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The IFC-based path planning for 3D indoor spaces

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ABSTRACT

Path planning is a fundamental problem, especially for various AEC applications, such as architectural design, indoor and outdoor navigation, and emergency evacuation. However, the conventional approaches mainly operate path planning on 2D drawings or building layouts by simply considering geometric information, while losing abundant semantic information of building components. To address this issue, this paper introduces a new method to cope with path planning for 3D indoor space through an IFC (Industry Foundation Classes) file as input. As a major data exchange standard for Building Information Modeling (BIM), the IFC standard is capable of restoring both geometric information and rich semantic information of building components to support lifecycle data sharing. The method consists of three main steps: (1) extracting both geometric and semantic information of building components defined within the IFC file, (2) discretizing and mapping the extracted information into a planar grid, (3) and finally finding the shortest path based on the mapping for path planning using Fast Marching Method. The paper aims to process different kinds of building components and their corresponding properties to obtain rich semantic information that can enhance applications of path planning. In addition, the IFC-based distributed data sharing and management is implemented for path planning. The paper also presents some experiments to demonstrate the accuracy, efficiency and adaptability of the method. Video demonstration is available from http://cgcad.thss.tsinghua.edu.cn/liuyushen/ifcpath/.

1. Introduction

Path planning generally refers to finding the shortest path connecting two points, while avoiding collision with obstacles. It is a fundamental problem in robotics, automation, computer-aided design and computer graphics. Especially, path planning may arise in various applications of construction automation, such as architectural design [1], indoor and outdoor navigation [2,3], emergency evacuation [4,5], and path planning of construction sites [6,7]. A common way to solve the problem of path planning in construction automation has been approached in a number of relevant literature, which primarily operates on 2D drawings or building layouts, possibly with few attached attributes for obstacles. Although several digital building models in the form of 3D CAD have been used for path planning, they usually contain only geometric information while losing abundant semantic information of building components (e.g. types and attributes of building components and their relationships). Therefore, it becomes important to develop a reliable method that can enhance applications of path planning by combining both geometric and semantic information of building components.

BIM (Building Information Modeling) technology has been receiving a growing amount of attention in the AEC (Architecture, Engineering and Construction) industries [8]. Compared to the traditional CAD technology, BIM is capable of restoring both geometric and rich semantic information of building components, as well as their relationships, to support lifecycle data sharing. As a major data exchange standard for BIM, the IFC (Industry Foundation Classes) standard led by the buildingSMART, formerly known as International Alliance for Interoperability (IAI), plays a crucial role in the process [9]. The IFC data model, which contains geometric and rich semantic information of building components, is intended to facilitate interoperability in the AEC industries. It is a neutral and open specification that is not controlled by a single vendor or group of vendors. Today, the IFC standard has been supported by most BIM software vendors. A list of software applications/utilities, that provide IFC import and/or export functionality, is available at the buildingSMART website [10]. A number of recent research articles have concerned extracting and managing

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semantic information on building components produced in the form of IFC for various applications, such as automatic rule-based checking [1], evaluation of design solutions [11], construction cost estimating [12], construction management [13], comparison and metrics between IFC files [14].

This paper aims to study the particular problem of path planning for 3D indoor spaces, all relying on the IFC building models as input. The system developed in the paper automatically extracts and manages geometric and semantic information on the building space and its inside components from the IFC file, which enhances applications of path planning.

2. Related work

Many path planning methods have been developed in the fields of computer science and robotics in the past 30 years [15,16]. Today some studies have begun to exploit the path planning methods in various AEC applications due to the significant improvement in computer power. One direct application is indoor and outdoor navigation (e.g. for the blind/vehicle/pedestrian) [2,3,17], in which a fast and efficient path planning algorithm often generates the collision-free paths for providing the navigational assistance. Another application is emergency evacuation simulation (e.g. for surveying fire safety design) in the public buildings [4,5], where the planed paths provide the possible evacuation alternatives in different hazard occurrence processes. In addition, path planning can help the architectural designer for implementing automatic rule-based checking of building designs [1]; for example, the shortest circulation path length between a public space and fire exits should be less than a minimum value in many fire-code checking.

Path planning is also a key element in many construction automation applications [18–21]. For instance, Kang and Miranda [18] developed three path planning algorithms for implementing the automated robotic crane erection processes in construction. Sivakumar et al. [20] provided a path planning algorithm to assist a cooperative lifting plan. Soltani et al. [6,7] presented a novel application of path planning in construction sites based on multi-criteria evaluation of transportation, safety and visibility measures. This application [7] can assist the site planners to reduce hazards and select the best available route for site operatives and vehicles.

Most of the above existing efforts require 2D drawings or building layouts as input, possibly with few attached attributes for obstacles, in path planning. However, they usually contain only geometric information while losing abundant semantic information. A survey of many available path planning methods in various AEC applications is beyond the scope of this paper. Instead, the following subsection briefly reviews the most related works associated with BIM models.

2.1. Path planning associated with BIM models

Successful path planning for 3D indoor spaces should depend on the accurate and updated geometry and semantics of building components, which include the correct geometrical positioning of indoor spaces, functions and properties of spaces and obstacles, information about threats and building accessibility, etc. The above geometric and semantic information, required for path planning, could be represented and recognized in BIM models. Several recent studies [1,22,23] have focused on some applications of path planning with BIM models.

Yan et al. [23] developed a prototype of BIM-Game system that integrates BIM and computer games for interactive architectural visualization. This prototype consists of three major modules: BIM, Crossover and Game. The BIM module is first designed by Autodesk Revit Architecture. Then the Revit model is extracted and translated into the Crossover module by using the Revit application programming interface (API). Finally, the Game module connects to the Crossover for applications, including path planning, collision detection, navigation, character modeling and animation, etc. For the special path planning application, Ref. [23] constructs a 'door-room' connectivity graph between the geometrical centers of the rooms via door properties based on the Revit model, where the constructed graph is used for automatic path planning in game development. However, the system in [23] is only available for the Revit models and it is not developed for the common IFC models yet.

One promising approach to combine the IFC models into path planning was introduced by Eastman et al. [1], which reported the Solibri Model Checker (SMC) platform [24] for pre-checking a BIM model. For facilitating some path planning applications, SMC extracts building components from an IFC model, and maps them to nodes and edges of a graph in a similar way to the door-room connectivity graph [23], where the graph represents the topological connections between rooms connected by their open doors. The derived graph is finally used to find the shortest path between two spaces for accessibility checking. One advantage of SMC for path planning is that it directly works with the open IFC building models as input. Another similar work was described by Li et al. [22], in which a similar connectivity graph is also constructed from IFC for finding the shortest path.

Although the above studies [1,22,23] have some valuable attempts in combining BIM with path planning, there are still several limitations.

- The common methods mentioned in [1,22,23] for finding the shortest path all are based on the door-room connectivity graph, in which the graph's nodes are simply defined as the centers of the accessible rooms and doors within floors. In essence, only some geometric position information in the BIM models is extracted and then used for constructing a topological graph representing connections between spatial components, but more semantic information (e.g. types of spaces, properties of building components and building functions) has not been considered yet. In contrast, the work presented in this paper fully extracts geometric and semantic information from IFC files for path planning.
- In addition, if there are some obstacles (e.g. furniture) or hazard zones (e.g. water heater) in 3D indoor spaces, the methods based on the door-room connectivity graphs [1,22,23] will fail or be not enough precise for approximating the reasonable shortest path, which may limit the path planning in many applications. To overcome this problem, we adopt the Fast Marching Method for tracking the shortest path and combines it with semantic information extracted from IFC based on space mapping, which can deal with the special obstacles and hazard zones.

2.2. The path planning approaches

The paper's goal is to study the particular problem of path planning for 3D indoor spaces represented by the IFC standard. After extracting geometric and semantic information of building components from IFC, the next task is to find the collision-free shortest path between two given points in the 3D indoor spaces. A variety of approaches can be used for the problem of path planning computation [15]. In a general 3D space, the problem becomes much harder, and it has been proved that computing a shortest path connecting two points even among the polyhedral obstacles in 3D is an NP-hard problem [15]. Recently, Liu et al. [25] presented a method for approximating the shortest path inside a discretized volumetric model with a visibility graph, which combines the Dijkstra's algo-