Digital Twins for **Greener** and more **Efficient Industrial Facilities:** Element Modelling and Relationship Inference

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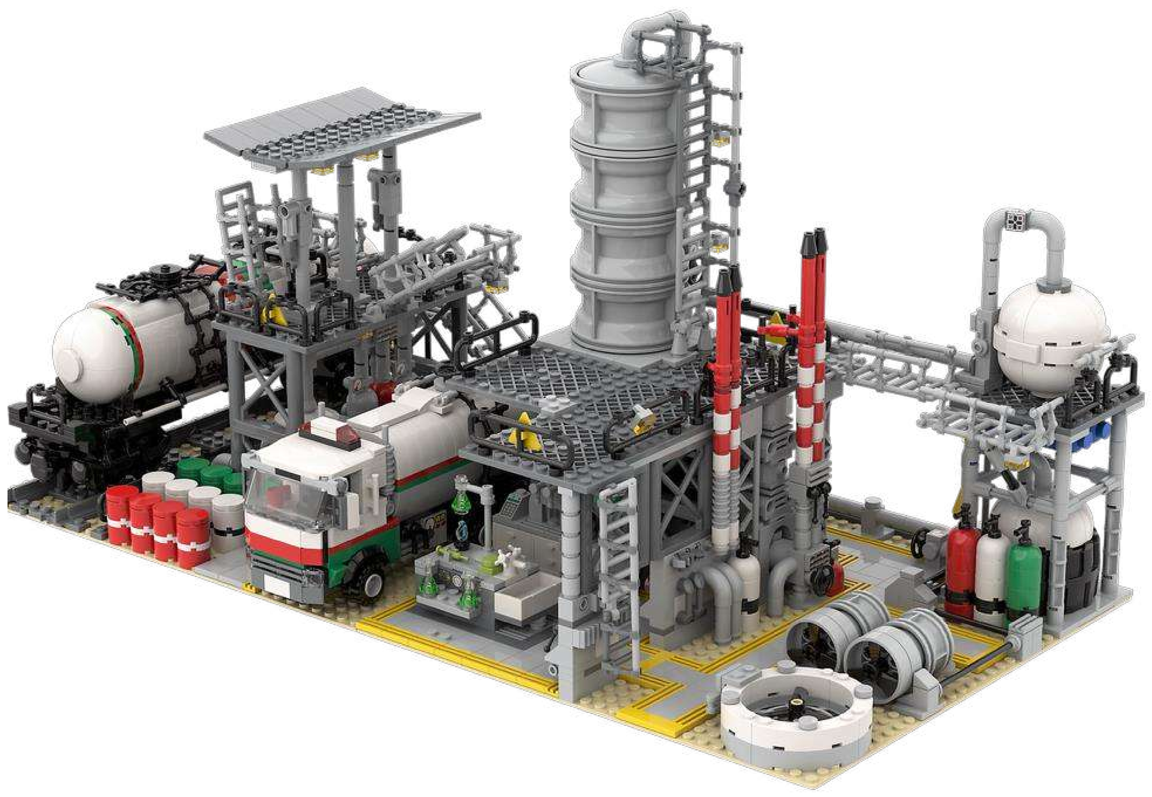
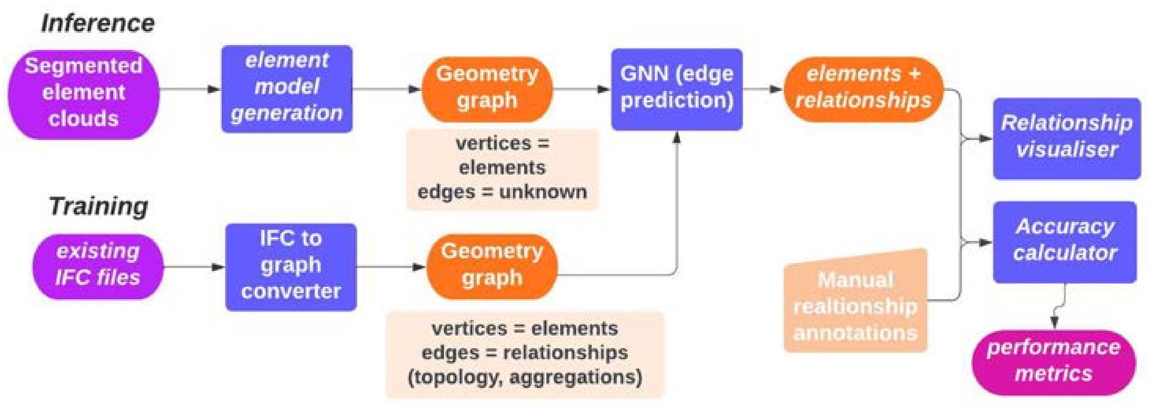
INTRO

- An industrial facility digital twin is a virtual model designed to accurately reflect a physical facility. It is generally created from a 3D scan of the facility.
- It represents not only the elements within the facility but also their interconnections.
- Digital twins aid in preventative maintenance, reduces risk of breakdown, and assist retrofitting [1]
- The cost of manually creating a digital twin often outweighs its perceived value, necessitating automation of the digital twinning process. [2]
- Point clusters of elements in the facility can be identified from the scans using 3D deep learning. [2]
- Converting these points to geometric models and inferring their connectivity is currently an open challenge.
- Currently, hand coded features are used to derive connections between elements such as pipes or elbows [3], which are inflexible, and do not adapt to new domains.
- Modelling is performed by substitution with models from an element library, lowering the level of detail of the twin. [4]



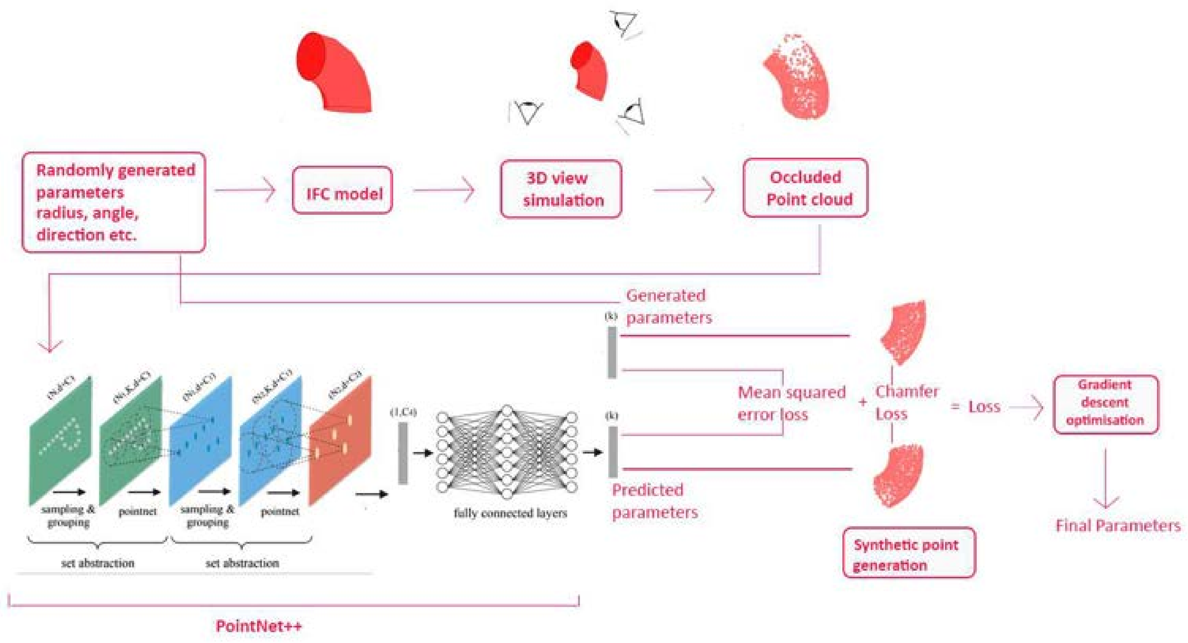
METHODS

- Elements are represented as nodes in a graph, and their connectivity as edges between the nodes.
- A dataset is generated using CAD design files to avoid manual connectivity labelling
- Element connectivity is modelled as a graph inference task and graph neural network is trained to infer connectivity between elements.



Connectivity inference pipeline

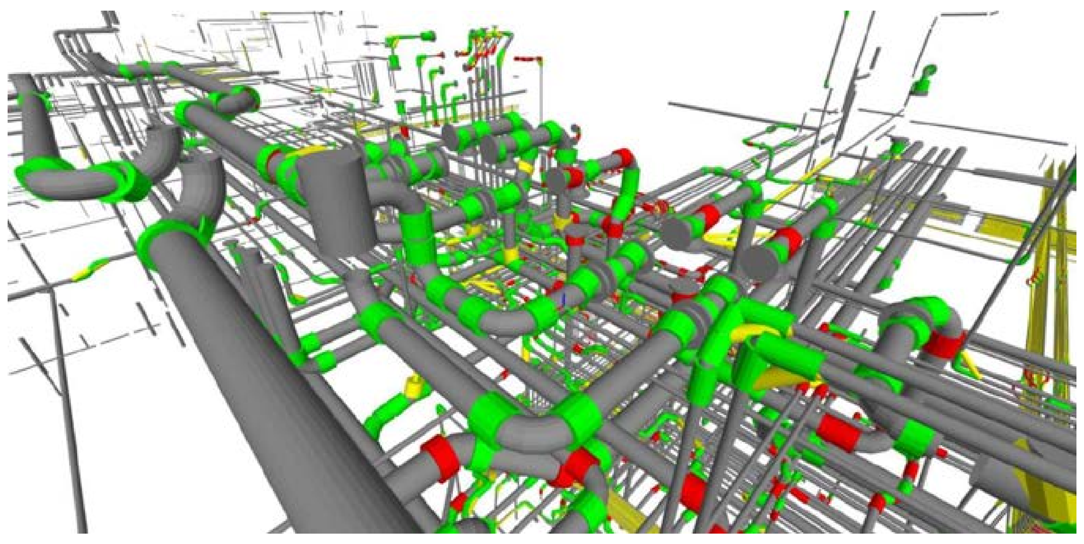
- The node representation of each element is made up of element parameters. The parameters are inferred using a point-net [5] based deep learning method and fine-tuned using gradient descent based on chamfer loss.



Element parameter prediction pipeline

RESULTS

- The connectivity inference model was tested on a dataset of around 17,000 elements and 15,000 relationships and achieved a F1 score of 0.64, 0.88 precision and 0.51 recall.
- Element parameters were successfully inferred from pipe, tee, elbow and flange elements.



Visualisation of connectivity inference results (green = true positive, red = true negative, yellow = false positive)

DISCUSSION

- We propose a novel method for automatically identifying topological relationships between elements in industrial facility models using GNNs.
- This demonstrates the feasibility of automated relationship inference, and can be used as guidance for annotators.
- The parameter inference approach ensures that element geometries are represented at a high level of detail.
- Crucially, in contrast with previous hand-coded approaches in various domains, this approach presents an automated alternative to relationship inference. It is thus suited for more complex scenarios, and is easily adaptable to other domains, making digital twinning more accessible to previously unexplored infrastructure domains.

REFERENCES

[1] Liu, R. and Issa, R. "Survey: Common Knowledge in BIM for Facility Maintenance," Journal of Performance of Constructed Facilities, vol. 30, no. 3, Jun. 2016, doi: 10.1061/(ASCE).
[2] Agapaki, E. 2022. "Automated Object Segmentation in Existing Industrial Facilities," University of Cambridge.
[3] Oh, I., · Kwang, and H. Ko. 2021. "Automated recognition of 3D pipelines from point clouds." Vis Comput, 37: 1385–1400.
[4] Agapaki, E., and I. Brilakis. 2022. "Geometric Digital Twinning of Industrial Facilities: Retrieval of Industrial Shapes."
[5] Qi, C. R., H. Su, K. Mo, and L. J. Guibas. 2016. "PointNet: Deep Learning on Point Sets for 3D Classification and Segmentation."

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TL;DR: How do we model an industrial facility with Lego bricks?
We use graph learning and 3D deep learning to find the perfect piece to represent each element, and to find how they connect to each other.

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