Automation in Construction 63 (2016) 48–56

Contents lists available at ScienceDirect

Automation in Construction

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

Automatic reconstruction of 3D building models from scanned 2D floor plans

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ARTICLE INFO

Article history:
Received 26 June 2015
Received in revised form 16 October 2015
Accepted 5 December 2015
Available online 23 December 2015

Keywords:
Building information model (BIM)
IFC
Image processing
2D plans
3D reconstruction
Model checking

ABSTRACT

The overall energy efficiency of existing buildings has to be significantly improved to comply with emerging regulations and to contribute to overcoming current environmental challenges. Many policies aim at accelerating the renovation rate. The effectiveness of renovation actions could be significantly improved through the systematic use of Information and Communication Technologies (ICT) tools and Building Information Modeling (BIM). But these solutions rely on full-fledged digital models, which, for most buildings, are not available. The present article introduces a research work aiming at the development of methods for the generation of 3D building models from 2D plans. The developed prototype is able to extract information from 2D plans and to generate IFC (Industry Foundation Classes)-compliant 3D models that include the main components of the building: walls, openings, and spaces. The article also presents the results of a quantitative assessment of the platform capabilities and performances, relying on a database of 90 real architectural floor plans. The results are very promising and show that such solutions could be key components of future digital toolkits for renovation design.

1. Introduction

In Europe, a large number of buildings have to undergo major renovation in order to comply with current regulations and environmental challenges. The European building stock includes around 40% of buildings erected before 1960 and the turnover is low (only 1% every year) [1]. Therefore, significant energy efficiency improvement can only be achieved through massive renovation strategies, implemented at National and European level [2]. The BIM and the related software support (e.g. energy simulation tools) help the designers to make better-informed decisions, and result in more optimal, more energy-efficient designs. They could significantly improve the effectiveness of renovation designs and, if systematically used, help to reach the goals set by contemporary environmental issues. This statement is confirmed by recent researches that have demonstrated that advanced ICT support, such as decision-support systems for renovation action selection and assessment, can bring significant benefits in terms of cost and energy efficiency [3].

While BIM ICT tools are undoubtedly beneficial to building design practices and, are now commonplace in new building design processes, they are still under-exploited in renovation projects. Indeed BIM is widely acknowledged as the basis of modern design and brings significant benefits, far beyond visualization and CAD-based design, spanning e.g. seamless design data flow and management [4,5]. However, such advanced design approaches require full-fledged semantized 3D digital models in order to realize their full potential. In most cases, such models are not available for existing buildings. Therefore, one critical short-term research challenge, in the scope of renovation, is to devise effective and reliable methods and tools to reconstruct 3D digital models of existing buildings. Some approaches already exist (e.g. laser scanning, photogrammetry) but the related costs (devices, workload) hinder their wider take-up. The difficulty of creating 3D models at reasonable costs is actually the main factor that still prevents the intensive use of BIM in renovation. Our motivation for the research presented in this paper stems from the recognition of this shortcoming, and aims at contributing to deliver cost-effective and reliable solutions for the reconstruction of 3D BIM of existing buildings.

This work has been initiated by a state-of-the-art review we recently lead [6], which gave an overview on techniques used to generate 3D building models. The main conclusion of this review was that there is currently no general answer about the best approach to generate 3D models of existing buildings: the selection of a method cannot be considered independently from the end user's objectives and the project constraints. The review also highlighted the breadth of the area, and the numerous techniques that aim at the creation of 3D models of existing buildings [7]: photogrammetry [8], laser scanning [9], tagging, use of preexisting information like sketches and tape measurers. But, despite this significant offer, no approach seems to allow for the generation of exploitable 3D building models, that would truthfully represent the geometry, topology and semantics of the buildings. For example, laser scanning results in detailed geometric information but falls short

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http://dx.doi.org/10.1016/j.autcon.2015.12.008
0926-5805/

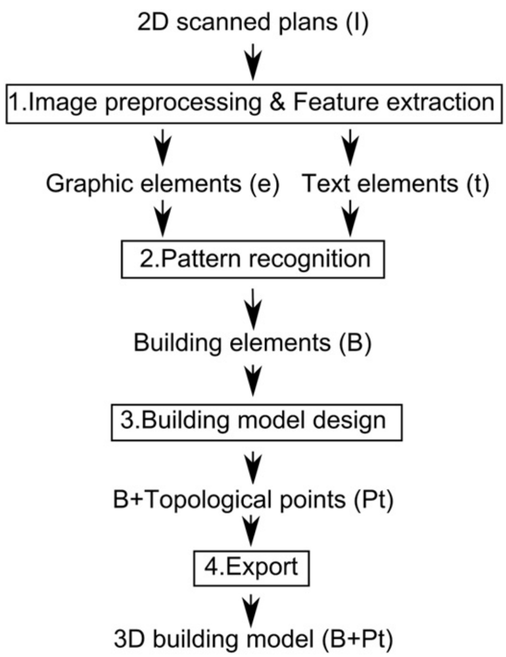

Fig. 1. General process to convert a 2D scanned plan into a 3D building model.

in extracting topology and semantics. The issue is that, to be considered as valid and complete, 3D digital models must include these three components: *geometry*, which defines shape and dimensions, *topology*, which defines the relationships between building components and, *semantics*, which describes additional characteristics, such as room function, usually through dedicated attributes.

Based on this initial assessment, the aim of our work has then been to devise, implement, and test a solution to generate 3D models of existing buildings at reasonable costs and, relying on easily accessible data. We acknowledged the creation of 3D models from 2D scanned plans as the best trade-off between cost and precision. This is an approach that relies on available data and which, does not require any on-site intervention. Moreover, the review highlighted that despite significant advances in document analysis domain, no available solution of this kind featured the whole process, from 2D plans processing to 3D BIM generation. One obvious shortcoming of these methods is that the quality of the generated 3D models highly depends on the quality of the input 2D plans. They can result in incomplete or incorrect models, when the 2D models have not been updated. This has led us to consider the combination of such 2D drawing based-approaches with computer-aided, semantic-aware manual correction. This article presents the design, development and testing of such a solution, starting with the description of the process developed to convert a 2D scanned plan into a 3D building model in Section 2. The subsequent section (Section 3) outlines the results of a validation based on a corpus of 90 architectural floor plans. Section 4 discusses the results obtained and highlights envisioned improvements, before concluding.

2. Overview of the 3D model creation process

In this section, the general process to convert a 2D scanned plan into a 3D building model is presented (Fig. 1). It starts with the generation of an architectural floor plan image from a 2D paper plan thanks to an optical imaging scanner. Then, three successive processing phases are defined as follows. The first (see Section 2.1) deals with preprocessing and extraction of image features, i.e. identification of the geometrical primitives and separation of texts and graphical elements). The second phase (Section 2.1) deals with the recognition of building elements graphical patterns (walls and openings in our case). At last, the building model is generated (Section 2.3).

2.1. Feature extraction

Prior to addressing graphical feature extraction, it is necessary to pre-process the image in order to clean it and remove useless information. This first preprocessing step consists in binarizing the image to remove potential noises caused by the original paper plan quality or by the scanning itself (step 1 of the process). In what follows, the original image will be noted *I*.

The second step of this first phase is focused on feature extraction, to separate geometrical primitives from text elements. This separation will then allow to adapt the subsequent processing to the type of the graphical element considered. To this end, the input image is separated into two images: the text image containing all textual information (annotations, title, room names) and the geometry image containing all geometrical elements (lines, circles). This separation is performed thanks to freely available tools from the image processing and document analysis domains [10] and is independent from text font, size and orientation. Once these two images are generated, they are further processed separately. The text image is analyzed thanks to OCR (Optical Character Recognition) techniques to identify text items and associated bounding boxes. This analysis relies on the tools developed by the Qgar project (Loria laborataries, France) that allow extracting sets of characters in the image and their bounding boxes. A bounding box is a rectangle defined by its diagonal that surrounds a given set of characters. Prior to defining a text element, it is necessary to give the definition of a point *P*.

$$P = (x, y) \quad (1)$$

A point is defined by two coordinates which correspond to a pixel in the image *I*. A text element (t) is therefore defined as:

$$t = \{P_1, P_2, textString\} \quad (2)$$

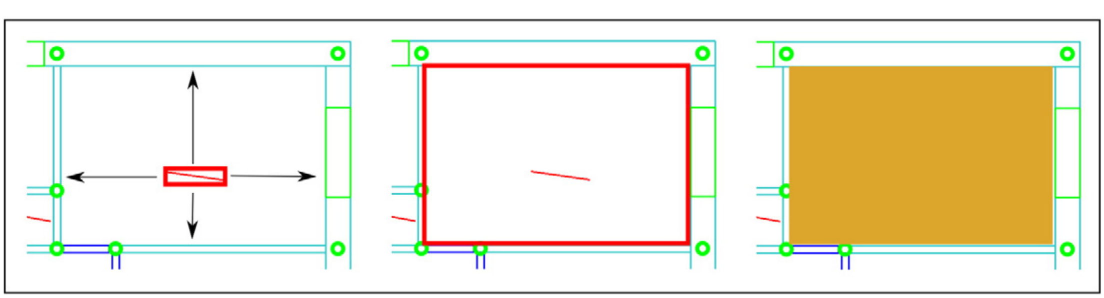

Fig. 2. Space reconstruction: case of a space representing by a rectangle. In the left image, the red segment represent a text element surrounding by its associated bounding box. The bounding box is extended along 4 directions. Green points represent the set of topological points. The middle image represents the region defined by the extension of the bounding box and the yellow polygon is the final identified space.