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Crowd simulation-based knowledge mining supporting building evacuation design

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ABSTRACT

Assessing building evacuation performance designs in emergency situations requires complex scenarios which need to be prepared and analysed using crowd simulation tools, requiring significant manual input. With current procedures, every design iteration requires several simulation scenarios, leading to a complicated and time-consuming process. This study aims to investigate the level of integration between digital building models and crowd simulation, within the scope of design automation. A methodology is presented in which existing ontology tools facilitate knowledge representation and mining throughout the process. Several information models are used to integrate, automate and provide feedback to the design decision-making processes. The proposed concept thus reduces the effort required to create valid simulation scenarios by applying represented knowledge, and provides feedback based on results and design objectives. To apply and test the methodology a system was developed, which is introduced here. The context of building performance during evacuation scenarios is considered, but additional design perspectives can be included. The system development section expands on the essential theoretical concepts required and the case study section shows a practical implementation of the system.

1. Introduction

The building design process has advanced significantly since the adoption of Building Information Modelling (BIM) tools and standards, leading to easier modelling and information sharing. However, there are currently very few ways in which to model and use information to provide knowledge outputs about the design, and thereby enhance the design decision-making processes. With increased interoperability and the use of common data formats such as IFC (Industry Foundation Classes), design disciplines can provide analysis models from various perspectives: costs, energy, fire safety, etc. However, most developments are focused on validation of BIM models [47] for various analyses and often apply prescriptive design rules [9] as opposed to performance-based analysis. The current state of using digital technologies for the building lifecycle is constantly developing and there is a need for more automatic, multi-disciplinary methods to deal with large data and interoperability issues [21].

In the field of fire safety, Crowd Simulation (CS) analysis tools are used to estimate building performance in terms of human movement behaviour [8]. This process requires several iterations in different scenarios following conventional workflows [34,5,20], which can be a very time-consuming process and can often lead to wrong estimations of the building performance [37]. There are currently no practical ways of leveraging building information and designer knowledge to enhance and speed up this process. The traditional process usually relies on designer judgement to identify performance problems, which cannot take into account all scenario types due to time-constraints, or the variance caused by human behaviour [22].

This research aims to bridge this gap by exploring the potential of representing information models, designer knowledge and design processes into semantic web ontologies. Using this methodology, ontologies can leverage information models through reasoning and data linking, thereby providing a more automatic process of analysing building performance. With the right operators in place, ontology rules and reasoning can provide insight from CS design scenarios. Another advantage which semantic web languages provide is a more complex integration of crowd simulation tools with BIM, but also with various other sources of information which are required the create realistic scenarios.

Succar [40] describes level 3 BIM as a network of integrated models and services which can be used beyond just the semantic properties of the used building models. Initiatives towards a BIM level 3 way of working [14] expect more intelligent model data and information, which can be leveraged to provide advanced and speedy design support

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for various Architectural, Environmental and Construction (AEC) applications. Thus, it is expected that level 3 BIM and beyond to be able to provide more than just data and information, but also knowledge about building models.

The paper begins with presenting some of the most important related work in the field of fire safety analysis and current uses of ontology tools. The system development outlines the main requirements for representing the CS domain and its interactions with BIM and other sources of information. A conceptual knowledge mining process, for creating valid simulation scenarios and returning results in accordance to design objectives is described. A case study outlines the process of using the system prototype with the scope of identifying advantages and limitations. This is then followed by a discussion on the practical use of this approach and planned future work.

2. Related work

This section outlines crowd simulation models and ontologies in the fields of BIM collaboration efforts. A review of CS models and tools was necessary to assess their limitations, ways of working and their interoperability with BIM processes. The overall research aims to bridge interoperability and perform knowledge retrieval from vast simulation data, for which ontologies are chosen as tools to achieve this. A review of ontology tools is also presented to establish current methodologies, especially in the fields of BIM and fire safety.

2.1. Crowd simulation analysis tools

There are several comprehensive crowd model reviews, which offer critical analysis regarding methodologies used [13,19], application domains [19], scale [49], degree of realism [8] and high-rise buildings focused [35]. The afore-mentioned authors agree that there is no comprehensive model which can simulate all the complexities of human behaviour. Such a model would not be practical because as the complexity of the model grows, so does the computation time. Kuligowski [19] advises that each model should be used for very specific purposes and users should be aware of each model's practical application and limitations. Ronchi and Nilsson [35] mention that for a more comprehensive view, several models can be considered at the same time, which might reveal more information from different perspectives. Zhou et al. [49] and Duives et al. [8] agree that models can be divided into microscopic models (small population) which have high precision, and macroscopic (large population) models with lower precision. From literature, the most prevalent use case scenario is concerned with the emergency evacuation of a building.

Crowd simulation analysis tools are now widely used in design decision-making to assess building performance. Thus, they are expected to provide relevant information indicating building behaviour in crowded scenarios. However, it is not always clear how relevant the simulation output is, as it is dependent on a large number of parameters [15,20]. To compensate for this limitation, it is often required to conduct several simulations using different assumptions and scenarios [13]. This becomes overwhelming when in the context of several design iterations, making it a highly inefficient process. This suggests the need to integrate and automate the process with de facto design processes and standards.

A number of studies are focused on integrating crowd simulation tools into various systems: Jalali et al. [17] integrate different domain tools together for fire evacuation management scenarios; Wang et al. [44] use BIM platforms to provide building environment information into a system that perform calculations of escape routes - the authors present a sophisticated system using several tools to compare results across different design perspectives. For the above-mentioned studies, there is no consensus on information formats, but they regard BIM as the source of information. However, no use of IFC is mentioned, and the BIM data imported is limited to geometry. Despite these attempts, a gap in the interoperability layer between BIM tools and fire safety tools is evident, with no common methodology or information transfer protocols, also pointed out by Wang and Wainer [45]. Additionally, studies focused on fire evacuation with BIM support are only concerned with geometric objects, with no mention to the importance of a context of a simulation model which is defined by more than just geometric components.

Apart from the geometric information, additional object properties are often used in rules checking for fire safety. There are several attempts to automate the rules checking for fire evacuation safety evaluation, with one of the first comprehensive attempts by Dimyadi et al. [7]. The study presents a system which relies on IFC model data and user input, which is compared against a Regulatory Knowledge Model (RKM) consisting of the design rules applied to the process. The research checks output from multiple tools to assess fire safety performance of building designs and is IFC focused. Although a good step in the right direction, the process of integrating the information is not collaborative enough (due to expressing regulations in XML format) for more holistic design views or across the BIM lifecycle stages where higher expressivity of the model information is more beneficial. This is also explored by the same authors in another study [6], where they recommend using semantic web linked data formats (such as ontologies) to express regulatory knowledge, due to higher expressivity and interoperability, making it easier to access the relevant information required in this sort of multi-disciplinary process.

Malsane et al. [23] try to identify the requirements of integrating simulation safety tools and regulations. The scope of the research is limited to regulation in England and Wales, but it discusses in detail the level of knowledge formalisation and concludes that there is no overall consistency on how many fire sub-system rules are addressed. Fire design is a very complex problem to solve due to the multitude of subsystems that require audit and their inter-dependencies. The authors further state that with the use of the IFC standards, regulation formalisation should be more object-oriented, thus more specific and easier to assess. However, due to the complex nature of describing regulations, IFC alone cannot encapsulate all the necessary information for valid performance and rules-compliance audit, where user input and designer personal judgement are part of the process [6].

The studies discussed above rely heavily on IFC, but still face difficulties when expressing rules and regulations on top of building models when trying to evaluate the performance of a design. While IFC is the best option for storing structured data, it does not meet all the information requirements needs for inter-disciplinary design processes when in the context of performance assessment, which often requires significant user input [6]. Additionally, no study investigated the interoperability with BIM beyond geometric information, which is insufficient for CS purposes, and that valid simulation models require input from various other information sources, not just IFC. Finally, the studies have expressed less interest in conceptualising and representing the factors which are the indicators of fire design performance or how they can be used in the context of automation.

2.2. Ontology models for building design

Pauwels and Van Deursen [29] is one of the pilot studies investigating the capabilities of semantic web rule checking, applied to acoustic building design, closely tied to IFC concepts. They state that the limitations in the IFC schema expressivity of concepts are overcome by an ontology approach. Another pilot study on using ontology tools is by Scherer and Schapke [38], which describes a framework for using ontologies as a means of integration on the project level, which can include multiple models and processes. The main benefits identified seem to suggest that an ontology approach enables further expressivity and linking of the data, thus allowing for more flexible definitions of model data, which is crucial in including non-traditional design analysis under the BIM umbrella. Long before these developments, Rűppel et al. [36] proposed an ontology model framework for fire safety

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