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InSpace3D: A Middleware for Built Environment Data Access and Analytics

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Abstract

Standardisation, archiving, and digital access of spatial data pertaining to built-up environments is an area acquiring increasing attention amongst several interest groups: policy makers, designers and planners, civil engineers, infrastructure management and public service personnel, building users. Initiatives such as the Building Information Model (BIM), Industry Foundation Classes (IFC), and CityGML are creating the information-theoretic backbone that guides the crucial aspects of *quality*, *exchange*, and *interoperability* of spatial data at the environmental and urban scale. However, due to the inherent scale, complexity, and detailed geometric character of building information data, extracting useful semantic and qualitative knowledge for accomplishing high-level analytical tasks is still an extremely complex and error prone process involving data intensive computing. We propose a uniform spatial data access middleware that can provide a combination of high-level, multi-modal, semantic, and quantitative-qualitative spatial data access and analytical capability. We present the core computational capabilities for the proposed middleware and present an overview of the high-level spatial model and its compliance with the industry standard IFC. A key theoretical contribution is a framework for investigating the computational complexity of deriving spatial artefacts within the context of building informatics. Additionally, we empirically investigate the feasibility and practicality of the derivation of spatial artefacts by conducting experiments on seven industry-scale IFC models. The experiment results show that, despite having non-linear polynomial increase with respect to time, deriving spatial artefacts is practical with large designs.

Keywords: Architecture; Spatial Analysis; Artificial Intelligence; Building Information Model

1. Introduction

Contemporary research trends in environmental spatial data modelling are questioning the conventional disparateness between indoor, environmental, and geographic spaces, in favour of a unified view across these areas. These initiatives are geared toward ensuring seamless access to detailed, high-quality environmental spatial data for stakeholders such as policy makers, designers and planners, civil engineers, infrastructure management and public service personnel, occupants, and other building users. For instance, in the area of Architecture, Engineering and Construction Informatics (AEC), detailed quantitative data about the internal layout and structural properties of buildings is made accessible by the standardisation initiatives that have materialised by way of the

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Building Information Model (BIM) [1] and Industry Foundation Classes (IFC) [2]. Similar trends are observable in the urban data management community, for instance, within the CityGML [3] initiative essentially aiming to define an encoding for the representation, storage, and exchange of virtual 3D city and landscape models at different levels of granularity.

It is expected that detailed, accurate metric data about the layout and structural properties of built-up space will rapidly become ever-more readily available. The availability of such data is even mandated by governments, or adopted as de facto in state owned public construction projects in some countries in the European region (e.g., Denmark, Finland). However, due to the inherent scale, complexity, and detailed geometric character of building information data, extracting useful semantic and qualitative knowledge for accomplishing high-level analytical tasks is a complex and error prone process. General tools and services embedding data-intensive computations for a wide range of *spatial assistance systems* are needed.

The range of expert domains involved in a building project are extensive: architectural design, structural, electrical, heating-ventilation-air conditioning (HVAC), project management (including risk assessment, cost estimation, etc.), energy management. Domain-specific software tools must be developed that can interpret raw numerical sensor data and geometric building models in a qualitative manner and provide high-level semantic analyses, for example: indoor navigation for wayfinding assistance based on research in cognition; qualitative spatial reasoning support for building maintenance to identify plumbing faults and leaks, electrical faults, or to detect warning signs of structural damage from stress or rot; real-time emergency services that employ high-level reasoning for interpreting temperature and other sensor measurements, video feeds, or predicting flashover; facilitating emergency prevention through early detection of fire hazards.

We propose InSpace3D —*Indoor Spatial Awareness Middleware for Built-Up Spaces*— a computational middleware for spatial data access and analytics providing a range of analytical capabilities that may be directly used by spatial services (e.g., indoor navigation assistance, emergency support, building maintenance) seeking to leverage on the availability of ubiquitous spatial data, e.g., via municipal data repositories, Google (indoor) maps. Figure 1 illustrates the integration of InSpace3D middleware within the workflow of BIM model servers and third-party semantically rich analytical tools, services, and applications. InSpace3D incorporates spatial data-structures, algorithms, and the overall methodology for automatically deriving higher-level qualitative spatial representations based on an extensible set of core modalities: movement, visibility, environmental affordance, operation, and empty space analysis. This multi-modal access to building data enables higher level spatial querying and reasoning, thus shifting the cognitive burden of dealing with enormous amounts of numerical data away from the user. InSpace3D serves as a uniform middleware that can provide a combination of a high-level, multi-modal, semantic, and mixed quantitative-qualitative data access and analytical capability.

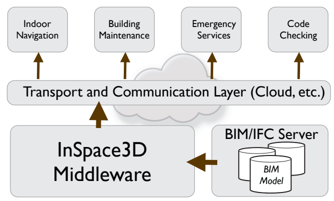

Fig. 1. InSpace3D Applications

The aim of this paper is to broaden these results by establishing InSpace3D as a middleware framework based on a solid theoretical foundation, and to investigate the computational practicality of employing InSpace3D middleware on real, industry-scale building models. Section 2 presents the development of BIM and related research. Section 3 enumerates a core set of spatial artefact primitives and presents the InSpace3D middleware architecture. Section 4 characterises the computational complexity of deriving spatial artefacts. Section 5 presents experiment results that show the practicality of InSpace3D, followed by the conclusions.

2. Spatial Data Handling in Achitecture and Construction Informatics

Unlike other domains that also heavily employ product modelling (aerospace, automotive, etc.), the AEC domain is characterised by distributed, specialised working groups collaborating on one-off projects [4], resulting in the fundamental challenges of model *exchange* and *interoperability*. One response to this has been the ongoing development of the Industry Foundation Classes (IFC) [2], a comprehensive building modelling schema that aims to cover *all* major aspects of the AEC industry, based on the ISO STEP product modelling standard and the EXPRESS language [5]. However, a large, complex, monolithic IFC model, in its entirety, does not support *any* particular stakeholder. Amor and Hosking developed a methodology of partial model *views* for each expert domain