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Construction-specific spatial information reasoning in Building Information Models

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A R T I C L E I N F O

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A B S T R A C T

In recent years, there have been significant advances in modeling technology for object-oriented building products. However, the building models are still lacking of providing construction-specific spatial information required for construction planning. Consequently, construction planners visually analyze building product models and derive geometric characteristics such as bounded spaces and exterior perimeter to develop detailed construction plans. Such a process presents fragmented information flows, from building product information to construction planning, that rely on subjective decisions of construction planners. In order to overcome these drawbacks, this research proposes a geometric reasoning system that analyzes geometric information in building designs, derives the construction-specific spatial information, and uses the information to assist in construction planning. The scope of presented work includes detecting work packages formed by faces during construction, such as large work faces and bounded spaces, and using information in the work packages directly to support planning of selected indoor construction activities. The main features of the proposed system named Construction Spatial Information Reasoner (CSIR) include a set of relationship acquisition algorithms, building component relationship data structure, and interpretation of the relationship to support detailed construction activity planning. The relationship acquisition algorithms identify adjacency between building components that is stored in the relational data structure. Then, acquired adjacency relationships are transformed into a set of graphs that represent work packages. To implement the proposed approach, CSIR utilized a commercially-available Building Information Modeling (BIM) platform and the algorithms were imbedded to the BIM platform. For validation, CSIR was tested on a real commercial building. For interior ceiling grid installation activities, CSIR successfully detected existing work packages and analyzed the spatial characteristics impacting construction productivity. The major contribution of the presented research would be to enable a realistic analysis of building geometric condition that is not possible in current BIM and a seamless information flow from building product information to construction process plans. These can potentially reduce current manual and error-prone construction planning processes. Limitations and future research suggestions are also presented.

1. Introduction

1.1. BIM and construction planning

Developing an effective construction plan is challenging but critical to successful delivery of a construction project [1,2]. Construction plans often involve many activities, from analyzing various construction site conditions, preparing construction equipment, tools, and temporary facilities, to assessing the feasibility of developed plans. Traditionally, such construction planning activities were conducted using two- or three-dimensional building drawings along with construction schedules in bar charts. Construction planners have to mentally simulate expected construction site conditions and rely on their intuitive understanding about the construction methods [3]. This is because the static views of the buildings cannot visualize dynamic and time-based construction processes, and the construction schedules in bar charts cannot explain geometric conditions of construction projects. Such challenges make construction planning mentally demanding while most construction projects are often short of human resource for construction planning [4].

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Developments in the modeling technology of object-oriented building products, such as Building Information Modeling (BIM), can reduce the intensity of such mental activities. The advanced 3D modeling of BIM enables accurate and consistent visualization of building appearances. Furthermore, Building Information Models (BIMs) can be integrated into construction schedules by establishing virtual links between individual components, e.g. walls and slabs, and schedule activities. Through the links, expected progress of construction plans can be graphically visualized in a pre-defined time interval [5–8]. Since a temporal dimension is added to a 3D BIM, the technology is called 4D BIM. As stated in several research studies, there are potential benefits of using 4D BIM techniques for construction planning. 4D BIM can assist in construction planning process [9], enable an accurate constructability analysis of the construction schedule [10,11], and facilitate collaborations between multiple project participants [12,13].

1.2. Lack of construction-specific information in current BIM-based construction planning

While the aforementioned benefits make 4D BIM one of the most dominant methods that incorporate construction process information into building product information, currently available BIM packages utilize rich information in BIM mainly for visualization of building products and construction processes. Several technical deficiencies have to be overcome to take full advantage of BIM which could assist construction planners in a way that reduces the mental activities required for planning.

First of all, there is a lack of technical capability to derive information relevant to construction from BIM. When a construction plan is established, there are several important issues to be addressed, such as geometric conditions impacting construction progress [14], characteristics of construction method applied [15,16], required temporary structures [17], potential construction hazards [18], spatial conflicts between work crews [19] and availability of work crews, etc. For a construction plan to be practical and executable, construction planners have to analyze a BIM and a construction schedule considering all such issues when they create 4D BIM. Construction planners of today still visually analyze building designs and construction schedules relying on their knowledge and experience since most of such construction-specific information usually does not exist explicitly in BIM [20]. Accordingly, the reliance on mental activities, driven by human cognitive capability, still exists even when BIM technology is used for construction planning.

1.3. Representational deficiencies in current BIM-based construction planning

Another drawback is representational deficiencies in current BIM-based construction planning tools. Today, 4D BIM is created based on virtual links between building components and construction activities. And, the resultant construction process is visualized by making solid models of the components appearing and disappearing according to the schedule. While this can enhance the intuition of project participants about the proposed construction process, this approach cannot analyze the relationships between contextually related components, which is vital for deriving construction-specific information from BIM. For example, when a wall is constructed, the geometric relationship between the wall and a slab adjacent to it has to be analyzed to determine if a temporary system (e.g., concrete form, shores, scaffolding) is required. Also, there are several construction activities that appearances and disappearances of solids cannot represent properly. For example, wall's faces, instead of its volume, better represent wall painting activity. Also, if a concrete slab is constructed by multiple sequential concrete pouring, only a segment of the slab better represents the result of one concrete pouring [21,22]. Furthermore, specific geometric conditions can be formed by a collection of objects. A bounded space (e.g., zone), for example, can be formed by several wall faces and segments of a slab and a ceiling. Thus, in order to derive contextual information from a building design, geometric relationships between geometric entities (faces, edges, and vertices) should also be analyzed by BIM software.

1.4. The need for a context-aware construction planning tools

As such, current practices of creating 4D BIMs are driven by intuitive understanding and knowledge of construction planners, and currently available BIM packages have several representational deficiencies to express realistic construction processes. Thus, labor-intensive mental activities are required to establish construction plans. This drawback prohibits a seamless information flow from building design to construction planning and further downstream construction planning activities, such as crew path planning, temporary structure, and safety planning.

In order to overcome these drawbacks, this research presents a geometric reasoning system named Construction Spatial Information Reasoner (CSIR) that automatically derives construction-specific spatial information from BIM and construction schedule. Since spatial conditions are formed by both geometric shapes of building components and spatial relationships between them [23–25], CSIR analyzes construction site conditions based on qualitative spatial relationships between building components. For that, a set of algorithms were proposed that analyze adjacency between faces of building components, and a new building component data structure was proposed that stores the relational information. In the presented work, the scope of geometric reasoning was limited to detecting work packages formed by building components' faces, such as continuous work faces and bounded spaces. Then, the results of geometric reasoning were used directly to support planning of selected interior construction activities.

This paper is organized as follows. Background section provides a review of previous works in analyzing relationships between building components and previous reasoning approaches in support of construction planning. The algorithm section presents descriptions about the proposed relationship data structure and geometric reasoning algorithms. Then, case study section presents the CSIR software prototype developed on top of a commercially available BIM platform and its implementation for a realistic building model. The last section discusses current limitations of the presented research, expected contributions, and potential future research topics that go beyond the current research scope.

2. Related works

Focusing on construction, this section presents relevant research studies in analyzing product information to assist product analyses and production planning.

2.1. Product-process integration

In several industries, such as manufacturing and the Architecture, Engineering, and Construction (AEC) industry, there have been approaches that use the product models to facilitate automation of product manufacturing and testing. In manufacturing industry, there have been efforts to integrate product Computer-Aided Design (CAD) systems to Computer-Aided Manufacturing (CAM) systems via automated Computer-Aided Process Planning (CAPP) systems [26]. The goal of such transformation, from design to production, is to interpret geometry information of a mechanical