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Bergen's Light Rail Extension

Background

The Bergen light rail system comprises of 21 km of double track between the city centre of Bergen located in Hordaland on the west coast of Norway and the airport. The first phase of the project (Starvhusgaten in the city centre to Nesttun) started in January 2008 and was opened for commercial business in June 2010. The construction of the second phase (Nesttun to Rådal) was completed in June 2013. In 2011, Mott MacDonald were appointed as consultant's for Phase 3 to provide a complete engineering and architectural design solution. This was to involve consultation on 7.8 km of double track, six tunnels totaling a length of 2,800m, four track bridges, three pedestrian bridges, four culverts for track, eight tunnel portals, seven tram stops, a depot with administration building and operation control centre, maintenance workshop and parking hall for 40 trams.

In order to achieve this scope of works Mott MacDonald applied a series of innovative techniques primarily the implementation of Building Information Modeling (BIM) design and collaboration tools in partnership with International processes. BIM helped to break down barriers, and design concepts were easily understood ensuring early-stage buy-in by all parties. Figure 1, details a rendered illustration from the 3D model.

Figure 1 – Rendered image from the model

Digital Innovations and Processes Adopted

The client requested that all design work was fully carried out in a 3D fully coordinated digital design environment. The extensive use of an integrated 3D design and advanced remote working tools throughout the design and construction of Phase 3, enabled a globally dispersed team from seven countries (Ireland, UK, Hungary, Czech Republic, Poland, South Africa, Norway) to produce a completely integrated 3D design for a light rail scheme. Construction information was derived directly from the design models within a common data environment (CDE) based on BS 1192-4 Collaborative production of architectural, engineering and construction information code of practice. The BIM execution plan defined project-standard computer-aided design and BS 1192-based design processes. The models were structured according to national public roads administration Statens Vegvesen's Handbook model requirements for highways projects.

Tightly controlled change management procedures were required for all models to ensure that they were updated in harmony, especially as the project moved from design to construction phase. The requirement to supplement models with drawings presented challenges with respect to conformity. To achieve this a bespoke project collaboration system was established using Bentley Systems' ProjectWise software to meet client and project requirements, to control and manage project data, and to facilitate sharing between parties. Many engineering models were produced and used intensively for interdisciplinary checking, client reviews and visualisations.

Model Use: Design and Construction

The model was used regularly in design review workshops at key project stages with the client and other stakeholders. Live remote reviews took place using collaboration software and conferencing between members of the design and client teams in Bergen, Dublin and the consultant's other offices. These 3D workshops facilitated comprehensive project reviews with participation from all key project members over a few days, which would not have been possible using conventional design and communication techniques.

Models were developed with all required information to enable contractors to construct directly from them. Visibility of the final design allowed contractors to appreciate construction constraints better. The consultant's construction support team in Bergen had direct access to the dispersed design team, providing immediate support as required. Models of existing terrain were available across the project. Point clouds, 3D mapping and survey data formed the background to design development and was regularly updated throughout the construction phase, allowing continual checking of progress.

Three-dimensional space analysis to prove every aspect of design prior to building resulted in very few site queries and virtually eliminated down-time and re-work on site. This approach enabled the project team to develop the design efficiently, with little divergence from the project's objectives.

The overall models were quality checked and compiled in Autodesk's Navisworks project review software prior to issuing a fully coordinated BIM and engineering deliverable. Figure 2 illustrates a Building information model for the depot which was reviewed in Navisworks prior to generating construction drawings

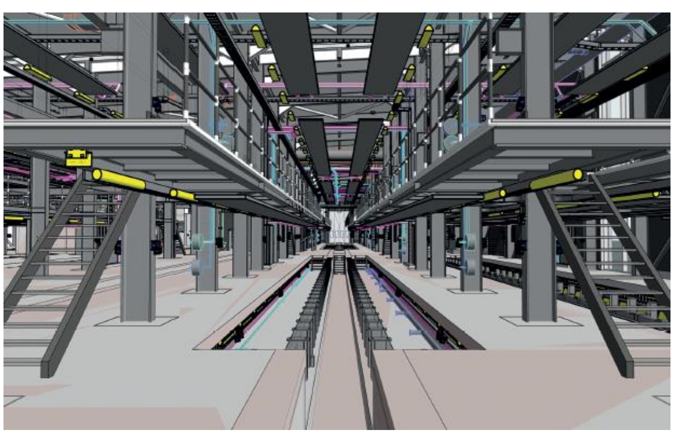

Figure 2 – Navisworks model

Construction progress was monitored using raster scans, sometimes taken from unmanned aerial vehicles. This was particularly useful where rock was being blasted at tunnel portals. Absolute blasting positions could be overlain on portal design models within minutes of data capture to assess the accuracy and any requirement for further rock removal or portal redesign.

A key success on this project was the management of data and file formats. By reducing the number of formats, thereby reducing the handling of the data, the consultant maintained the integrity of information and eliminated errors that tend to occur within any transformation of data between formats. The need for traditional setting out was eliminated, increasing accuracy and improving site safety. Model information was transferred to satellite positioning enabled plant. Surfaces contained within the model were loaded directly into construction machinery and used for blasting tunnels, rock, and earth-moving and laying finished pavement surfaces. All trenches, utilities and pipeline designs carried attribute data which were conveyed directly to the construction teams.

Direct benefits of innovation

The immediate direct benefits of the live integrated 3D design include the following.

- **Advance visibility of final scheme**: Early 3D modelling provided scheme visualisation for consultation with passenger and resident groups, thus enabling their appreciation of the design and allowing relevant feedback.
- **Improved aesthetics:** By having the real design available to all the design team, the architects, landscape architects and lighting engineers were able to analyse and optimise the design at an earlier stage and in more detail than normal i.e. decluttering sensitive areas, providing realistic feature lighting, etc.
- **Integration with adjacent developments, including the airport**: With 3D designs available, the passenger experience was inspected visually, and lighting and movement studies were provided based on the real design

- **Predictable construction programme:** Providing 3D models enabled the contractors to understand the design intent as they were able to take measurements and quantities directly from construction stage 3D models. This ensured a continuous construction phase with few unexpected delays and with well planned construction activities.
- **Value for money:** Developing a design in a fully detailed model environment allows early treatment of the vast number of interfaces that naturally occur with a complex project in the design phase rather than later on site, thus providing great value for money.
- **Quality:** Design quality was maximised through significant ongoing interrogation of the developing design by the client's own specialists reviewing the developing model.
- **Smooth handover from designer to contractor:** The BIM process and the controlled use of 3D models enabled full efficient transfer of information from design to the overlapping construction phase.
- **Integration of BIM information into cable management system:** The consultant delivered a complete 3D ducting design and then developed a complete electrical cable schedule, producing duct, cable-routing and earthing-points schedules.
- **Reuse of waste material:** Using the models to optimize cut and fill using true cut surfaces and to manage stockpiles during construction, helped to reduce earthworks costs significantly.
- **Reduced service diversions:** Accurate modelling from the 3D survey and designs enabled detailed service diversion designs in advance of construction and a good agreement process with the local authority to avoid unnecessary diversions.
- **Model use beyond construction:** There was a robust as-built process which included updating the models where construction differed beyond a certain tolerance. This provided the client with a reliable and accessible design and construction record.
- **Safety reviews during design stage:** The models were used in a number of design review workshops at key project stages with the client and safety representatives to undertake reviews totally independently of the design process.

Conclusion

The innovation used in the Bergen Light Rail Stage 3 helped to provide the required high-quality infrastructure on the programme. Ultimately, the client and the passengers were pleased with the functionality of the system and also with the associated architecture. The project has set a standard for BIM adoption in the further development of Bergen's light rail system and in other Scandinavian infrastructure developments.

Acknowledgements

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