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Prioritizing object types for modelling existing industrial facilities

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ABSTRACT

The cost of modelling existing industrial facilities currently counteracts the benefits these models provide. 90% of the modelling cost is spent on converting point cloud data to 3D models due to the sheer number of Industrial Objects (IOs) of each plant. Hence, cost reduction is only possible by automating modelling. However, automatically classifying millions of IOs is a very hard classification problem due to the very large number of classes and the strong similarities between them. This paper tackles this challenge by (1) discovering the most frequent IOs and (2) measuring the man-hours required for modelling them in a state of the art software, EdgeWise. This allows to measure (a) the Total Labor Hours (TLH) spent per object type and (b) the performance of EdgeWise. We discovered that pipes, electrical conduit and circular hollow sections require 80% of the TLH needed to build the plant model. We showed that EdgeWise achieves cylinder detection with 75% recall and 62% precision. This paper is the first to discover the most laborious to model IOs and the first to evaluate state-of-the-art industrial modelling software. These findings help in better understanding the problem and serve as the foundation for researchers who are interested in solving it.

1. Introduction

"As-Is" Building Information Models (AI-BIMs) are the 3D digital representation of the existing condition of facilities and encompass geometric definitions at different levels of aggregation and parametric rules [1]. The clear majority of large refineries were built before the advent of CAD in 1977: as-is models, therefore, do not exist to assist their maintenance operations [2,3]. AI-BIMs of industrial plants have substantial impact in various applications. Some of these include maintenance, strategic planning of their operations, revamping purposes, retrofitting of old sites and preparation for dismantling [4–7].

Inexistence of AI-BIMs will result in time lags for these operations. This is crucial for industrial managers, since without detailed planning, productivity will be substantially affected, and the agreed budget and timeline expectations will not be met. Moreover, there are thresholds on the acceptable shut down duration that will not impede production, and those limits cannot be violated without incurring extra costs. For instance, Sanders [45] reported that 40% of the total 3D modelling cost of retrofitting a Chevron plant was spent on data-processing labor and the shut-down time was limited to 72 h to avoid additional costs. Every modelling hour saved can prevent critical failures or unexpected accidents, thus continuous production flow of these assets is achieved. This work aims to assist the tedious current practice in this regard.

Modelers use the following four main steps to manually process AI-BIMs: (a) data collection, (b) point cloud registration, (c) geometric modelling and (d) addition of accompanying information. Initially, data is collected using laser scanners and photogrammetry, which are represented by their Cartesian or polar coordinates, the point cloud, and in some cases by their color data (RGB). The scans need to be registered in a consistent coordinate system by calculating inter-scan rigid body transformations and the registered point cloud represents the complete measured data. Then this data needs to be geometrically modelled.

Geometric modelling entails (a) primitive shape detection, (b) semantic classification of detected shapes and (c) fitting. Firstly, primitive shapes are detected (e.g., cylinders, tori, planes) and classified (e.g., pipes, elbows, I-beams). Afterwards, the primitives are fitted to known solid shapes to obtain their geometric parameters. Their relationships to other objects need to be obtained in order to produce a complete AI-BIM in the Industry Foundation Schema (IFC) format. The IFC schema is a software-agnostic platform that allows geometric, material and other construction related information to coexist in a single model.

Geometric modelling is the "bottleneck" during the Scan-to-BIM modelling process of any industrial facility given how costly and time consuming it is. Recent studies have reported that geometric processing takes 90% of the modelling time [8,9]. Hullo et al. [9] reported that 10 operators were needed to process 1084 scans of a nuclear reactor and

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model its objects in around 6 months using Dassault Systems SolidWorks and Trimble Realworks. In contrast, laser scanning of the plant was completed in only 35 days. This significant time required to model the large number of industrial objects impedes adoption of as-is 3D modelling for these plants.

The research presented in this paper is exploratory in nature, not causal. It does not seek to solve the problem of automating the modelling of industrial facilities. It rather seeks to improve our understanding of the problem and the extent to which it has been resolved so far and provide a foundation for future researchers interested in solving it. This is why the main objective of this paper is to identify the most important industrial object types given how frequent and laborious they are for modelling, as well as to measure the performance of existing tools in modelling these particular object types. The authors identified the most frequent objects based on a frequency-based, statistical analysis of 3D modelled industrial objects in a variety of industrial plants. The most frequent objects were then modelled in the state-of-the-art, semi-automated modelling software, EdgeWise, and their modelling time was measured. Finally, the most important industrial object types were ranked based on their frequency of appearance and average modelling time. This analysis will substantially assist automated modelling efforts to efficiently reduce modelling time and facilitate facility management.

2. Background

Industrial plants can be divided into fifteen main categories [10]: (a) onshore and (b) offshore oil platforms, (c) chemical, (d) mining, (e) pharmaceutical plants, (f) power plants, (g) water and wastewater treatment facilities, (h) natural gas processing and biochemical plants, (i) refineries, (j) food processing factories, (k) defense facilities, (l) metal production facilities, (m) nuclear plants, (n) research facilities and (o) warehouses and silos. The object types of industrial facilities belong to the main object categories: (a) structural elements, (b) piping system, (c) electrical, (d) safety and (e) general equipment, (f) architectural elements, (g) instrumentation, (h) Heating, Ventilation and Air Conditioning (HVAC) and (i) civil elements. Representative examples of structural elements include barricades, catwalks, mod pilings, steel platforms, stairs, pipe racks, supports and structural steel elements. Respectively, examples of safety equipment include deluge systems, cameras, fire extinguishers, fire aid stations and fire detectors. General equipment includes lifting mechanisms, pumps, compressors, tanks, turbines, vessels, degassers, air coolers, drainers, water heat recovery units and exchangers. Civil elements include curbing, foundations and bollards. Examples of architectural elements are windows, slabs and walls. Instrumentation includes sensors (temperature, pressure, etc.) and controllers. Indicative examples of electrical equipment are cable trays, conduit, electrical panels, power outlets and lights.

2.1. Value of modelling industrial object types

Petitjean [11] prove that 85% of objects in industrial scenes can be approximated by planes, spheres, cones and cylinders. These primitive shapes, however, have not been assigned to specific industrial object types. The value of modelling those is measured in terms of safety, maintenance and retrofitting [12]. AI-BIMs for industrial plants have significant value for facility managers since these models assist them to be proactive in decision making that involves maintenance, operations and health and safety. Recent studies of the Chartered Institute of Building [13] have shown that the need for refurbishing and retrofitting 93% of existing industrial facilities will be a major focus in the U.K. construction industry by 2050. As a result, modelling these assets using digitization technologies is an imperative need.

Extensive research has been conducted to identify critical industrial objects under the above-mentioned values of modelling [14–20]. Susceptibility to failure is measured based on failure rate metrics. The nominal mean failure rate (λ_0) is the frequency that an industrial object type or object component fails and is usually expressed in failures per year [17]. The sample data for electrical component failures can be combined from different data sources and calculation of a mean failure rate is reasonable. Moss and Strutt [17] list several factors that affect the mean failure rate of mechanical components in industrial facilities. These factors depict the design, the size of equipment, environmental conditions and level of operation compared to the mechanical capacity of an object [17]. For example, outdoor facilities that are affected by more challenging weather conditions tend to be more prone to rust. The same paper specifies factors calculated to modify the standardized life of a component given those factors. Particularly for chemical plants and offshore platforms, these factors increase the nominal mean failure rates of mechanical components due to environmental conditions and heavy equipment operation compared to average industrial conditions. Steel sections are also critical for fatigue and fire, dependent on the load imposed and welding [14,15].

The criticality of industrial object types is then defined as the likelihood of failure multiplied by the consequence of failure for an industrial object or a process line of a plant [19]. There are three methods in literature used to evaluate the hazards and assess the consequences of accidents for a plant. These are HAzard and OPerability (HAZOP), Failure Mode and Effect Analysis (FMEA) [16] and Fault Tree Analysis (FTA) [18]. What is missing, though, is a justified study on which critical objects should be modelled for maintenance, safety or retrofit purposes.

Examples of critical object types that should be considered are given below. Hazardous subsystems should be modelled in finer detail for safety purposes. Highly hazardous object types are separators, compressors, driers and flash drums, whereas moderately hazardous ones are pipelines and pumps [20]. The identification of hazardous equipment elements will remarkably improve safety management.

Valves are a final control element in nearly all chemical process control loops and regulate the flow through piping systems. Failure to quickly locate and identify control and safety valves during inspection can result in significant damages or even massive, unprecedented disasters such as Texas City Refinery [21] or Piper Alpha [22]. Safety system deficiencies that occurred due to poor inspection and inadequate maintenance are reported as some of the main factors of the devastating incidents mentioned above.

Another important control measure in industrial facilities is maintenance of pipelines and pipe supports. Insulated pipes and pipelines carrying flammable, hazardous or toxic materials are highly important for inspection. One of the most important concerns of inspectors for maintenance of pipelines is corrosion. Pipes of Nominal Bore (NB) > 2 in. (50 mm) are considered critical for corrosion [23].

Structural steelwork and equipment are also vital for the structural stability of the plant and oil and gas production especially in cases of fire. Given the short lifecycles of refineries, which range from 15 to 30 years, structural design is challenging since the layout should be flexible and expandable [24]. Seismic and energy refurbishments for pipes are typical retrofitting operations in industrial plants [25]. AI-BIMs can significantly assist these operations, should accurate as-is models of these objects be created.

Table 1 summarizes the critical elements for each category (maintenance, safety and retrofit) based on their failure rates λ_0 (high, medium and lower impact) based on Umar [20] and Keeley et al. [26]. These values are calculated for major accidents that involve dangerous substances and cause serious damage/harm to people and/or the environment. The piping system is generally subdivided in two meaningful subgroups with respect to their Outer Diameter (OD). Small bore pipes are the pipes whose OD is less than or equal to 2 in. (50.8 mm) and the rest (pipes with OD > 2 in.) are considered large bore pipes. Table 1 shows that small bore pipelines are considered to have higher impact than large bore. Some categories listed in Table 1 are critical but not frequent. For this reason, they do not appear in Tables 3–5.

The critical industrial object types have been investigated in the literature. However, those that need automated modelling due to