Advanced Engineering Informatics 27 (2013) 413–426

Contents lists available at SciVerse ScienceDirect

Advanced Engineering Informatics

journal homepage: www.elsevier.com/locate/aei

Graph-based retrieval of building information models for supporting the early design stages

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ARTICLE INFO

Article history:
Received 14 October 2012
Accepted 24 April 2013
Available online 20 May 2013

Keywords:
Building information modeling
Graph theory
Sketch-based interaction
Information retrieval

ABSTRACT

Building information modeling (BIM) principles are transforming today's communication and working processes in the field of construction, however the early design phases are only rarely supported and information technology is therefore not exploited to its full potential. The early design phases are characterized by an iterative process of searching for plausible solutions. A common approach is to refer to similar examples, which are conventionally found using keyword-based search strategies.

To this end we propose a method for indexing spatial configurations along with a sketch-based input method for search strategies that uses so-called semantic fingerprints of buildings. The topology of spatial configurations is extracted from building information models and represented as graphs. For both building information models and the user sketches, the extracted graphs are used as the basis for a subgraph-matching algorithm facilitating an intuitive novel query method for researching similar reference examples. The system is able to present corresponding existing solutions to even rudimentary sketches or fragments of a design idea. In addition to graph matching and sketch-based interaction, more recent BIM-based approaches are also taken into account.

1. Introduction

Our research focuses on providing support for the early-stages of the architectural design process using information technology. Hillier [1] describes the design process as follows: It begins as an idea for the building, then becomes an idea of the building, then a more formalized concept, then a series of more and more refined representations, then a set of instructions and finally a building. The design process is an iterative process of searching for a plausible solution and involves a continual back and forth between creative and analytical and evaluative steps in which potential solutions or variants are developed by various means before narrowing down the selection to the most promising candidates. For this, traditional design tools are most commonly used in the early design stages such as model-making, sketches and the use of reference examples. Using reference examples is an acknowledged method in both education and architectural practise and helps in learning design principals and guiding the design process as well as for inspiration or even as an explicit solution.

Digital equivalents have already been devised for several traditional design tools, however many of these do not fully translate the original strengths of the analog methods into the digital world and fail to make maximum use of digital possibilities. The approach discussed in this article aims to overcome these shortcomings and proposes a new paradigm for designing with reference examples that takes into account the typical way a designer works in the early design phases and makes full use of current methods and technologies.

Current electronic search methods use textual rather than graphical representations for search queries. However, the configuration of spaces and the relations between rooms are hard to represent using keywords, in fact transforming these spatial configurations into verbally expressed typologies tends to result in unclear and often imprecise descriptions of architecture. Finding relevant reference examples is therefore often a tedious task and at present there is a lack of appropriate IT support for this task. A central problem in this context is finding a way of determining similarity between the designer's query and the data stock. The solution we are proposing is based on graph representations that capture the topological relationships between spaces.

As BIM and interoperable standard for semantic building models such as the Industry Foundation Classes (IFC)[1] become more widely adopted, information on buildings will increasingly be recorded in building information models, which can then be used for other purposes. Currently, however, there are no adequate means

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1 http://www.buildingsmart.com/: Last accessed: 01/10/2013.

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http://dx.doi.org/10.1016/j.aei.2013.04.005

of using such building information models and the information they contain for supporting the early stages of the architectural design process. To retrieve and use this information, we propose the workflow depicted in Fig. 1.

To be able to search efficiently for relevant examples, we developed a sketch-based query language [2] with which it is possible to submit imprecise or fuzzy queries that may be vaguely formulated or that represent only part of the problem. In addition, we want to design a system that aligns with traditional ways of working using hand-drawn sketches to allow the user to explore and assess the retrieved information in the building information model.

For indexing and determining similarities we propose the use of semantic fingerprints [2] as a way of describing the arrangement of buildings in a manner analogous the way that fingerprints can be used to identify a person. In addition, to make searching easy and natural for the user, we propose a user interface which allows users to sketch floor plans and define qualitative relationships. From this sketch a graph is derived that forms the basis for the search query in a database containing reference solutions that are represented as building information models. Corresponding graphs therefore have to be derived from these models. The query graph and model graphs are compared on the basis of a similarity measure, and corresponding building configurations that are similar to the sketch are found and presented to the user.

In this article, we present methods for digitally combining two traditional design tools: sketches as a means of externalizing ideas, and reference examples as a source of inspiration and guidance for the design process with the aim of finding an appropriate solution. Important terms used throughout the paper can be found in the following publications: Spatial Configuration [1], Visual Language [3], Vague Query [4], Space Connectivity Graph [5], Sketches [6] and Labeled Graph [7]. Where necessary, further definitions are provided in the text. The term Semantic Fingerprint was proposed by the authors in [2] and is used to explain the basic idea of identifying buildings for search purposes without implying any specific data model, method or technology. Semantic Fingerprints of buildings can contain a variety of different types of building information such as topology and geometry, the orientation of spaces, energy performance and geo-reference to identify a building. These and other definitions are noted in the text. Mathematical definitions are given in Section 4.1.

In the following section, we discuss approaches from the field of case-based reasoning (CBR), sketch-based interaction, and graph theory. The concepts and approaches of the system and components are discussed in Section 3, and in Section 4 we present an approach for determine similarity (a modified approach based on Messmer's method [8]). Finally, in Section 5 we present our experiments on similarity analysis and conclude with a summary of our findings and their interpretation in Section 6.

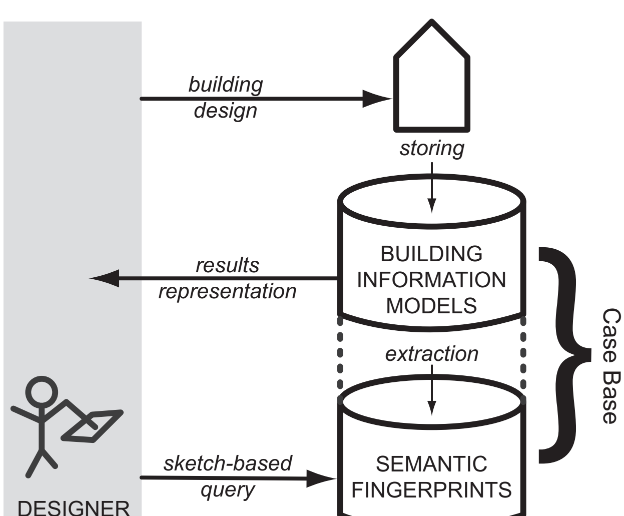

Fig. 1. Proposed workflow for querying a case base to retrieve previously designed and stored building designs in building information models.

2. Related work

Based on the description of the problem as discussed in Section 1, in the following we discuss CBR-approaches in architecture for deriving similarity assessment strategies. Related work on sketch-based interaction and information representation focus on the generation of semantic fingerprints using graph theory approaches. For similarity assessment, we elected to use the decision tree approach outlined by [8] in an optimized form (see Section 4) which we tested experimentally in Section 5.

2.1. Similarity – case-based reasoning in architecture

In the early stages of the architectural design process, architects are only rarely able to specify precise criteria with which to formulate a query. To support vague or incomplete criteria – an important issue of the present approach – we examine Case-based Reasoning (CBR) methods as an Artificial Intelligence (AI) approach to performing this retrieval process. CBR attempts to assess similarities according to the basic premise that similar problems have similar solutions (see Fig. 2). In CBR a case consists of a problem description and solution description. Aamodt and Plaza [9] described the whole process within the CBR cycle using the verbs retrieve, reuse, revise and retain. Since the mid-1990s the approach of applying CBR to design and architectural tasks has been known as Case-Based Design (CBD).

The case base can contain different information depending on the scope of the CBD system. The following brief overview of CBD systems is based on two studies published by Heylighen et al. [10] and by Richter et al. [11]. CADRE [12], FABEL [13], IDIOM [14], SEED [15] and TRACE [16] aim to partially or completely automate the generation of building layouts by applying the retrieved solution to generate new building layouts. CADRE and IDIOM leave the selection of the reference solutions to the user and FABLE, SEED and TRACE apply the solution to the given architectural problem automatically and generate building layouts independently with very little user input. More design support orientated approaches – in line with the approach proposed in this article – include, for example, Archie-II [17], PRECEDENTS [18], CaseBook [19], MONEO [20], CBA [21] and DYNAMO [22].

Richter [11] identifies an acquisition bottleneck in putting complete case descriptions (problem and solution) into the case base. Our approach is based on a semantic case base and focuses mainly on the retrieval part of the CBR cycle depicted in Fig. 2 following the basic concept that similar problems have similar solutions.

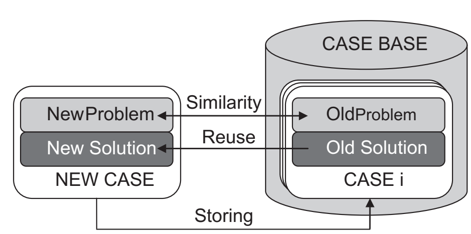

Fig. 2. Proposed approach for the retrieval step and similarity assessment based on the case-based paradigm.