders. Steps toward that include increased use of integrated contracts and open standards for data sharing. Adoption also requires a coordinated effort to attract new talent with digital and BIM skills, upskill existing workers, and changing corporate cultures to support new processes. As major owners of built assets, governments must make a long-term commitment to the technology by piloting it in public works projects and creating regulations conducive to its acceptance, including backing innovative forms of financing'

The report identified actions that companies, industry bodies and governments can take responsibility for to accelerate BIM adoption and better capitalise on delivering better project outcomes. The output of a consultation roundtable discussion with over 35 globally respected stakeholders in construction is illustrated in Figure 2.

Figure 2 – WEF BIM Adoption Circle [1]

Specific actions are further delineated in twenty seven actions with responsibility apportioned to each of the following stakeholders.

1. Companies
2. Industry bodies
3. Government

III METHODOLOGY

The authors selected a sample of respondents representative from the three stakeholder groups identified earlier with the purpose of reflecting on the recommendations of the 2018 WEF Action Plan for BIM Acceleration.

A total of six representative stakeholders from each of the above stakeholder groups were targeted. The sample consisted of senior/middle management who had a particular responsibility, knowledge and interest in the digital transformation of the Irish construction industry.

Table 1 is a summary of the respondent organisations that participated in the survey.

Stakeholder Category	**Respondent Organisation**
Company	Arcdox
	Undisclosed
	BAM Ireland
	Undisclosed
	Ardmac
	Varming Consulting Engineers
Industry Bodies	Construction Industry Federation

	Engineers Ireland
	Society of Chartered Surveyors Ireland
	Association of Consulting Engineers of Ireland
	Royal Institute of Architects in Ireland
Government	Department of Housing, Planning and Local Government
	National Standards Authority of Ireland
	Dublin City Council
	Transport Infrastructure Ireland
	Irish Water
	Grangegorman Development Agency

Table 1 – Survey Respondents

Each sector representative was presented with the WEF BIM Adoption Circle and asked a series of questions pertaining to the likelihood of their organisation accelerating their use of BIM as a direct result of actions identified in the report. Respondents were asked to elaborate on their responses where possible.

1. Would you make any changes to the THREE KEY actions identified as accelerants to motivate your organisation to use BIM?
2. Would you make any changes to the THREE KEY actions identified as accelerants to foster collaboration and risk sharing in your organisation to use BIM?
3. Would you make any changes to the THREE KEY actions identified as accelerants to help enable stakeholders to gain the necessary skills and knowledge that will in the long term change behaviours to achieve better project outcomes in the Irish construction industry?

In addition, respondents were asked to identify which of the 27 actions identified by the WEF could be applicable in Ireland and to share any additional actions that Ireland could introduce to accelerate BIM Adoption.

IV SURVEY SAMPLE

A total of 17 out of the 18 sample identified responded providing a sound platform for analysis..

The following is a brief summary of the profile of the respondents.

a) Industry

The contributors were broadly drawn from three categories, namely:

1. Tier 1 contractors
2. Design firms
3. IT companies

The tier 1 contractors included BAM Ireland and Ardmac who together had a combined turnover in 2018 of in excess of €600 million. Both organisations are renowned companies in their deployment of digital on signature projects and both respondents were of a very senior level and active in the Irish BIM and lean construction communities.

The design firms contributing included Arcdox who are an established BIM specialist providing consultancy service, support and training. In addition Varmings Consulting Engineers are market leaders in commercial, education, healthcare and industrial projects with a mature aptitude and proficiency in BIM. Both respondents are very knowledgeable in respect to national BIM initiatives with one in particular who is recognised as one of the leading authorities in respect to BIM in Ireland for the past decade. Two additional respondents in this category preferred that their organisation was not listed as a contributor to the survey. Both of these organisations are world renowned creators of digital solutions for professionasl across the globe and are presently very active in Ireland.

b) Industry Bodies

Five out of the six representative industry bodies who make up the Construction Industry Council contributed to the survey with each respondent holding an executive role within that organisation. These bodies included representatives from the following Irish construction stakeholders.

1. Contracting
2. Engineering
3. Surveying
4. Architecture

The combined representation of these organisations accounts for up to 30,000 businesses across the Republic of Ireland. Each of the representative bodies are represented on the CSG and have active interest groups looking at BIM and digital construction, as discussed earlier in this paper.

c) Government

The government respondents were purposefully selected to provide a representation from key government departments, local authorities, standard authorities and special public sector infrastructure agencies and authorities. The particular respondents were all very senior in their respective public sectors organisations with a particular responsibility to embrace BIM and other digital innovations in the delivery of public works projects.

IV FINDINGS

The respondents were broadly asked to comment on the WEF BIM Adoption Circle looking at their motivation, collaboration and enablement framework and how they might make changes to these implementation tactics. A summary of the high levels actions are shown in Table 2.

Pillars	Actions
Motivation	Articulate BIM's benefits across the entire lifecycle.
	Think of BIM as a value creator, not as a cost factor.
	Approach BIM as the essential first step to IU digitization[i].
Collaboration	Use integrated contracts and redefine risk-return mechanisms.
	Set up early collaboration and communication among stakeholders.
	Establish data sharing standards and open systems.
Enablement	Establish BIM skills along the full value chain.
	Change behaviours and processes, not just technologies.
	Make a long-term commitment and support innovative financing.

Table 2 – WEF BIM Adoption Circle Action

a) Motivation

In respect to the motivational theme examples of feedback received from the respondents are included below.

'Yes to articulating the benefits of BIM and seeing BIM as a value creator. DHPLG priorities would be foremost to address housing, building standards and planning needs, including prioritising the delivery of housing with value for money and efficient programme to address the current urgent national housing crisis'

'Education, CPD events, seminars etc so that people start to become comfortable and familiar with BIM as BIM can be daunting for non-bimmers or people on the periphery'

'In terms of digitisation of contractors, BIM does not have to be the first step. Use of mobile applications for data collection and use on projects are considered low hanging fruit with digital construction related processes in the field'

'Use examples such as highlighting compliance with Client statutory duties e.g. Project Safety File compliance - BIM links to associated docs such as certs/O&M manuals at handover stage'

Although half of the respondents suggested changes to the three broad actions identified under the motivation pillar there were no specific changes recommended.

It was clear however from the respondents that the government need to play a key role in any driving the adoption of BIM in Ireland by setting an example and mandating BIM on public works projects. Respondents were also of the opinion that the government needs toc commission an entity to manage the digital transition programme and fund the NBC Roadmap in a sustainable way moving forward. Both the industry and the representative need to play their part but these actions should flow from specific actions funded by a national BIM programme.

b) Collaboration

In respect to the collaboration theme examples of feedback received from the respondents are included below.

'Establish a leadership and co-ordination platform to drive digital transformation in the short term'

'Standardised government led guidelines are needed to support the implementation of any BIM mandate to ensure its adoption consistently, otherwise its adoption becomes fragmented, confusing to the industry and by default loses any potential value from the mandate intent'

'It is not clear what is meant by 'integrated contracts' and also what is meant by the redefinition of 'risk-return' mechanisms'

It is clear from the feedback from the respondents that the three actions presented in the model will need to be refined further and that the government once again must play a key role in encouraging collaboration by incorporating this practice in future government public works projects and also demonstrate leadership by driving the digital transformation of the sector.

c) Enablement

In respect to the enablement theme (Table 3) examples of feedback received from the respondents are included below.

'A cultural change to the delivery of building needs to be enabled'

'Again provide more education, seminars, workshops, media coverage etc so that people learn and become familiar with BIM almost by osmosis'

'In relation to (c), is it government that it is proposed should make a long-term commitment? If so this is not clear. In relation to (a) it is not clear what exactly is meant by 'BIM skills'? and the 'full value chain'? Overall, in order to provide clarity to stakeholders, it is important to limit the use of jargon where possible in these accelerators'

'Embed BIM as a contract requirement on a pilot basis in public works projects – the actions are non-specific and read more like general objectives and read more like specific actions will flow'

The imprecise nature of the language used by the WEF meant that a number of the respondents found it difficult to endorse the three actions presented in their present form.

In particular, there was a lack of a lack of understanding by the respondents on the meaning of the reference 'innovative financing' and the particulars of the 'long-term commitment' referred to in the WEF model.

There was, however, a clear and consistent message among stakeholders of the importance that the government must make a long-term commitment to BIM by incorporating this concept into future public works projects and the urgent need for the public sector entities involved in these projects to up skill in BIM workflows and technologies.

It is clear from the feedback of this first component of the survey that the model and the nine actions that were present had merit but did not have sufficient detail in order for the majority to confirm their full applicability in an Irish context. The consistent reference to the government to take responsibility and leadership however was very evident.

The second phase of the survey involved presenting to the respondents a more detailed breakdown of twenty seven actions together with how the WEF envisaged the particular stakeholder taking responsibility for those actions.

A summary of the feedback received for this part of the survey is shown in Tables 3, 4 and 5.

Motivation Pillar	**Companies**	**Industry Bodies**	**Government**
Articulate BIM's benefits across the entire lifecycle			
Develop and pilot use cases that include BIM 6D and 7D applications	27%	**40%**	33%
Leverage BIM data to optimize design regarding O&M costs	**80%**	13%	7%
Use BIM in O&M for public assets and demonstrate benefits in pilot projects	14%	0%	**86%**
Think of BIM as a value creator, not as a cost factor			
Develop benchmarks against which BIM costs and benefits can be measured	13%	**74%**	13%
Allocate BIM costs and savings separately from other financial data to increase transparency	**73%**	7%	20%
Develop an industry standard for calculating BIM ROI	27%	**52%**	20%
Publish BIM ROI assessments of pilot projects	14%	36%	**50%**
Approach BIM as the essential first step to IU digitalization			
Implement BIM as platform to store, manage and share data required by new technologies	**73%**	7%	20%
Develop BIM standards and specifications for digitized built environments	27%	13%	**60%**
Build up digitized built environments and use them for financial planning	33%	13%	**54%**

Table 3 – Feedback on Motivational Actions

In respect to the motivational pillar there was a large degree of similarity between the results of this survey and the findings of the WEF recommended distribution of responsibilities.

1. In respect to the companies there was agreement that they should take responsibility for leveraging BIM data to optimize design regarding O&M costs; allocate BIM costs and savings separately from other financial data to increase transparency and implement BIM as a platform to store, manage and share data required by new technologies. There was varied agreement on whether this stakeholder should take any further responsibility or indeed share responsibility with other stakeholders as envisaged by the WEF.

2. The industry body responsibilities were broadly agreed in respect to developing benchmarks against which BIM costs and benefits can be measured and developing an industry standard for calculating the BIM ROI.

3. The respondents concurred with the government responsibilities identified by the WEF, namely :

    a. Use BIM in O&M for public assets and demonstrate benefits in pilot projects.
    b. Publish BIM ROI assessments of pilot projects.
    c. Develop BIM standards and specifications for digitized built environments.
    d. Build up digitized built environments and use them for financial planning.

In conclusion the respondents largely concurred on the distribution of the actions in regard to the motivational pillar.

In respect to the collaboration pillar (Table 4) there was a degree of variation between the results of this survey and the findings of the WEF recommended distribution of responsibilities.

1. In respect to the companies there was agreement that they should take responsibility for revising corporate cultures, structures and processes for more comprehensive collaborations and support bottom-up consortia to standardize BIM data exchange.
2. Whilst the WEF had allocated particular responsibilities to the industry bodies in in respect to establishing data-sharing standards, the respondents did not concur. No particular actions were identified as the responsibility of the industry bodies in regard to the collaboration pillar.

Collaboration Pillar	**Companies**	**Industry Bodies**	**Government**
Use integrated contracts and redefine risk-return mechanisms			
Increase the share of projects that use integrated contracts	13%	13%	**74%**
Set up early collaboration and communication among stakeholders			
Revise corporate cultures, structures and processes for more comprehensive collaborations	**60%**	20%	20%
Develop BIM collaboration procedures (e.g. CIC BIM Protocol)	13%	33%	**54%**
Establish data-sharing standards and open systems			
Support developing global conventions for data generation	7%	27%	**66%**
Support bottom-up consortia to standardize BIM data exchange	**47%**	27%	26%
Support emerging data marketplaces	47%	6%	47%
Develop regulations to protect BIM IP and data ownership	13%	20%	**67%**

Table 4 – Feedback on Collaboration Pillar

3. Whilst the WEF had allocated particular responsibilities to the industry bodies in in respect to establishing data-sharing standards, the respondents did not concur. No particular actions were identified as the responsibility of the industry bodies in regard to the collaboration pillar.
4. The respondents concurred with the government responsibilities identified by the WEF, namely :

    a. Increase the share of projects that use integrated contracts.
    b. Develop BIM collaboration procedures (e.g. CIC BIM Protocol).
    c. Develop regulations to protect BIM IP and data ownership.

It is clear that there was some variance between the respondents view and that of the WEF in respect of responsibilities for the collaboration pillar but largely the responsibilities allocated were similar.

Once again it is clear to see the dominant role expected of the government in developing guidelines, protocols and use of collaborative contractual frameworks coupled with the necessity of companies to start to change the culture within their own organisations. It can be seen that the industry body played a passive role in regard to fostering collaboration.

Enablement Pillar	**Companies**	**Industry Bodies**	**Government**
Establish BIM skills along the full value chain			
Integrate BIM into general design and engineering classes	20%	**47%**	33%
Create upskilling courses with professional education providers	13%	**60%**	27%
Institute a broad set of upskilling programmes (e.g. job rotation, mentorships etc)	**47%**	27%	27%
Develop simple BIM software that emphasizes usability	**73%**	27%	0%
Incorporate BIM skills training in public engineering, procurement and O&M organizations	7%	7%	**86%**
Change behaviours and processes, not just technology			
Adopt BIM as part of a comprehensive change management programme	**67%**	7%	26%
Streamline processes before adopting BIM	**67%**	13%	20%

Make a long-term commitment to include BIM in projects			
Create innovative BIM business and financing models (e.g. BIM-as-a-service, low budget BIM)	**93%**	0%	7%
Create a regulatory framework for private-investor BIM funding	7%	7%	**86%**

Table 5 – Feedback on Enablement Pillar

In respect to the enablement pillar (Table 5) there was a degree of similarity between the results of this survey and the findings of the WEF recommended distribution of responsibilities.

1. In respect to the companies there was broad agreement with the WEF distribution of responsibilities to ensure that that companies upskill their staff, change the culture within their organisations to use of new digital workflows but also commit in the long term to introducing BIM into their project portfolio.
2. The singular responsibility identified by the WEF of industry bodies to create upskilling courses with professional education providers was agreed by the respondents.
3. The respondents concurred with the government responsibilities identified by the WEF, namely :

    a. Incorporate BIM skills training in public engineering, procurement and O&M organizations.
    b. Create a regulatory framework for private-investor BIM funding.

    The action identified by the WEF in regard to introducing design and engineering classes was not seen as a government responsibility by the respondents.

In conclusion the respondents largely concurred on the distribution of the actions in regard to the enablement pillar. Respondents agreed that all three of the stakeholders should play take on responsibility to ensure that the industry is enabled to work routinely with BIM workflows and technologies.

The importance of the industry upskilling their staff, fostering a change management approach within their businesses and making that long-term commitment to use of BIM on their future projects was supported by the respondents.

The importance of the industry body stipulating the inclusion of BIM into accredited courses and the importance of the bodied developing a broad suite of BIM programmes was also widely supported by the respondents.

Finally the critical role of the government was once again clearly evident with respondents agreeing on:

1. The importance of their role in incorporating BIM skills training in public engineering, procurement and O&M organisations.
2. Creating a regulatory framework for private-investor BIM funding.

The respondents were asked to provide any other additional comments in respect to the WEF Adoption Circle. A selection of these comments are shown below.

'Great framework. But only useful if it is actually followed'

'I believe that some of the 27 actions suggested by the World Economic Forum should be a shared responsibility of two or more stakeholders identified'

'Maybe some renewed language/description in the motivation section ie future skills, climate change, sustainability understanding that these are all goals in their own right but speaks better to the cohort of people who'll be engaging with BIM'

'it is very comprehensive, but many of the action items would benefit from clarification/simplification before being applied in an Irish built environment context'

'I feel BIM as a process has too much jargon, simplifying the language will make BIM accessible to all members of project teams. From experience people can be intimidated by all the technical terms used in BIM execution plans and tend not to engage'

'Careful alignment should be given to the specific actions in the NBC roadmap'

It is clear from the final feedback from the respondents that careful consideration should be given to shared responsibility and refinement of language used in the actions.

In addition careful consideration should eb given to alignment the BIM implementation plan with those specific actions identified in the NBC Roadmap.

V CONCLUSION

The purpose of this paper was to stress test the WEF BIM Adoption Circle with a focused group of stakeholders. The methodology adopted followed that sued in the production of the WEF BIM Adoption Circle model.

It is clear from the feedback that there was broad agreement with respect to the WEF actions envisaged in 2018, however, a broader consultation process would need to be carried out in order to better refine the actions and the responsibilities for those actions.

Respondents were very clear in their feedback that no action plan will have 'teeth' unless the plan is funded and management by a central entity. Perhaps this could be an important role for the CSG's vision for a new Centre of Excellence for digital construction. At the time of writing this paper there is no clarity in respect to these plans in the near future.

It is also clear from the feedback to this survey that it is now time for the Irish government to take responsibility and drive the digital transition programme in Ireland and put into effect a robust BIM implementation programme that will support companies, industry bodies and the government itself to delivery the type of actions envisaged by the WEF in 2018.

Whilst the sample selected in this study was relatively small the results show that there is broad agreement on the applicability of the implementation WEF model in Ireland but that there would need to be further refinement by whatever organisation is given the task to produce such an implementation programme.

The role of each of the stakeholders identified in this paper cannot be underestimated and it will take a co-ordinated effort to but in place a robust implementation plan for an order to be brought to the formal introduction of BIM in Ireland.

There is no doubting the need for this order given that the Irish government have committed to rolling out BIM across the public sector building programme over the next number of years.

Whilst many stakeholders might question the application of the WEF model in Ireland the authors respect the position, respect, experience and authority that the WEF bring to the debate and would strongly advise those entities that will be the custodians of Ireland's national BIM programme to give it due consideration.

It is also important that any such implementation plan should be compatible with the vision and objectives set in the 2017 National BIM Council of Ireland Digital Transition Roadmap (2018-2021) despite the fact that the vision of this roadmap published in 2017 has still not been funded or an entity identified to manage its programme.

Time is now of the essence if the Irish government is to realise the efficiencies envisaged in its Project 2040 National Development and Plan and in the publication of the government's recent climate change action plan.

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Centres of Excellence and Roadmaps for Digital Transition: Lessons for Ireland's Construction Industry

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Abstract− Like most sectors in today's working world, construction businesses are challenged to work in an increasingly digitised world with sophisticated demands from intelligent clients. So much has been written about the inefficiencies of the construction industry, its fragmentation, lack of collaboration, low margins, adversarial pricing, poor productivity, financial fragility, lack of research and development, poor industry image and relatively weak use of digital solutions. The Irish government recognises the importance of digital innovation to address many of the challenges the construction industry faces. With recent high profile reports of escalating spend on signature public sector projects and weak productivity performance in the sector, the Irish government is seeking out new strategies that will help create improved value for money for publically funded projects including stimulating economic growth and competitiveness in the sector. One such approach is the creation of a new Centre of Excellence for digital construction to help encourage both the government and industry to work together to create a more agile and innovation-rich sector, create jobs and improve project outcomes for public sector projects. In this paper, the authors will examine the current context surrounding this recommendation, in particular the vision of Ireland's National BIM Council to instigate the formation of a national central resource to support the rollout of digital tools and processes in Ireland. This paper serves mainly as a relatively high-level early desktop study that will document the missions and activities of particular international exemplars of such centres. The paper also seeks to potentially influence representative groupings in Ireland that have been charged with the responsibility of recommending to the Irish government the likely implementation model and funding mechanism that will help drive a sustained transformational programme for the Irish construction industry. The authors did not seek to consult with these stakeholders directly in preparation of this paper given the ongoing consultations at governmental level taking place in mid-2019.

Keywords－Digital, Excellence, Transformation, Ireland, BIM

I INTRODUCTION

In 2017 the Irish government launched their strategy to increase the use of digital technology in key public works projects with Building Information Modelling (BIM) to be mandated in the design, construction and operation of public buildings and infrastructure over the next 4 years [1]. This statement of intent from the Irish government demonstrated an acute awareness of the importance of BIM and how it brings together technology, process improvements and digital information to radically improve project outcomes and asset operations. The industry reacted to this call for digital workflows and proposed, through a publication of the National BIM Council (NBC) of Ireland, a roadmap to digital transition for Ireland's construction industry from 2018 – 2021 [2]. This industry roadmap is an initiative that advocates more productive ways of working that improves competitiveness at home and overseas. This roadmap not only seeks to increase efficiency and productivity in the industry but also aims to support an SME community that makes up almost 95% of the sector both in Ireland and across the broader European Union. The roadmap was divided into four key pillars; leadership, standards, education and training and procurement. One of the key recommendations within the leadership pillar in the roadmap was the establishment of a National BIM Centre of Excellence with a focus on driving the digital transformation of the sector. Such a resource can support the roll-out of digital tools and processes in Ireland while in the short term provides a platform for the digital transformation programme envisaged by the NBC in 2017.

A proposed centre has long been voiced in Ireland with Hore et al. outlining, as far back as 2011, their vision for a dedicated competence centre to facilitate the Irish construction industry [3].

The construction industry has responded to the requirement to keep pace with other sectors by its proposal for its own Digital Centre of Excellence. While the roadmap has been in circulation since late 2017, there has been no official announcement of its funding and formal implementation. To assist with the establishment of an Irish Digital Centre of Excellence, this paper will explore existing centres globally, to establish a possible framework that the Irish AEC Sector can follow once adequate funding becomes available.

The purpose of this paper is to undertake a scoping desktop exercise to be used in influencing any future proposal for a proposed Irish centre. The authors intend to extend this research at an appropriate time once the framework for such a centre has been established when those stakeholders charged with this responsibility have concluded their work. The authors contend that any proposed Irish entity will initially focus on BIM implementation support and the role out of the NBC roadmap. The centre, once established, should expand to focus on a broader spectrum of digital innovations.

It will be seen in the conclusion of this paper that the delivery of the NBC roadmap and any proposal for a newly established Centre of Excellence for Irish construction are extrinsically linked and connected projects.

II METHODOLOGY

The methodology involved an initial high-level desk-top based research exploring existing international exemplars of such centres by primarily reviewing website content. Particular international centres were selected based on previous research by McAuley et al., (2018) and Hore et al., (2017a and 2017b) which recommended that Construction Scotland Innovation Centre and the Centre for Digital Built Britain be reviewed as potential best-case exemplars of such centres[4] [5] [6].

The authors do not intend to focus on the formal meaning of a Centre of Excellence but to locate international exemplars of communities of practices that focused primarily on the digitisation of construction. While it is expected that any future established entity will eventually focus on a more comprehensive range of digital construction innovations, the author's key focus was placed on supporting the roll-out of Ireland's BIM mandate, and, therefore, it is logical to limit the selection, at present, to those which are primarily focused within this area.

On that basis, the following centres were selected:

1. Centre for Digital Built Britain
2. Construction Scotland Innovation Centre
3. Global BIM Centre of Excellence China
4. NUS Centre of Excellence in BIM Integration Singapore
5. Australasian Joint Research Centre for BIM
6. The Digital Innovation Lab Georgia
7. Centre for Integrated Facilities at Stanford University

The authors focused on their mission/vision, governance, services offered, funding and a sample of their contributions.

III CONTEXT

Project Ireland 2040 is the Government's long-term overarching strategy for Ireland (Government of Ireland, 2018a), which was further supported by a National Development Plan 2018-2027 (Government of Ireland, 2018b). The plan outlines how investment is made in public infrastructure in Ireland, moving away from the approach of the past, which saw public investment spread too thinly and investment decisions that did not align with a well-thought-out and defined strategy. Alongside the development of physical infrastructure, Project Ireland 2040 vision is to support businesses and communities across all of Ireland in realising their potential [7] [8].

As part of this initiative, a Construction Sector Group (CSG) was formed to ensure that regular and open dialogue between government and industry takes place on how best to achieve and maintain a sustainable and innovative construction sector positioned to successfully deliver on the commitments in Project Ireland 2040. The CSG is made up of representatives of key industry bodies, as well as senior representatives of relevant government departments and agencies with responsibilities for policy and the delivery of infrastructure. Chaired by the Secretary General of the Department of Public Expenditure and Reform (DPER), the group reports to the Minister of the DPER [9].

The Project Ireland 2040 National Development Plan 2018-2027 outlined the key role of CSG Part of the group's remit will be to consider matters such as:

- the data/trends relating to the construction sector in Ireland;
- the supply of necessary skills and enhancing capacity;
- the role of Building Information Modelling and adopting other technologies and innovative
- practices in driving improved productivity and efficiencies;
- the use of sub-contracting and the level of self-employment and
- the productivity of the construction sector.

At the time of writing this paper, DPER, in collaboration with the CSG, has commissioned a study of the root causes of the poor productivity prevalent in the Irish construction industry together with potential Government policies and industry actions to tackle the root causes of this poor productivity (Government of Ireland, 2019) [10]. The Construction Industry Federation (CIF) recently published an important contextual report on the productivity of the Irish construction industry (CIF, 2019) which provided recommendations that were complementary to these tactics [11].

IV DIGITAL CENTRE OF EXCELLENCE FRAMEWORK

This section will explore the seven selected international entities in more detail.

a) *Mission*

Dermol and Breznik (2012) describe a mission statement as an organisation's "credo," "philosophy," "core value," "reason for being," "image creator," or "a distinctive factor" as frequently used concepts that describe the importance and the value of an organisation [12]. The majority of entities selected had multiple strategic goals.

The Centre for Digital Built Britain's mission is to "*develop and demonstrate policy and practical insights that will enable the exploitation of new and emerging technologies, data and analytics to enhance the natural and built environment, thereby driving up commercial competitiveness and productivity, as well as citizen quality of life and well-being"*. This is expanded to "*act as the custodian of the integrity of the UK BIM, and Digital Built Britain Programmes across all the levels and to be recognised both nationally and internationally as that institution"*. This is further advanced to include commitments to technical standards and protocols, acting as an academic bridgehead, tracking digital capabilities, inspiring the industrial community, adopting and implementing new digital approaches and ensuring that the findings and insights from the centre inform future policy, industrial practice, standards and research initiatives.

The Construction Scotland Innovation Centre vision *"is to uncover and develop with industry the value that lies in innovating and drive future demand for the innovation support available from Scotland's leading universities."* They also aim to empower industry, align academic expertise and public sector support, match industry needs to appropriate innovation support packages and deliver support from inception to commercialisation.

Other mission statements, such as that of the Global BIM Centre of Excellence, are not so task orientated and simply state that they aim to "*gather top BIM experts and excellent BIM enterprises both at home and abroad."*

The Centre of Excellence in BIM Integration in Singapore mission is *"to transform the way people design, deliver and manage the built environment through BIM innovation and practice."* This is expanded to include how this will be achieved, through high-impact research, broad-based education and collaboration with industry.

The Australasian Joint Research Centre for BIM focuses on developing leading research that integrates BIM with other advanced concepts and technologies to improve the performance and productivity of building projects in the energy, mineral and construction industries worldwide.

The Centre for Integrated Facilities' vision is to apply "*VDC principles and methods to help projects deliver exceptional value and help member organizations achieve breakthrough objectives in support of their exceptionally reliable design, engineering construction, and management to develop and operate sustainable facilitie*s."

The Digital Innovation Lab in Georgia aims to *connect industry to research, creating innovative ways to design, build, and operate buildings, cities, and infrastructure*.

Whilst not a mission per se, the NBC Roadmap envisaged that any new central resource established would '*support the rollout of digital tools and processes in Ireland. It will be a resource with both public and private commitment, which will leverage from existing digital interest communities'* (NBC Roadmap

2017, pp. 10).

b) Services Offered

The services offered by any organisation is ultimately the critical area of interest concerning the users. For the purposes of this paper, the authors focus primarily on BIM support services. The authors acknowledge that many of the centres selected have a remit beyond BIM and are now looking at a much broader ecosystem of digitalisation taking into account the impact of digital technologies, modern methods and broader innovative practices in construction.

The Centre for Digital Built Britain envisions a broad scope of commitments to support the adoption of BIM as business as usual and the evolution of the UK BIM Programme. They articulate the creation of a digital framework for infrastructure data through applied research including standards guidance, delivering pilots and outlining how the industry needs to change to establish how information-rich assets in the built environment can be planned and used to perform their functional service. They also generate informative publications, case studies, videos and blogs.

The Construction Scotland Innovation Centre offers skills programmes designed to support industry, educators, and learners. They also offer seminars, workshops, and conferences, providing a range of information suitable for all levels of BIM understanding. Also, they provide access to resources and industry experts.

The Global BIM Centre of Excellence aims to support BIM development by providing the latest BIM information, promoting industry communication, providing professional assessment, stimulating BIM application, accelerating BIM innovation and creation, and ultimately making contributions to BIM through sharing members' knowledge, techniques, experience, and opinions. The NUS Centre of Excellence in BIM Integration has two units. Their research unit focuses on developing leading research that improves building construction and performance through the integration of BIM with other advanced concepts and technologies. Their innovation and education unit focuses on developing guidelines, best practices, journals, etc. along with designing short term courses in BIM for the industry workforce.

The Australasian Joint Research Centre for BIM, through a series of pilot projects, aims to create and share knowledge to enhance policy development and enable key industry stakeholders to improve informed decision-making throughout a project's life cycle. The Digital Innovation Lab in Georgia provides a link that connects technology and professional members with real-world problems, while researchers try to provide emerging technology innovation and solutions to these problems. They have an annual symposium, member workshops, professional courses and a living laboratory that maintains a physical testbed for digitally integrated design, construction and operations projects. The Center for Integrated Facilities broadly covers a range of research areas. It is a mature research entity of international reputation working with industry to develop and test innovative ways to model and increase awareness of and competence in the use of the methods and to understand the value and costs of Virtual Design and Construction (VDC).

All of these entities have a central message that the construction industry is ripe for digital transformation and use a variety of tactics to drive this agenda within their network.

On further analysis of the services provided by these entities, there were three recurring pillars of activities, namely:

1. Research – systematic inquiry of particular studies or a particular problem of concern to industry. Many entities investigated included a resource of funded full-time and part-time investigators.
2. Education – provision of industry-led training, workshops, seminars, conferences, published papers, videos, webinars and case studies.
3. Guidance - publication of guidance material to assist industry in transitioning to BIM and other digital innovations.

c) Governance Models

The entities investigated had varying governance models. Table 1 provides a summary of the key stakeholders involved in each entity. A key feature was the hosting of such centres in Higher Education Institutes (HEIs).

Entity	**Key Stakeholders**
Centre for Digital Built Britain	Department of Business, Energy & Industrial Strategy University of Cambridge (host)
Construction Scotland Innovation Centre	Scottish Funding Council Scottish Enterprise, Highlands & Islands Enterprise 14 Scottish university partners
Global BIM Centre of Excellence	University of Nottingham Ningbo Chartered Institution of Civil Engineering Surveyors China Member firms

NUS Centre of Excellence in BIM Integration	NUS Department of Architecture and the NUS Department Building (host) Real Estate Developers' Association of Singapore Member firms
Australasian Joint Research Centre for BIM	Curtin University (host) and Huazhong University of Science and Technology in Wuhan, China
The Digital Innovation Lab	Georgia Tech includes inter-department collaboration (host)
Centre for Integrated Facilities at Stanford University	Stanford University (Host) Member firms

Table 1: Stakeholders involved in selected entities

All of the entities investigated appear to have strategic alliances with industry and parent governmental departments, which is a crucial element to any proposed strategic offering in Ireland.

A case in point is the Centre for Digital Built Britain in the UK where there is a strategic partnership between the UK government and the University of Cambridge. The Construction Scotland Innovation Centre differs in that it was an independent centre formed with links to government and multiple HEIs. The Scottish centre was only one of nine such centres in Scotland focusing on alternative industries.

The following alternative governance models were evident from this study of the seven entities selected.

- Model 1: Entity established in a single HEI with links to industry and government. These models tend to have a predominant research focus.
- Model 2: Entity establishes in two or more universities with links to industry and government. These models tend to have a predominant research focus with inter-institutional collaboration in specialist research areas.
- Model 3: Entity founded on a strategic partnership between government and academia with links to industry. These models tend to have a programme of activities that shape the strategic focus of the entity that includes the establishment of interest groupings, commissioning research, a dissemination programme that include hosting seminars, conferences, etc.
- Model 4: Entity established in an independent organisation with links to academia, industry, and government. These entities tend to be non-profit organisations.

d) *Funding*

Acknowledging the limitations of the desktop exercise, it is possible to deduce the funding mechanisms evident for each of the entities investigated

1. Funding Model 1: This model is focused on attracting research as part of a university's strategic research programme plan. The universities, in this case, compete for available funding to conduct high-impact research through research and development funding by a dedicated research resource of principal investigators and research students.
2. Funding Model 2: Funding, in this case, is provided by government and then acquired by a university that will work in partnership to deliver the requested R&D. The university is responsible for delivering the government's required BIM programme. An example of this is the Centre for Digital Built Britain who are funded, as part of the recommendations of the HM Government in the 2017 Autumn Budget, up to £5.4 million. This enables it to launch initiatives such as "Delivering a Digital Built Britain" which is a request for feasibility studies, research projects or experimental development projects ranging in value from £50,000 to £250,000.
3. Funding Model 3: Funding for this model is sought by an independent body outside of academia who receive funding by way of government or through industry. An example of this is the Construction Scotland Innovation Centre, which received almost £11 million of core funding to support the sector to innovate, modernise and grow from government funding. This funding can be then dispersed to universities or research bodies to do part of the required research, such as through Innovation Vouchers and collaborative innovation projects in which a percentage of overall project costs are provided from this source.

The above funding models offer alternative approaches and it seems likely that in an Irish centre would need significant state funding initially before it could become *more reliant on alternative funding streams.*

e) Sample Contributions

The paper thus far has investigated mission statements, services offered and funding models. While Section 4.2 investigated general services, this part of the paper will examine particular projects or contributions within each of the centres investigated. This will help to provide an understanding of the expected scope and type of projects envisaged for any new centre to be instigated for Ireland.

The Centre for Digital Built Britain has launched a "Research Bridgehead" which aims to build effective relationships with the research community to harness value, enabling results of innovative academic research to inform the development of Digital Built Britain. The bridgehead developed a network model that will bring together academic researchers, industry and stakeholder organisations to drive the creation of a digitally enabled landscape.

The centre is also establishing the "Digital Twin Hub," a collaborative web-enabled community for those who own, or who are developing, digital twins within the built environment. They have published the first output of its "Digital Framework Task Group", The Gemini Principles. The paper sets out proposed principles to guide the national digital twin repository and the information management framework that will enable it. They have also published the "Roadmap to the Information Management Framework for the Built Environment".

The Construction Scotland Innovation Centre offers skills programmes designed to support industry, educators, and learners. The renewed "BIM in Practice" programme provides a unique opportunity to learn, collaborate and implement all things BIM. Working with the Scottish Funding Council, the centre part-funds the course fees of the students, who will also benefit from working closely with industry, contributing to industry research and helping participating businesses achieve higher levels of innovation and productivity. They also have a 3,500m2 facility designed to support construction-related enterprises to collaborate and innovate.

Some of the research outputs from the NUS Centre of Excellence in BIM Integration include establishing an electronic Quick Bills of Quantities, safety risk drivers to assist with risk management and a BIM-based integrated workflow for the design of sustainable tall buildings. The Australasian Joint Research Centre for BIM has published more than 200 technical journal articles over the past five years and has presented innovative solutions to the oil and gas, mining and infrastructure sectors. Both the Digital Innovation Lab and Center for Integrated Facilities are renowned for their prodigious outputs and have been responsible for transformational changes, such as the National BIM Standard for Reinforced Concrete and pioneering research in the area of 4D BIM, respectively.

While some of the centres selected are more academically focused, this may not necessarily be the core focus of an Irish centre which could seek a more "applied" and pragmatic construction innovation programme where practical guidance and training is part of its core service model.

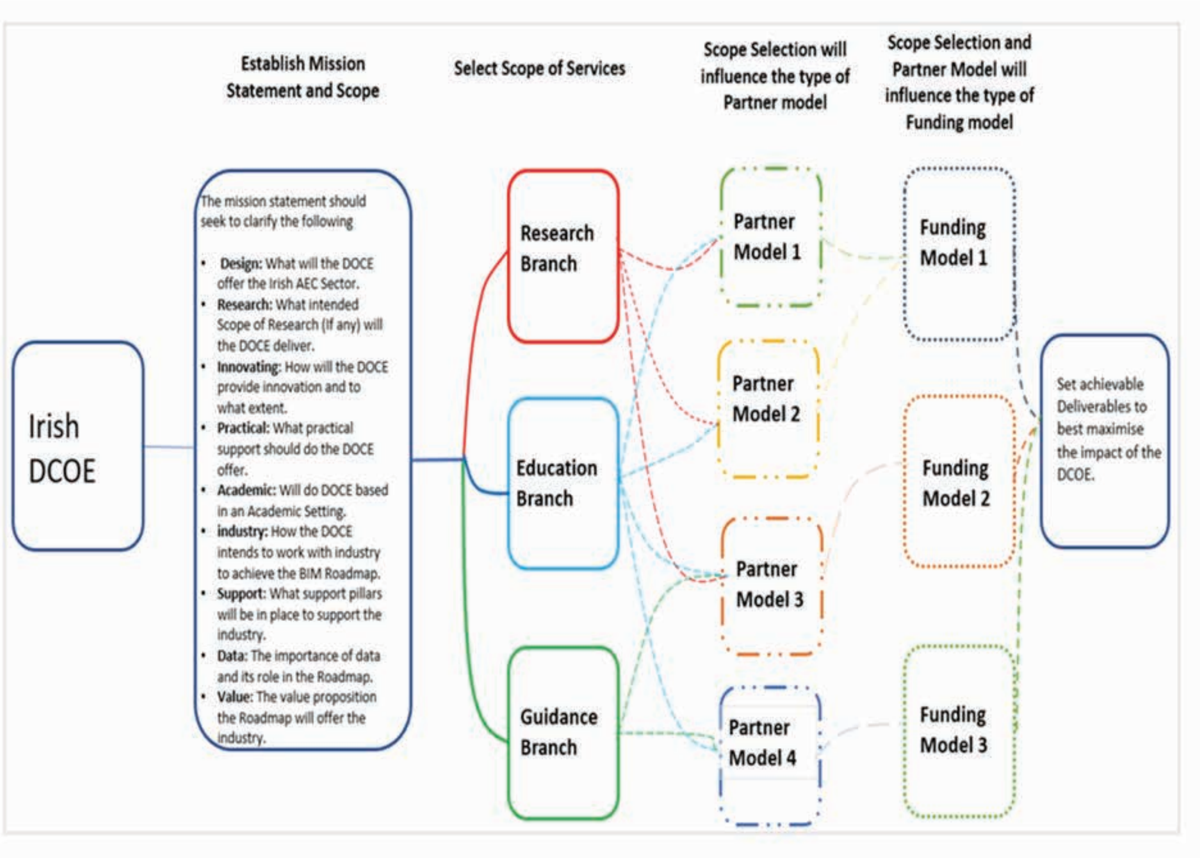
f) Proposed DCoE Framework

Based on the findings from this desktop-based research, the following framework is proposed to assist Ireland in the establishment of their Digital Centre of Excellence. The framework, illustrated in Figure 1, outlines the essential items that will need to be addressed, thus:

1. The mission statement should state the key areas outlined in Figure 1 and establish an initial scope of work.

2. The scope of work should be refined such that it dictates what area of expertise is required, such as, will the DCOE offer a research branch with innovation funding, etc., an education branch offering courses and workshops and a guidance branch offering consultancy through access to BIM experts?

3. The next stage involves the selection of a partner model that best represents the most advantageous way of achieving the agreed scope of services. While all partner models can be adapted to meet the range of services, some work better than others, for example, a DCOE established within a university would not be required to offer a guidance branch because it would not be expected that industry experts would be freely available to assist with BIM implementation.



Once an adequate mission statement, scope of services, areas of expertise and suitable partner model have been established, then one can identify what type of funding is required, whether governmental, industrial or a combination of both.

Finally, once funding has been secured, an achievable set of deliverables should be set, to maximise the impact.

V GOVERNANCE OF DCOE

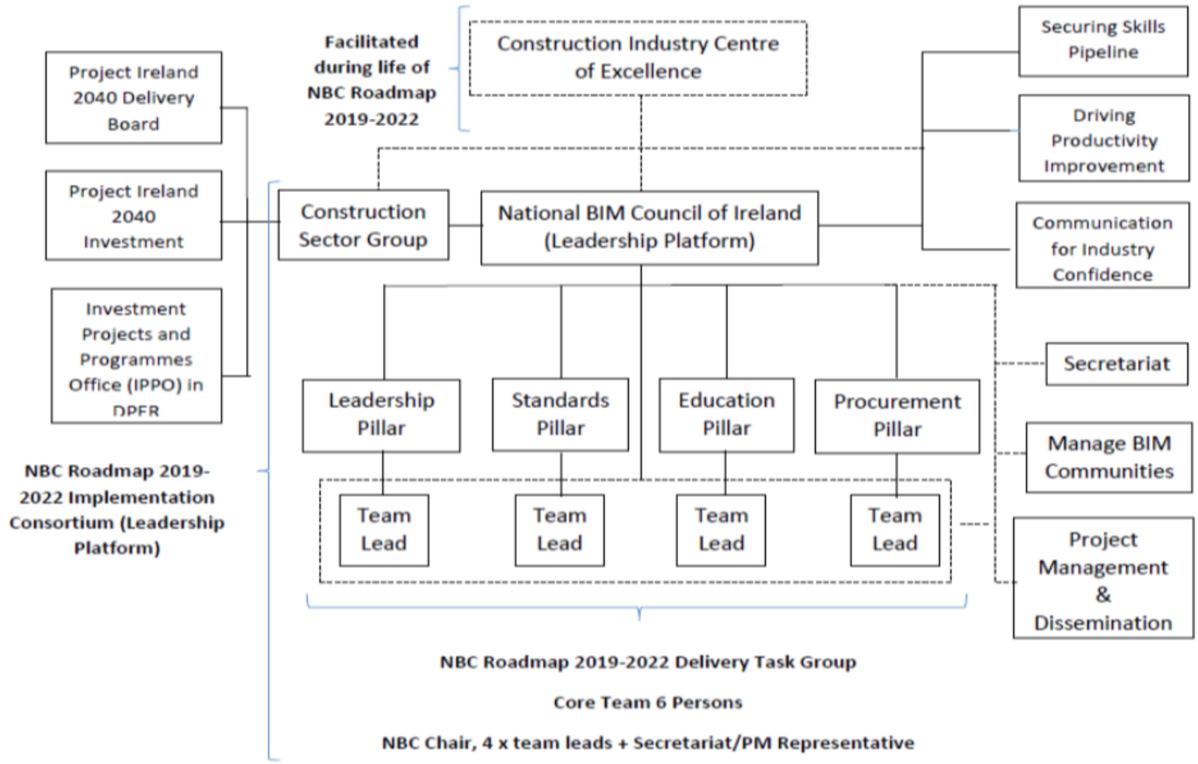
/hile the paper has established a proposed generic amework with different pathways, this section will xplore how such an Irish focused Digital Centre of xcellence will potentially managed. Figure 2 lustrates how the authors envisage the governance amework for the newly proposed centre. At the core f the framework is the re-establishment of the NBC eadership Platform). It is recommended that a latform of the most knowledgeable persons presented by relevant stakeholders sits on this ouncil and that a chairperson with appropriate edentials is appointed to lead this council.

is recommended that the NBC will in turn report to

Project Ireland 2040 programme. It was stated earlier that the initial focus of the NBC would be the implementation of the NBC Roadmap for Digital Transition of Ireland's Construction industry. The NBC roadmap will need to be adapted to cater for the period 2019-2022. In the author's opinion, the original remit and vision of the roadmap should be largely retained with the exception of the output from the recently commissioned construction productivity study by DPER, which should be included in an updated Roadmap.

It is recommended further that the Council include team leads for each of the four pillars outlined in the NBC Roadmap (leadership, standards, education and procurement). The authors believe it would be appropriate that the four-team leads are joined by a secretariat representative and progamme manager to make up the newly formed NBC Roadmap 2019-2022 Delivery Task Group who will be tasked with the delivery and roll out of the roadmap to support the Irish governments phased introduction of the public sector BIM mandate.

The core vision of the NBC will seek be to support the CSG remit of 1) securing the skills pipeline 2) driving productivity improvement in the Irish construction industry and 3) communication for



VI RECOMMENDATIONS

The paper has proposed two different frameworks; 1) a generic DCOE framework, and 2) Irish Digital Centre of Excellence Governance framework that will need to be considered in partnership. On this basis, the authors have made a series of recommendations that will require the two frameworks to be considered in unison, that is, a management framework will need to be agreed before a pathway can be established within the generic DCoE framework. Taking this into consideration, the authors recommend the following

1. The first step should be the re-establishment of the NBC as a platform of leadership comprising of the most knowledgeable persons represented by relevant stakeholders and that a chairperson with appropriate credentials is appointed.

2. The NBC roadmap should be updated to reflect the recommendations from aspects of the DPER commissioned report on construction productivity believed to be completed in Q4 2019.

3. The NBC roadmap should be funded in advance of any decision to set up a new DCoE and that an NBC Roadmap 2019-2022 Delivery Task Group be appointed to support the rollout of the Irish government's public sector BIM mandate.

4. The leadership platform formed by the NBC should be the seed for the formation of a new CoE for Irish construction. It is essential that this platform consists of a strategic alliance between a parent government department and industry with academic input. A further more detailed study will be required prior to a preferred partnership model being suggested, before any final decision is made on the design and location of any new centre.

5. The Centre will need significant state funding initially before it could become more reliant on external alternative funding streams. Consideration should be given to the funding models in Figure 1 with a preference established once an agreed governance model is known.

6. Any new Centre envisaged should leverage the achievements of existing established communities focused on digital construction, for example, the Construction IT Alliance (CitA), and the CIF Construction 4.0 committee.

VI I CONCLUSION

The Irish construction sector has experienced a return to productivity since the lows of the recession. To meet the requirements of an overworked and under skilled sector, as well as compensating for years of underfunding for infrastructure, the construction sector has embraced digital technologies, primarily BIM. This has resulted in the launch of a digital roadmap with a specific recommendation for a Digital Centre of Excellence. While funding has not yet been secured for such a centre, it was the purpose of the authors to investigate a potential framework that can be used to inform its design and implementation. An initial desktop-based research project exploring existing centres globally has determined that any future Irish Centre will need to follow international best practice. In the author's opinion, the original remit and vision of the roadmap should be primarily retained and implemented as soon as possible. This work will provide an essential backdrop for facilitating the formation of any newly proposed Centre of Excellence for Irish construction.

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Notes

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