Journal of Building Engineering 2 (2015) 24–35

Contents lists available at ScienceDirect

Journal of Building Engineering

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

# Review: reconstruction of 3D building information models from 2D scanned plans

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ARTICLE INFO

*Article history:*
Received 30 October 2014
Received in revised form
8 April 2015
Accepted 9 April 2015
Available online 11 April 2015

*Keywords:*
Building Information Model (BIM)
3D building models
2D scanned plans
3D automatic reconstruction
Building model checking
IFC

ABSTRACT

3D digital modeling, Building Information Modeling (BIM) and numerical simulation are widely recognized as essential components of building design support tools, but require a significant amount of digital data to truly achieve their potential. Currently, they are mostly applied in the design and construction of new buildings but rarely in renovation projects, since few digital data are available for the majority of existing buildings. It is therefore urgent to devise reliable and effective approaches to the generation of 3D digital (BIM) models of existing buildings. This recognition is widely shared and has resulted in a substantial amount of research work and significant innovations in various fields: 3D laser scanning, images processing, etc. With the aim of bringing some significant contribution to this state-of-the-art, this paper provides a critical review of the methods and tools for generating 3D building models from 2D drawings, developing along two complementary lines: a wide-spectrum assessment of 3D generation techniques, and a more focused, in-depth review of 2D drawings-based approaches (from image processing to BIM creation and validation). The review follows a well-defined methodology and builds on the work of more than 100 relevant references. It includes substantial discussions to highlight the strengths, weaknesses and preferential applications of the reviewed research works, and provides a research agenda. The study particularly highlights that the state-of-the-art is fragmented: most research works focus on specific, limited steps of the 3D models generation process, but no solution has yet been able to tackle the whole generation chain. An additional conclusion is that the selection of the most effective approach largely depends on the intended application, and on project-specific constraints. Also, the study highlights that significant benefits could be drawn from combining existing approaches.

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http://dx.doi.org/10.1016/j.jobe.2015.04.002
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## 1. Introduction

The motivation for improving the effectiveness of renovation designs comes from three simple facts. The first is that building stocks increase slowly (by 1% every year) and are therefore mainly composed of constructions [1]. The second is that developed countries face several environmental challenges that require drastic measures to dramatically enhance energy efficiency. The third is that building energy consumption represents between 20% and 40% of the total energy use in Europe and as such, building energy efficiency is one of the main levers to significantly impact global energy efficiency [2]. The combined consideration of these factors leads to the conclusion that only through significant enhancement of the renovation practices will we be able to reach the challenging goals set by contemporary environmental issues. This view is widely acknowledged and some research works have already demonstrated that advanced support such as decision–support systems for renovation action selection and assessment can bring significant benefits in terms of cost and energy efficiency [3].

However, some hurdles remain, among which one stands out clearly: the lack of digital information for existing buildings and, especially, of computable data, which prevents any intensive use of ICT tools (CAD tools, numerical simulation) that are so beneficial to building design practices. Most existing buildings have been designed and built following paper-based, 2D approaches, which result in few, if any, digital data. This particularly applies to 3D digital models (and more widely to Building Information Models) that, despite their importance to ICT-enabled design, are rarely available for existing buildings. One critical short term research challenge is therefore to devise effective and reliable methods and tools to reconstruct 3D digital models of existing buildings.

This diagnosis is not new: numerous research works have attempted to deal with the creation of existing buildings' 3D digital models. For instance, a recent literature survey [4] classified techniques into two groups, namely: non-contact techniques such as photogrammetry, videogrammetry, laser scanning, tagging and the use of available information, and a second group based on contact techniques such as tape measures or calipers. An alternative technique is to redraw 3D models manually using 3D modelling software tools but, in any case, all studies highlight that, regardless of the method chosen, the 3D model creation is a complex (requiring advanced skills) and time-consuming task.

The corollary of the above consideration is the impossibility of creating 3D models at reasonable costs. This explains the relatively low take-up of BIM (Building Information Modeling) and numerical simulation in the scope of renovation design practices and highlights the importance of the research area considered in this paper. Relying on extensive BIM and simulation design–support is, at the present time, particularly detrimental to the effectiveness of renovation design and construction. Indeed, BIM is widely acknowledged as the basis of modern building design [5] and brings significant benefits, far beyond visualization and CAD-based design: BIM embeds most of the building technical information about the building being designed and allows for seamless design data flow and management. The main difference between BIM and sole CAD tools is that digital models do not only include 3D geometrical and topological information, but also structured and semantic data, allowing for advanced query and analysis of design options [6]. One issue, however, is that BIM translates into expended but also more complex digital information. In the case of existing building digital model creation, this generates additional difficulties and requires more reliable model checking and validation techniques on top of 3D model generation tools.

The motivation for writing this paper can therefore be summarized as follows: (a) renovation can have a major impact on building stocks global energy efficiency; (b) advanced software design–support (of which BIM is a key element) significantly enhances the building design effectiveness; (c) enabling BIM-based, ICT-supported renovation design processes call for an effective and reliable approach to create and generate existing buildings' BIMs.

With these issues in mind, the objective of this paper is to pave the way for cost-effective generation of 3D BIM models through three key contributions: (i) the first is a critical review of a wide spectrum of techniques to generate 3D BIM, which highlights their strengths, weaknesses related applications and potential synergies. One important conclusion of this analysis is that there exists no universal solution; i.e., choosing one approach over the other significantly depends on the intended application, and on project-specific constraints; (ii) a focus on 3D BIM generation approaches based on scanned paper plans, including a step-by-step study of the generation process (image processing, building elements

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