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Challenge, Change, Learn

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Machine Learning to Support BIM-based Material Analysis for Embodied Carbon Assessment

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CitA BIM Gathering 2021

A Proposal to Harmonize BIM and IoT Data Silos Using Blockchain Application

https://www.youtube.com/watch?v=cxDjuknPj9E

CitA Tech Trend |Blockchain

Developing Blockchain Use Cases for AEC Industry

https://www.cita.ie/cita-tech-trend-blockchain-technology/

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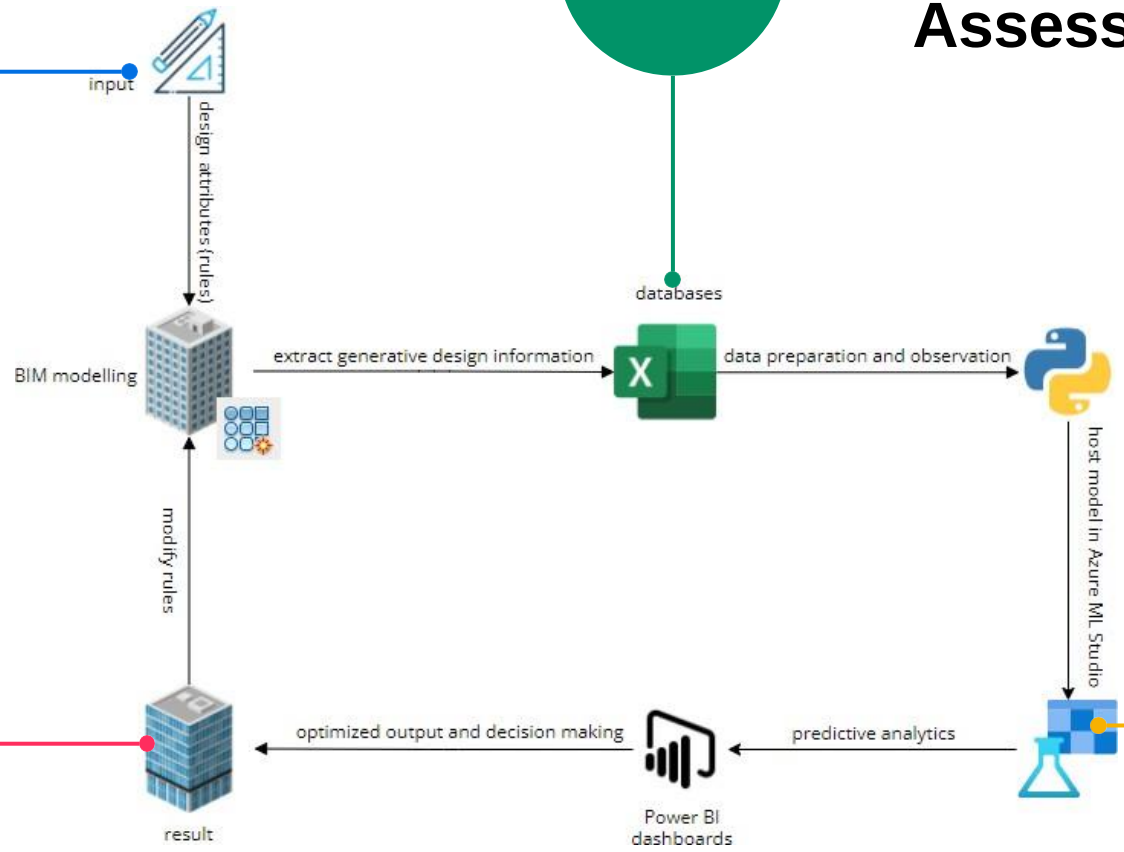
Learning Points

1

BIM-based Material Analysis

2

Machine Learning Assessment



Results

4

Application

3

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Methodology & Objective

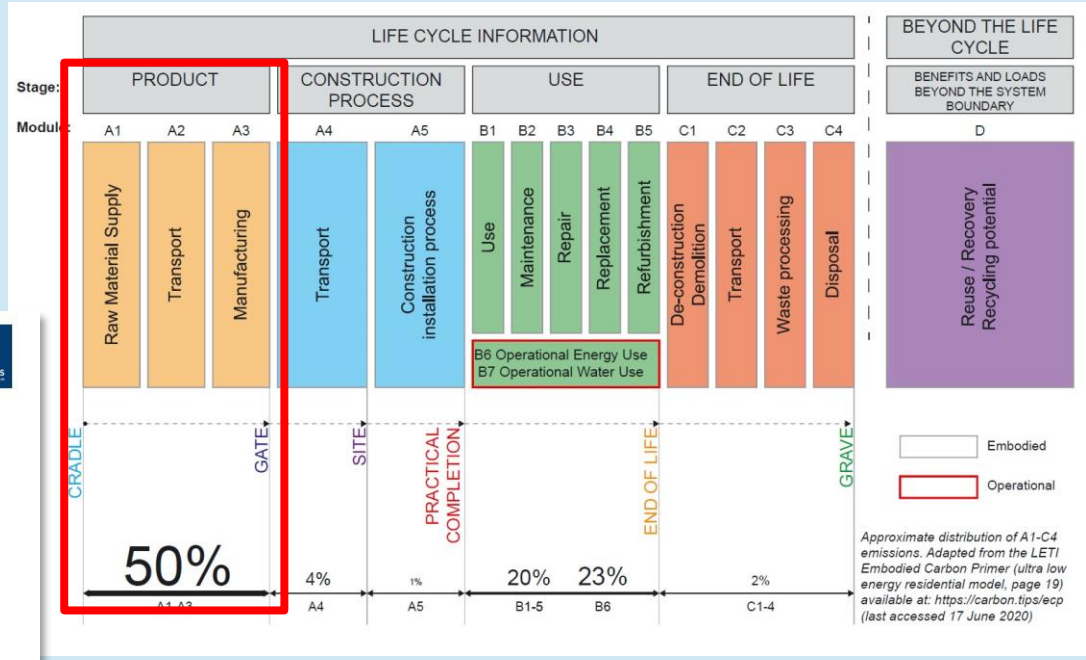
- Scope of this project within the **Cradle-to-Gate** boundary (A1-A3).
- Data collection from **EPD, ICE** database, and **generative** datasets.
- Learning Objectives – learn how to generate data for the ML assessment. Use the ML techniques and model to support BIM material analysis. This exploration help users to understand and assess embodied carbon influence in **building materials and designs**

REYNAERS ALUMINIUM NV/SA

TOGETHER FOR BETTER

ENVIRONMENTAL PRODUCT DECLARATION
in accordance with ISO 14025 and EN 15804

Product	Concept Patio 130 Sliding Door
Declaration holder	REYNAERS
Publisher and programme holder	European Aluminium EUROPEAN ALUMINIUM
Declaration number	EPD EUROPEAN ALUMINIUM 2016 – REYNAERS 6
Issue date Valid until	1 Nov 2016 1 Nov 2022* *This EPD has been prolonged by the program operator for a period of 1 year
Weblink	www.reynaers.com



Environmental impact per m²

PARAMETER	UNIT	A1	A2	A3	TOTAL A1-A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
GWP	[kg CO_2-Eq.]	3.47E+02	4.99E+00	3.86E+00	3.56E+02	1.79E+00	1.60E-01	MND	MND	MND	MND	MND	MND	MND	0.00E+00	7.45E-01	1.35E+01	8.74E+00	MND
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.21E-07	6.73E-08	MND	MND	MND	MND	MND	MND	MND	0.00E+00	1.34E-07	6.84E-07	-2.92E-08	MND
AP	[kg SO_2-Eq.]	1.76E+00	1.39E-02	2.07E-02	1.79E+00	4.28E-03	9.47E-04	MND	MND	MND	MND	MND	MND	MND	0.00E+00	1.78E-03	6.62E-02	1.35E-03	MND
EP	[kg (PO_4)-Eq.]	1.56E-01	2.17E-03	7.49E-03	1.66E-01	6.79E-04	1.21E-04	MND	MND	MND	MND	MND	MND	MND	0.00E+00	2.83E-04	1.13E-02	2.60E-04	MND
POCP	[kg ethene-Eq.]	1.50E-01	2.51E-03	2.87E-03	1.55E-01	8.48E-04	1.33E-04	MND	MND	MND	MND	MND	MND	MND	0.00E+00	3.53E-04	5.79E-03	-2.53E-04	MND
ADPE	[kg Sb-Eq.]	5.46E-01	1.50E-05	4.64E-05	5.46E-01	7.15E-06	8.94E-07	MND	MND	MND	MND	MND	MND	MND	0.00E+00	2.98E-06	4.60E-03	-2.97E-03	MND
ADPF	[MJ]	4.71E+03	7.62E+01	2.18E+01	4.81E+03	2.70E+01	7.04E+00	MND	MND	MND	MND	MND	MND	MND	0.00E+00	1.12E+01	1.47E+02	7.94E+00	MND

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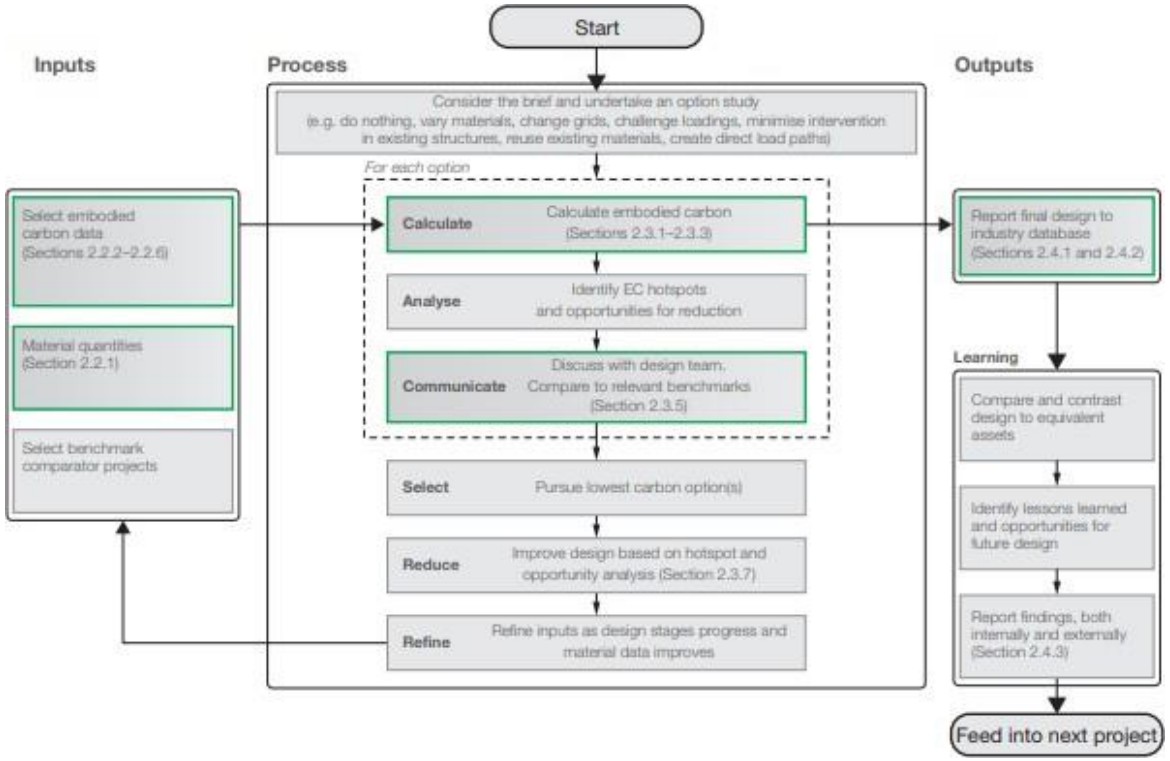
Embodied Carbon

- Embodied carbon means **all the CO2 emitted in producing materials**. It's estimated from the energy used to extract and transport raw materials as well as emissions from manufacturing processes. Embodied carbon is usually expressed in **kilograms of CO2e per kilogram of product or material**.

Embodied carbon = quantity × carbon factor



Embodied Carbon calculation process. Source The Structural Engineer UK (2018)

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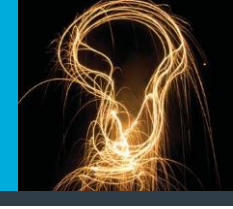
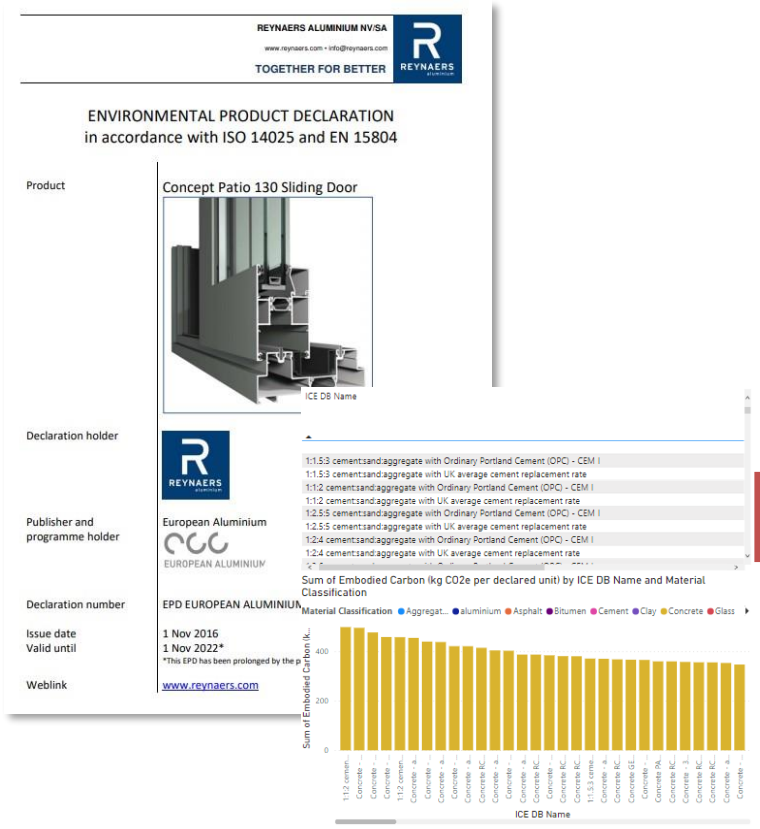
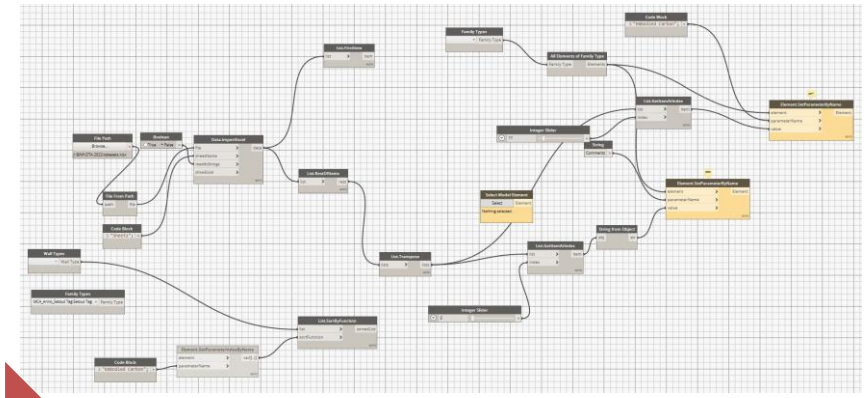
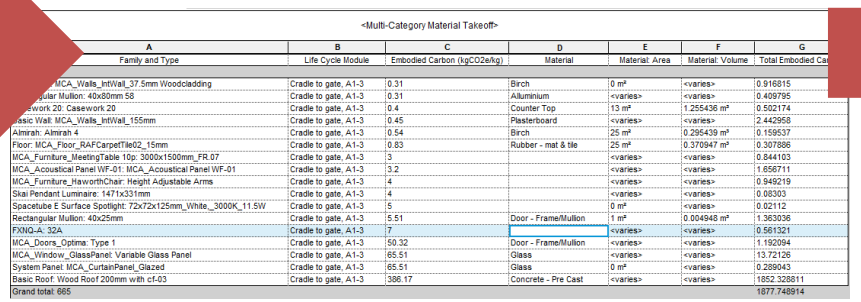
BIM Materials Analysis



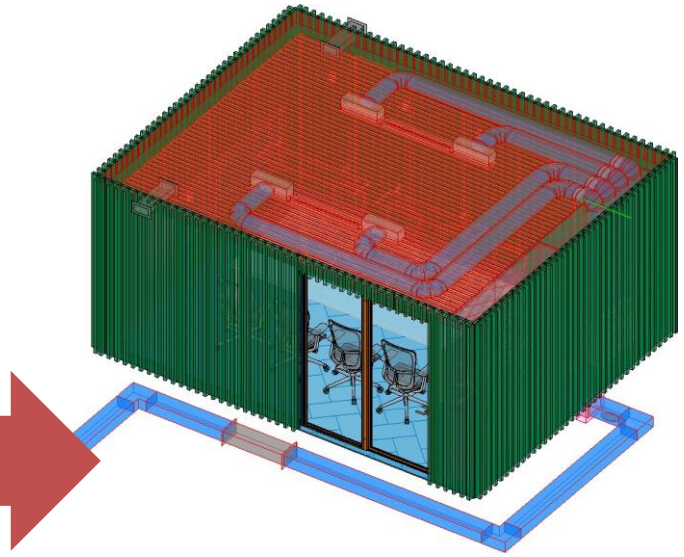






<Multi-Category Material Takeoff>

A	B	C	D	E	F	G
Family and Type	Life Cycle Module	Embodied Carbon (kgCO2e/kg)	Material	Material: Area	Material: Volume	Total Embodied Car
MCA_Walls_IntWall_37.5mm Woodcladding	Cradle to gate, A1-3	0.31	Birch	0 m²	<varies>	0.916815
gular Mullion: 40x80mm S8	Cradle to gate, A1-3	0.31	Alluminium	<varies>	<varies>	0.409795
ework 20: Casework 20	Cradle to gate, A1-3	0.4	Counter Top	13 m²	1.255436 m³	0.502174
sic Wall: MCA_Walls_IntWall_155mm	Cradle to gate, A1-3	0.45	Plasterboard	<varies>	<varies>	2.442958
Almirah: Almirah 4	Cradle to gate, A1-3	0.54	Birch	25 m²	0.295439 m³	0.159537
Floor: MCA_Floor_RAFCarpetTile02_15mm	Cradle to gate, A1-3	0.83	Rubber - mat & tile	25 m²	0.370947 m³	0.307886
MCA_Furniture_MeetingTable 10p: 3000x1500mm_FR.07	Cradle to gate, A1-3	3		<varies>	<varies>	0.844103
MCA_Acoustical Panel WF-01: MCA_Acoustical Panel WF-01	Cradle to gate, A1-3	3.2		<varies>	<varies>	1.656711
MCA_Furniture_HaworthChair: Height Adjustable Arms	Cradle to gate, A1-3	4		<varies>	<varies>	0.949219
Skai Pendant Luminaire: 1471x331mm	Cradle to gate, A1-3	4		<varies>	<varies>	0.08303
Spacetube E Surface Spotlight: 72x72x125mm_White_3000K_11.5W	Cradle to gate, A1-3	5		0 m²	<varies>	0.02112
Rectangular Mullion: 40x25mm	Cradle to gate, A1-3	5.51	Door - Frame/Mullion	1 m²	0.004948 m³	1.363036
FXNQ-A: 32A	Cradle to gate, A1-3	7		<varies>	<varies>	0.561321
MCA_Doors_Optima: Type 1	Cradle to gate, A1-3	50.32	Door - Frame/Mullion	<varies>	<varies>	1.192094
MCA_Window_GlassPanel: Variable Glass Panel	Cradle to gate, A1-3	65.51	Glass	<varies>	<varies>	13.72126
System Panel: MCA_CurtainPanel_Glazed	Cradle to gate, A1-3	65.51	Glass	0 m²	<varies>	0.289043
Basic Roof: Wood Roof 200mm with cf-03	Cradle to gate, A1-3	386.17	Concrete - Pre Cast	<varies>	<varies>	1852.328811
Grand total: 665						1877.748914



Name	Enable Filter	Visibility	Projection/Surface			Cut		Halftone
			Lines	Patterns	Transpare...	Lines	Patterns	
Embodied Carbon 0.5	☑	☑	Override...		Override...	Override...	Override...	☐
Embodied Carbon 5-10	☑	☑						☐
Embodied Carbon 10-50	☑	☑						☐
Embodied Carbon 150	☑	☑						☐
Embodied Carbon 50-100	☑	☑						☐

Environmental Product Declarations (EPD)
The Inventory of Carbon and Energy (ICE)

Material take-off and EC visualization in BIM tools

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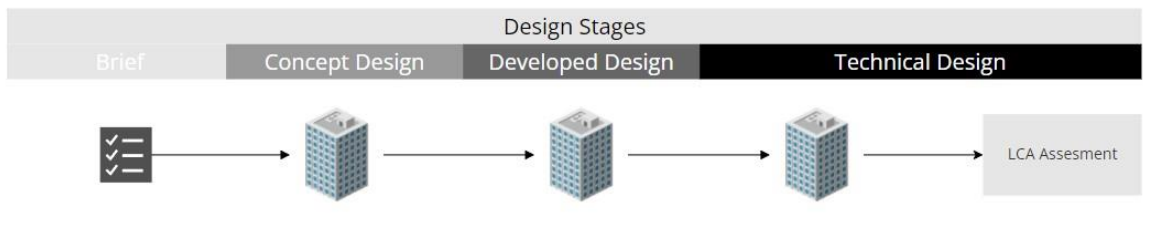
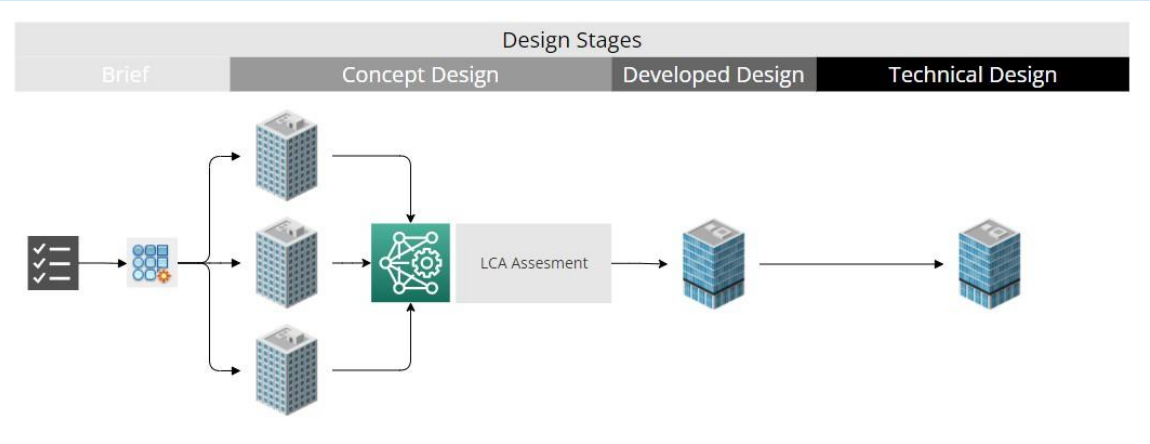
Problem Statement

- The **accuracy** of material selection is important in the early design phase of a construction project. However, this evaluation is typically carried at **late** in the design stage when cost is **high**, and changes is **difficult** to iterate.

  - **Minimize environmental impact**
  - **Reduce cost**
  - **Improve design and construction process - Benchmark**



Typical LCA-based EC assessment workflow.
Source Author (2022)



Proposed data-driven EC assessment workflow.
Source Author (2022)

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Machine Learning Assessment

Machine Learning is the study of algorithms that

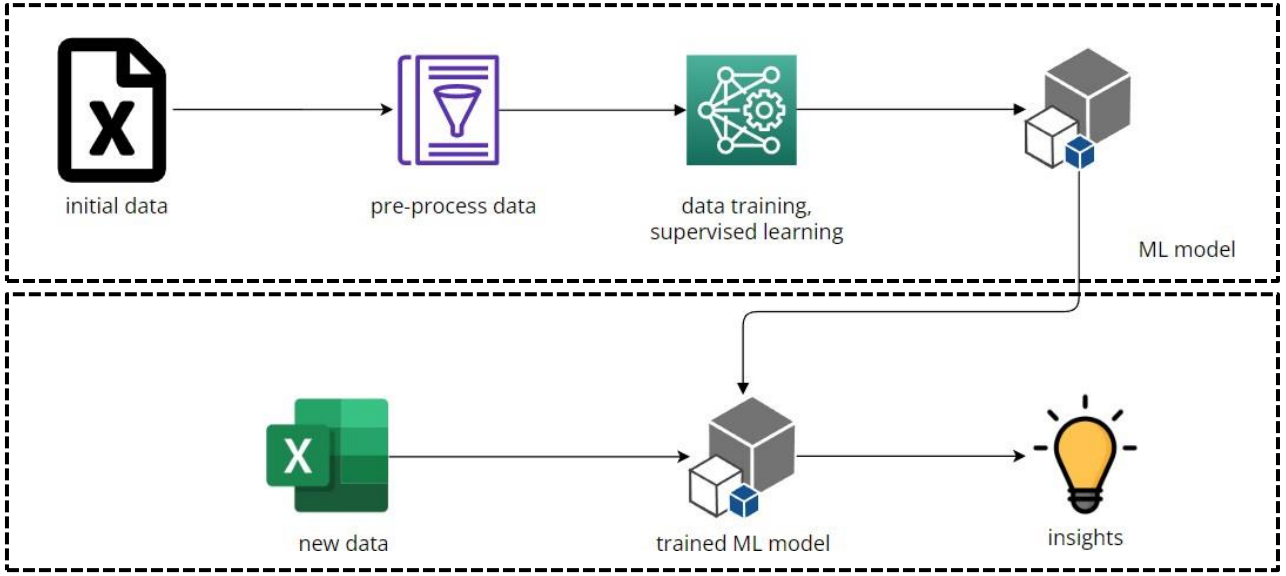
- Improve performance **P**
- At some task **T**
- With experience **E**

A well-defined learning task is given by **<P,T,E>**

Source Tom Mitchell (1998)

T: Identify material performance
P: Forecast environmental impact (GWP)
E: Embodied carbon assessment from material selection

- Machine Learning (ML) sequence processes, **data collection, data pre-processing, modelling** and **visualization.**



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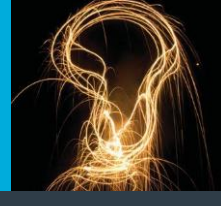
Machine Learning Assessment



Program	Version	Description
Revit	2022	BIM model authoring tool
Dynamo	2.13.0	Visual programming for Revit that allow generative design creation
MySQL Workbench	8.0 CE	Visual database design tool
Excel	2021	Spreadsheet program
Jupyter Notebook (python)	3.0	Open-source software development tool to support Python programming for ML. Python libraries (Scikit-Learn, NumPy, Matplotlib, Seaborn, Pandas)
Visual Studio	2019	Integrated development environment from programming to testing
Visual Paradigm	online	UML supporting tools for creating system framework and diagrams
Notepad++ (html, CSS, java)	2021	Text editor used for html programming
Power BI	desktop	Analytics tool for user to create report and dashboard
Azure ML Studio	online	Web portal for ML model hosting, authoring and development

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Data Collection

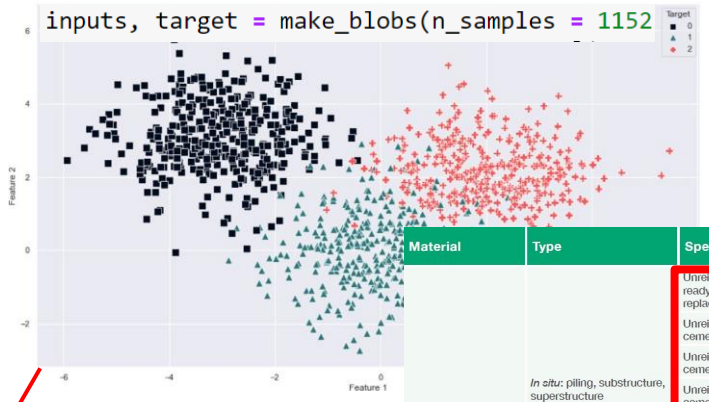
- Challenge to obtain real life **datasets**
- **Generate** normally distributed datapoints to represent floor types
- To **predict** floor type (dependant variable) relative to other design features

```
# present information about the datatype
df.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 1152 entries, 0 to 1151
Data columns (total 13 columns):
 #   Column                Non-Null Count  Dtype
---  ------                --------------  -----
 0   ID                    1152 non-null   int64
 1   embodiedcarbon        1152 non-null   float64
 2   embodiedcarbonfloor   1152 non-null   float64
 3   buildingheight        1152 non-null   float64
 4   buildinglength        1152 non-null   float64
 5   buildingwidth         1152 non-null   float64
 6   floorarea             1152 non-null   float64
 7   orientation           1152 non-null   int64
 8   roomwidith            1152 non-null   float64
 9   floornumber           1152 non-null   int64
 10  floortype             1152 non-null   int64
 11  floorthickness        1152 non-null   float64
 12  gwp                   1152 non-null   float64
```

Kailun Feng, Weizhuo Lu, Yaowu Wang. 2019
https://doi.org/10.1016/j.scs.2019.101596.

```
inputs, target = make_blobs(n_samples = 1152
```



Material	Type	Specification/details	A1–A3 ECF (kgCO$_2$e/kg)	Data source
Concrete	*In situ*: piling, substructure, superstructure	Unreinforced, C30/37, UK average ready-mixed concrete EPD[1] (35% cement replacement)	0.103	MPA, 2018[2]
		Unreinforced, C32/40, 25% GGBS cement replacement[3]	0.120	ICE V3[4]
		Unreinforced, C32/40, 50% GGBS cement replacement	0.089	ICE V3
		Unreinforced, C32/40, 75% GGBS cement replacement	0.063	ICE V3
		Unreinforced, C40/50, 25% GGBS cement replacement	0.138	ICE V3
		Unreinforced, C40/50, 50% GGBS cement replacement	0.102	ICE V3
		Unreinforced, C40/50, 75% GGBS cement replacement	0.072	ICE V3
		Unreinforced, C40/50 with average UK cement mix	0.178	ICE V3
	Precast	Reinforced, 150mm prestressed hollow core slab: British Precast Concrete Federation average EPD	50.2kgCO$_2$e/m²	BPCF, 2017[5]

```
# Importing the dataset
df = pd.read_csv (r'J:\BIM\CitA 2022\datasets\generate_dataset.csv') #place "r" before the path string to address special charact
df.head(10)
```

nbodiedcarbon	embodiedcarbonfloor	buildingheight	buildinglength	buildingwidth	floorarea	orientation	roomwidith	floornumber	floortype	floorthickness	gwp
1055184.491	3.237600	3.859	18.128	7.441	134.9000	206	3.375	1	1	0.2	0.12
1087264.839	3.129658	3.919	17.313	7.532	130.4024	110	3.516	1	1	0.2	0.12
1389018.880	1.195532	3.888	17.491	7.233	126.5113	93	3.175	1	1	0.2	0.12
1408206.082	1.751654	4.021	26.255	7.060	185.3602	172	3.043	1	1	0.2	0.12
1430838.166	1.425412	4.175	21.205	7.113	150.8373	262	3.539	1	1	0.2	0.12
1519521.924	3.198758	3.700	17.731	7.517	133.2816	340	3.551	1	1	0.2	0.12
1546029.034	4.284710	3.855	23.564	7.576	178.5296	190	3.253	1	1	0.2	0.12
1559771.606	1.647734	3.990	21.835	7.986	174.3634	136	3.353	1	1	0.2	0.12
1580124.073	1.823464	3.767	25.774	7.486	192.9592	147	3.011	1	1	0.2	0.12
1619620.228	1.771990	7.462	13.725	6.831	187.5122	265	3.226	2	1	0.2	0.12

Dependent and independent variables

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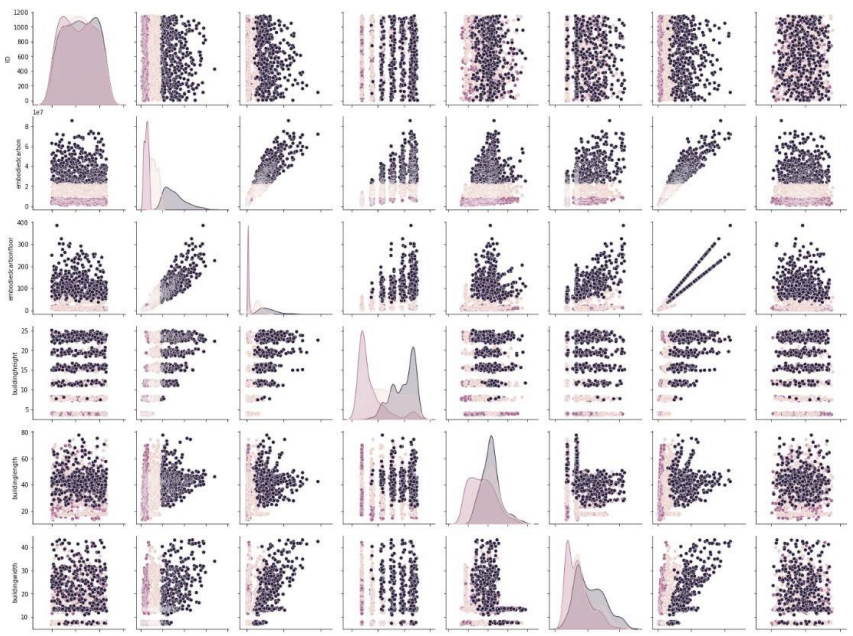
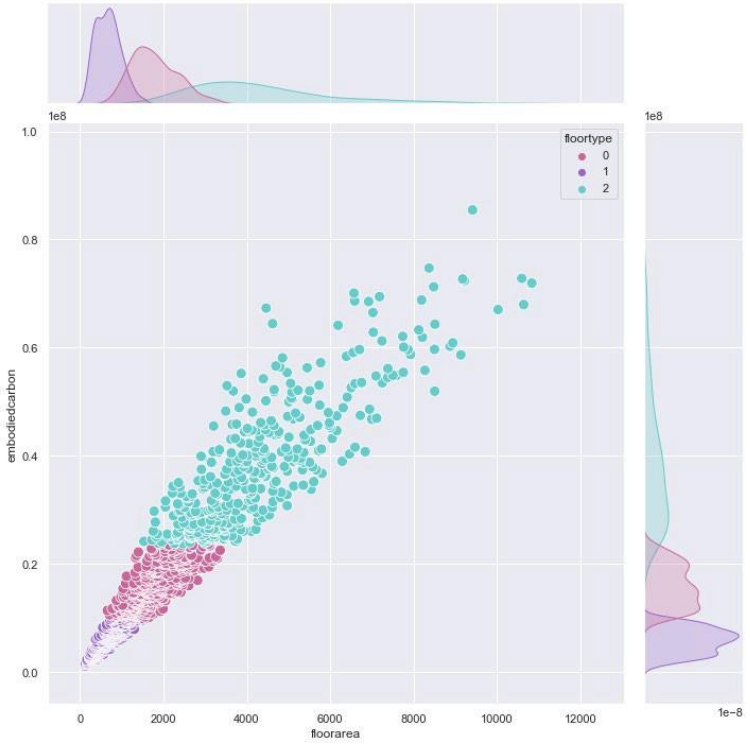
Data Evaluation

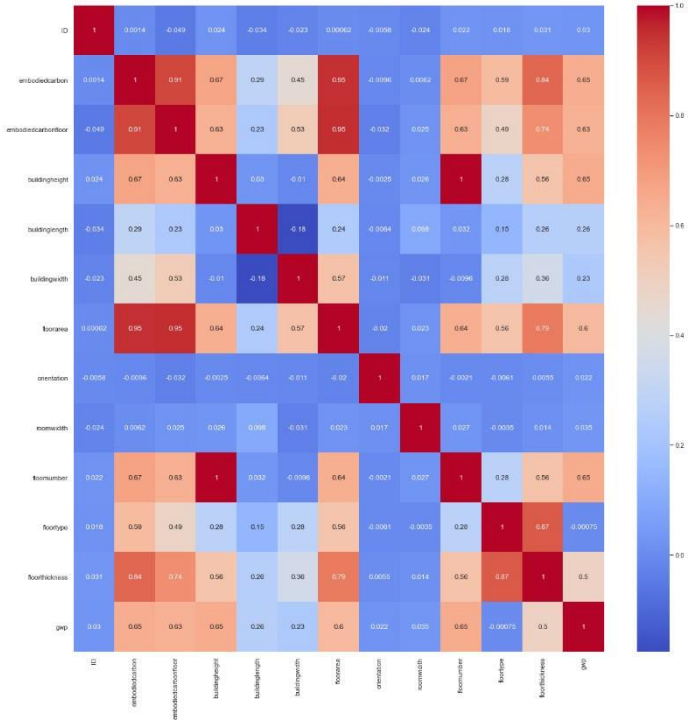


```
sns.pairplot(df, hue = 'floortype')
```




```
sns.set()

sns.jointplot(x = 'floorarea', y = 'embodiedcarbon',
              data = df,
              hue ='floortype',
              palette = knn_palette,
              height = 10,
              s = 100,
              legend = True);
```



```
corr = df.corr()
fig, ax = plt.subplots(figsize=(20,20))
sns.heatmap(corr, annot=True, ax=ax, cmap = 'coolwarm')
```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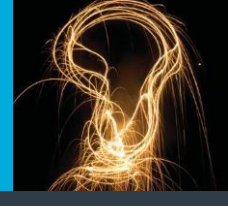
Data Training



testing

```
from sklearn.model_selection import train_test_split
# train - 70
# test - 30
x_train, x_test, y_train, y_test = train_test_split(X,Y, test_size=0.30)
```

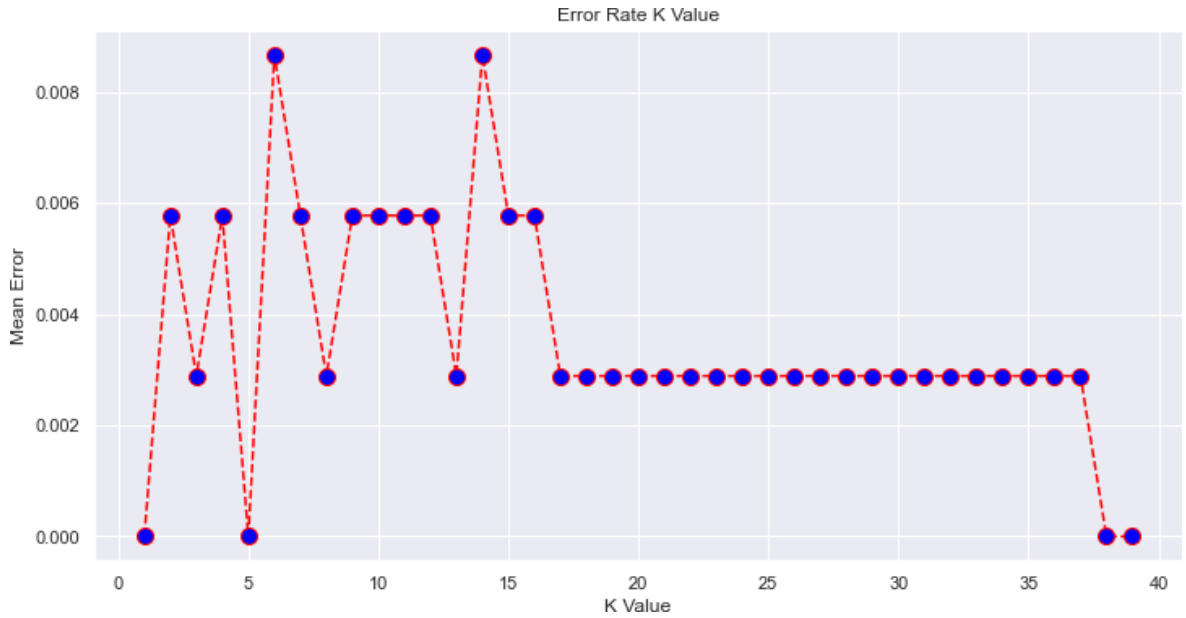
```
# knn - K-nearest neighbours
from sklearn.neighbors import KNeighborsClassifier
knn = KNeighborsClassifier(n_neighbors = 2)
```

```
# model training
knn.fit(x_train, y_train)
```

```
▾ KNeighborsClassifier
KNeighborsClassifier(n_neighbors=2)
```

```
# accuracy metric for model performance
print("Accuracy: ",knn.score(x_test, y_test)*100)
```

```
Accuracy:  99.42196531791907
```




```
error = []

# Calculating error for K values between 1 and 40
for i in range(1, 40):
    knn = KNeighborsClassifier(n_neighbors=i)
    knn.fit(x_train, y_train)
    pred_i = knn.predict(x_test)
    error.append(np.mean(pred_i != y_test))
```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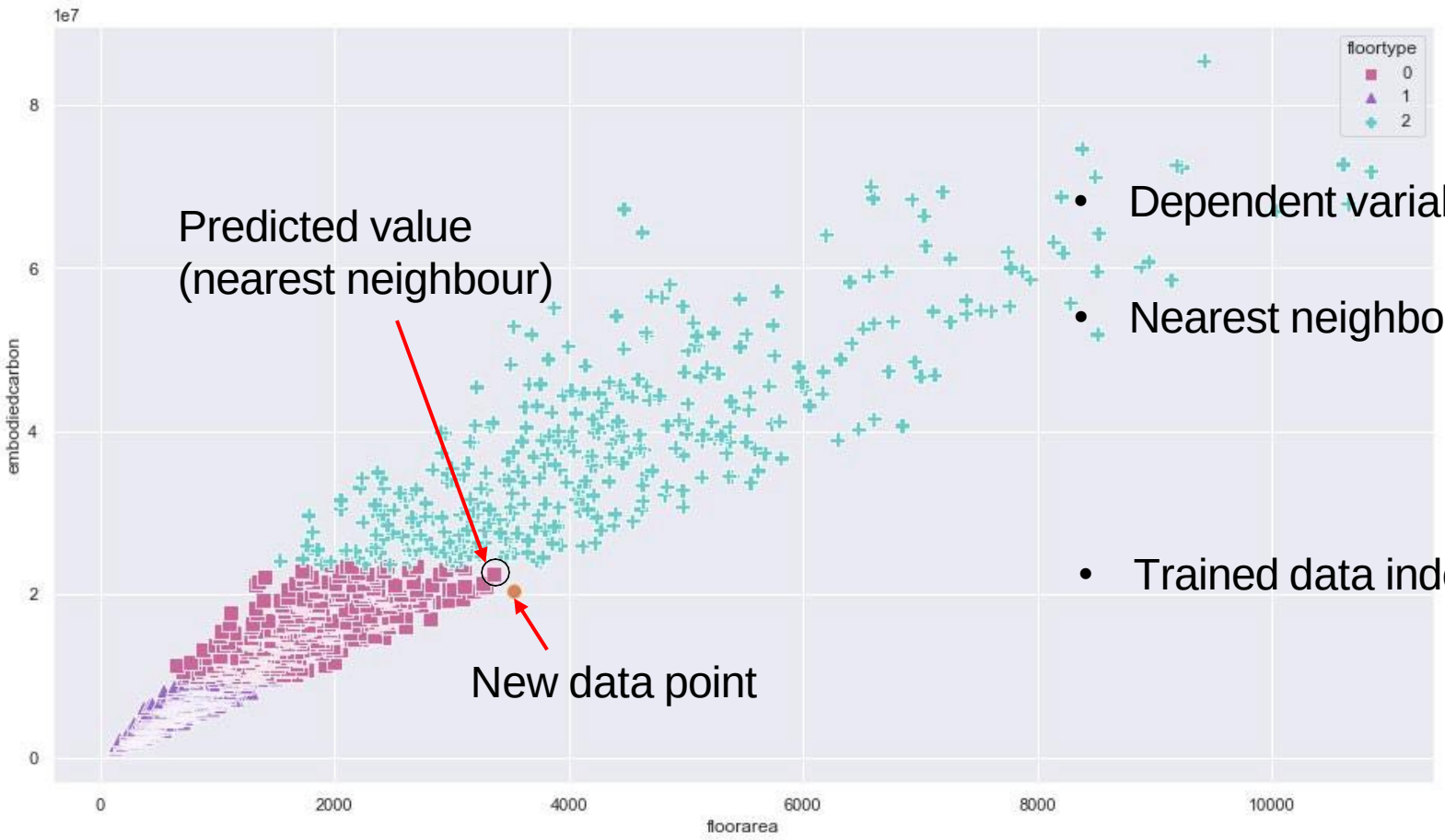
Prediction



- Dependent variable
- Nearest neighbour
- Trained data index

prediction

```
# Define the coordinates of a point whose class we want to identify.
floorarea = 3521
embodiedcarbon = 20353245.047
```

```
# Predict the class of a sample given these twelves features.
knn.predict([[floorarea, embodiedcarbon, embodiedcarbonfloor, buildingheig
```

```
array([0], dtype=int64)
```

```
# Get the distance to the neighbour and its index in the array
neighbors = knn.kneighbors([[floorarea, embodiedcarbon, embodiedcarbonfloor, buildinghei
neighbors
```

```
(array([[  3649.70966027,  5371.88624362,  63220.66719889,
          86732.0458949 , 136501.04980911, 186415.7077102 ,
         194871.58523608, 233478.97243302, 247594.77129799,
         255115.463895  , 265781.62902557, 275566.90491929,
         276260.40052593, 280945.25264038, 288456.92834048,
         307138.67772208, 342760.94950289, 365514.50018534,
         377008.39242897, 428859.92504087, 447065.88357393,
         468706.01416711, 472490.51091408, 516649.87336281,
         517901.40197217, 554056.65842542, 558650.02051855,
         586729.20392369, 657180.27011938, 706086.7131566 ,
         728402.11861702, 751473.52948038, 753531.79703169,
         761938.65025422, 780960.26110781, 793459.67965908,
         802668.62606026, 832364.31671285, 835533.03520324]]),
 array([[735, 459, 484, 292,  79, 405, 218, 414, 116, 592, 242,  84, 299,
          78, 290, 110,  42, 220, 173,  25, 140,  71, 464, 308, 247, 646,
         520,   1, 234, 661, 383, 618, 174, 379, 482,   2,  19, 417, 645]],
       dtype=int64))
```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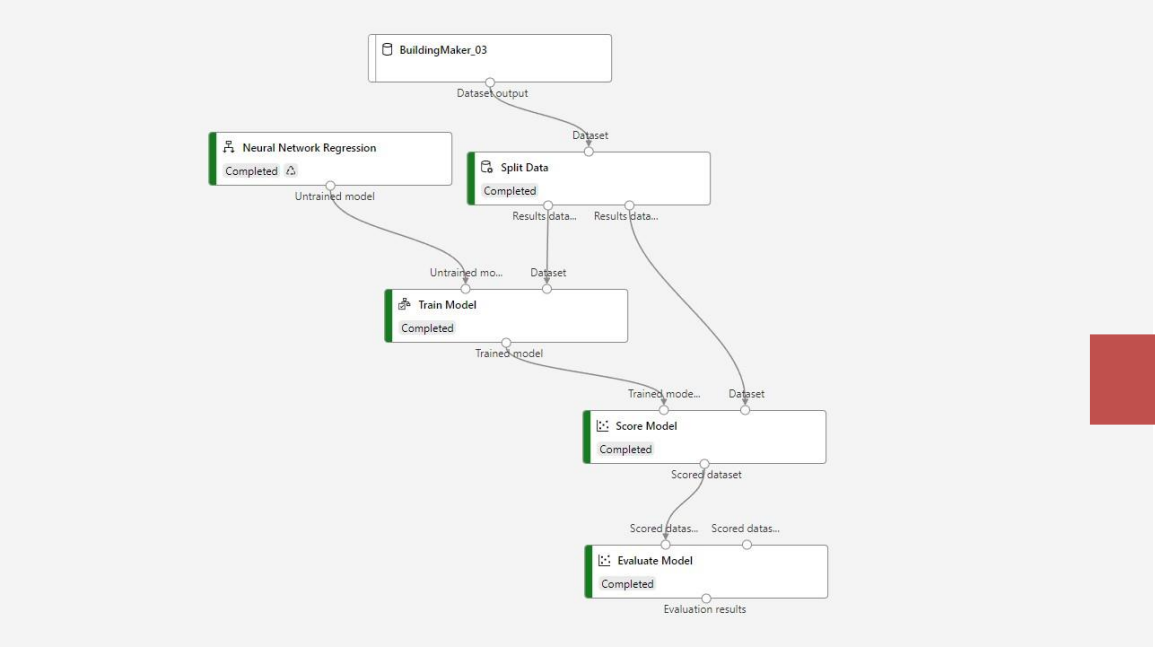
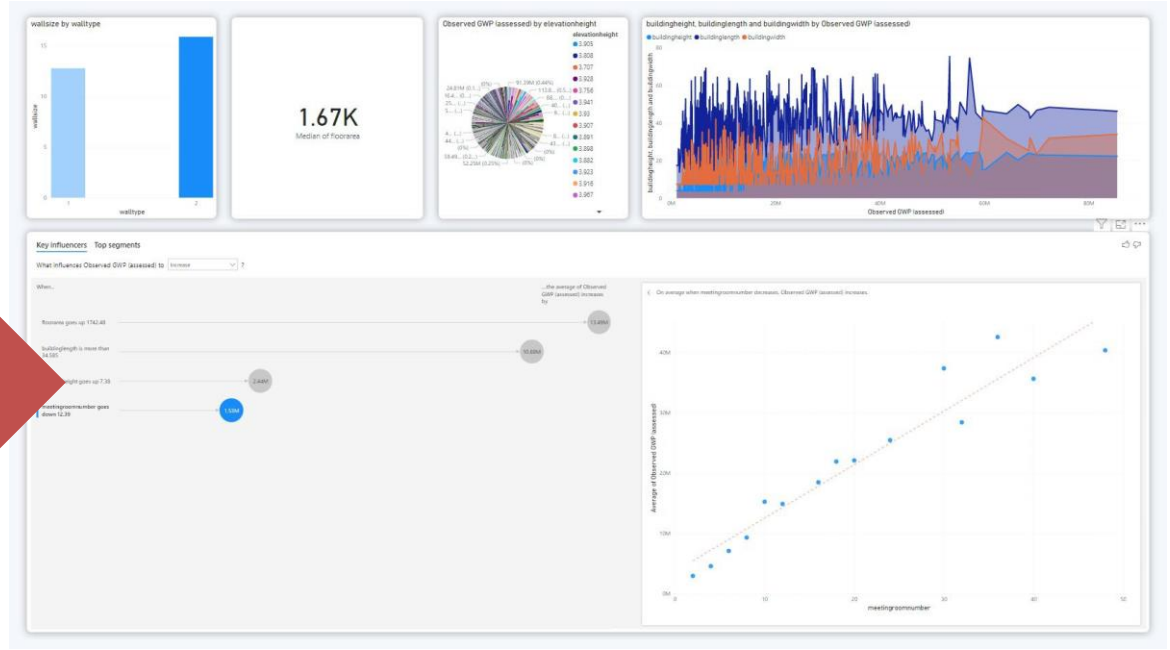
Deployment



Azure ML Studio. Source Author (2020)



Embodied Carbon impact indicator. Source Author (2022)

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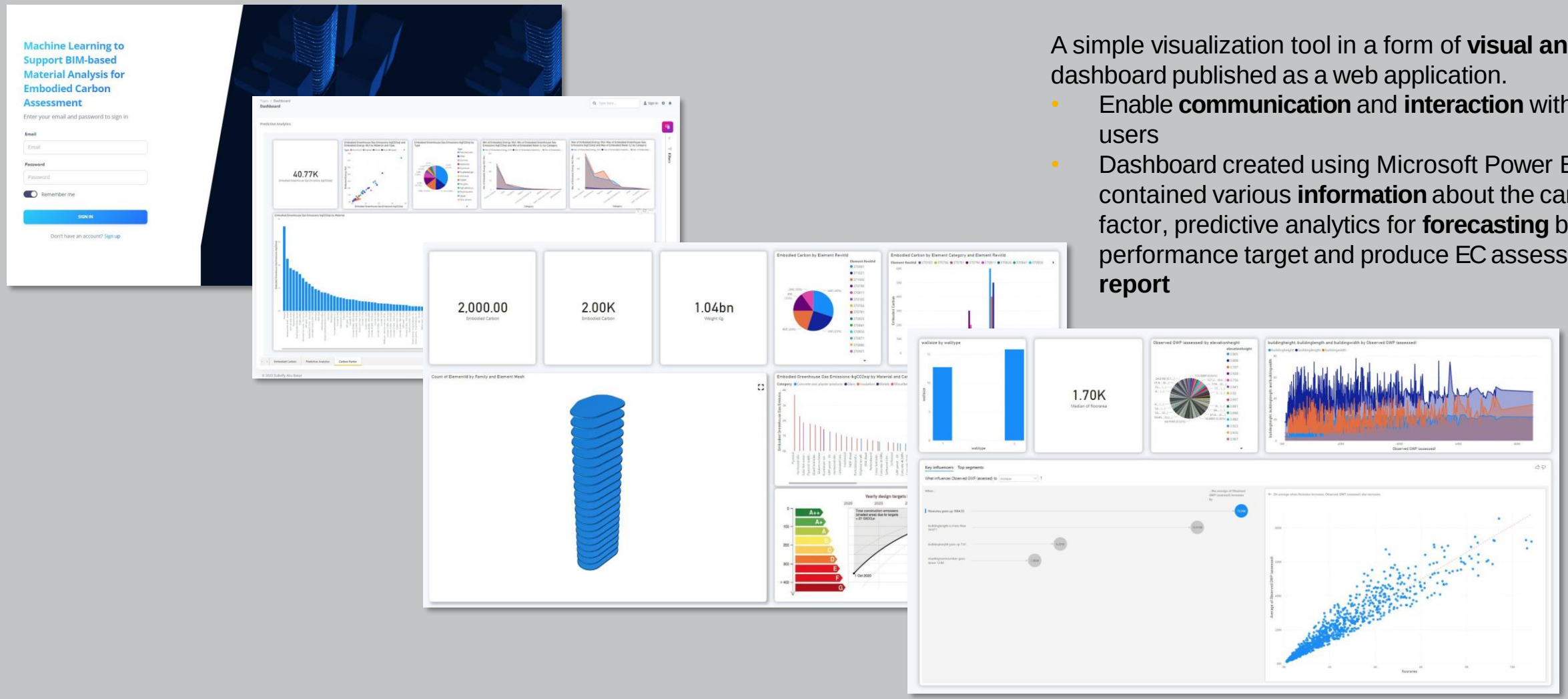
Application



A simple visualization tool in a form of **visual analytics** dashboard published as a web application.

- Enable **communication** and **interaction** with the users
- Dashboard created using Microsoft Power BI contained various **information** about the carbon factor, predictive analytics for **forecasting** building performance target and produce EC assessment **report**

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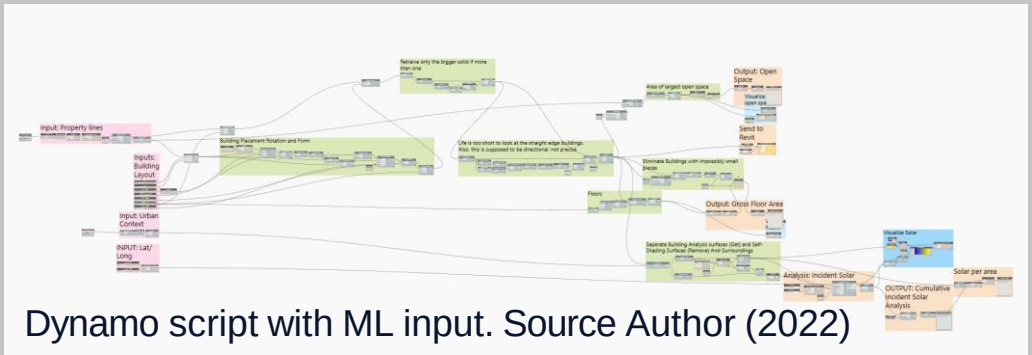
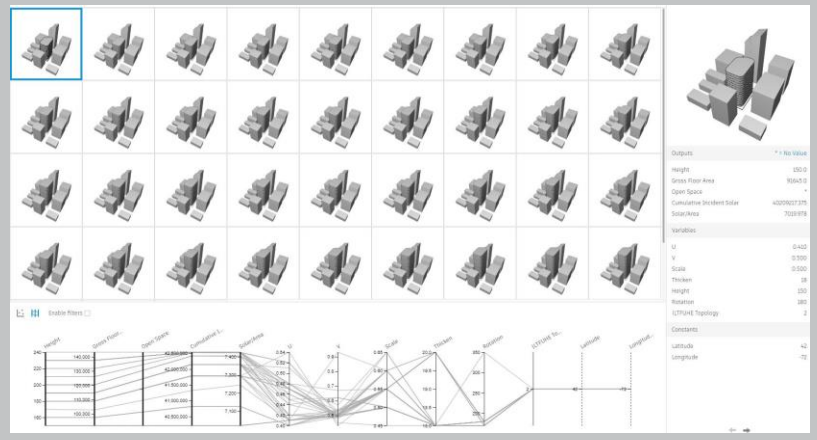
Future Study

- Compile and 'push' the trained ML model to BIM authoring tool that could be used as **Generative Design** input.



Dynamo script with ML input. Source Author (2022)



Generative design iteration. Source Author (2022)

- To extend the study beyond **building lifecycle** and **zero energy assessment**.

Building level with activation of air conditioning system (6.30 to 18.30)	The average of energy formed / Kilowatt / hour (Kw/h)		
	Per day / 12 hours	Per month / 20 days	Per year / 12 months
Promenade	114.29	2,285.80	27,429.60
Ground	215.31	4,306.20	51,674.40
1st floor	178.63	3,572.60	42,871.20
2nd floor (roof level	219.26	4,385.20	52,622.40
Total	**727.49**	**14,549.8**	**174,597.6**

Building simulation results on the value of carbon emissions generated by the study building for one year. Source Muhd Zaki PhD (2022)

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Thank you for your participation