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## To cite this version:

Lucile Gimenez, Sylvain Robert, Frédéric Suard, Khaldoun Zreik. Cost-effective reconstruction of BIM from 2D scanned plan : experiments on existing buildings. Sustainable Places 2015, Sep 2015, Savona, Italy. pp.68-77. hal-02109541

**HAL Id: hal-02109541**

**https://univ-paris8.hal.science/hal-02109541v1**

Submitted on 6 May 2019

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# Cost-effective reconstruction of BIM from 2D scanned plan: experiments on existing buildings

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## 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. The effectiveness of renovation actions could be significantly enhanced 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. This paper gives an overview of the semi-automatic generation process of 3D models from existing buildings developed by combining 2D scanned plan recognition with assisted human interventions. The implemented process 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. This paper also highlights the extension of the methodology to cope with additional drawing conventions and to allow for more genericity. The results obtained with experiments on plans of existing buildings are encouraging and suggest that the mix of software assistance and focused human interventions may be a good trade-off for the quality of the resulting models.

## Keywords

Building Information Modeling (BIM), Image processing, 3D building models, 3D reconstruction, model checking.

## Introduction

In Europe, the households sector is the second consumer of energy (27% in 2009) just behind the transport domain (33% in 2009). Moreover, more than 40% of the residential housing stock was erected before 1960 and new buildings built each year represent only 1% of the overall stock (Atanasiu *et al.*, 2011). Therefore, renovation of existing buildings is a key enabler to any significant energy efficiency improvement of the European building stock (Pérez-Lombard *et al.*, 2008).

To improve the renovation relevance, one has to run computer simulation to optimize the coming operations. So the emergence of BIM (Building Information Modeling) and the evolution of AEC practices and tools such as decision-support systems for renovation actions can bring significant benefits in terms of cost and energy efficiency. One major hurdle however is the lack of 3D digital models for the majority of existing buildings, which calls for cost-effective and widely applicable methods and tools for the reconstruction of 3D digital models from available information.

A large set of techniques exists to create 3D models of existing buildings such as tape measures, photogrammetry, laser scanning, etc. (Volk *et al.*, 2014). These approaches differ in several aspects. The first is the cost and time required for data acquisition and process, including both the materials and the human resources needed. Further, all these techniques do not provide the same level of details. As shown by a recent review, the selection of the most adequate method will highly depend on the specifics of the project and context of future use of the 3D models (Gimenez *et al.*, 2015).

The aim of our work is to provide a methodology to generate 3D models of existing buildings that is say to rely on existing and easily available data and software processing by avoiding any time-consuming process and costly data acquisition. Hence our choice to focus on 3D model creation from 2D plans, which are available in most of the cases even if the result depends on the reliability of the plans. However, considering the large variety of existing plans, an exhaustive and fully automated process could be difficult to implement without implying huge and complex computation. To tackle such issue and containing the software cost, our solution proposes to combine the automatic generation of 3D models with focused manual interventions to minimize the time spent on manual corrections and to maximise their impacts.

The reconstruction encompasses the three components that are essential to generate complete and coherent 3D models: the geometry to define shapes and dimensions, the topology to define relations between features and the semantics to describe additional characteristics. In previous papers we presented the overall process to extract such information from real plans and validated the software tools for 3D models generation developed with a database of 90 plans (Gimenez *et al.* 2014). This paper focuses on a major improvement of our approach to deal with additional drawing conventions. The representation of building elements may actually vary significantly from one 2D plan to another, depending on the architecting company, the country, or the individual preferences of the architect. For example, a wall can be filled with white or black pixels, or even hatched. It is necessary to extend the methodology to deal with such variety of symbols and graphic standards, and to allow for easy parameterization of the graphical identification conventions.

In what follows, we first outline the semi-automatic process to convert 2D scanned plans into 3D building models and we focus on the extension of the prototype to deal with various representations and quality of the initial plans. Then, we give some results of the experiments led with plans of existing apartments.

## Overview on the semi-automatic process

This section gives an overview of the semi-automatic process developed to generate 3D IFC models from 2D drawings by combining automatic recognition and guided human interventions. The second part is dedicated to the extension of this methodology to enhance genericity.

### Motivations for introducing human interventions

The process is focused on the extraction and recognition of the three digital models components: geometry, topology and semantics. The complete process is described in Figure 1. The first step is based on the separation in the original image of text and graphic elements (Tombre *et al.*, 2002). Using the graphic elements images, building elements such as candidate walls and openings are identified based on methods of vectorisation and pattern recognition. A semantic distinction is made between outdoor candidate walls represented in red and indoor candidate walls in blue. To validate candidate walls, some rules help to verify the exact nature by calculating for example the density of black pixels in the original image.

Then, using results from the automatic recognition of text elements, the detection and identification of building elements, and some complementary assisted human interventions, the building model is created by reconstructing the outer shape of the building and indoor elements. Openings and spaces (yellow areas) are also recognized and their semantic is precised, e.g. door are coloured in pink while windows are coloured in green.

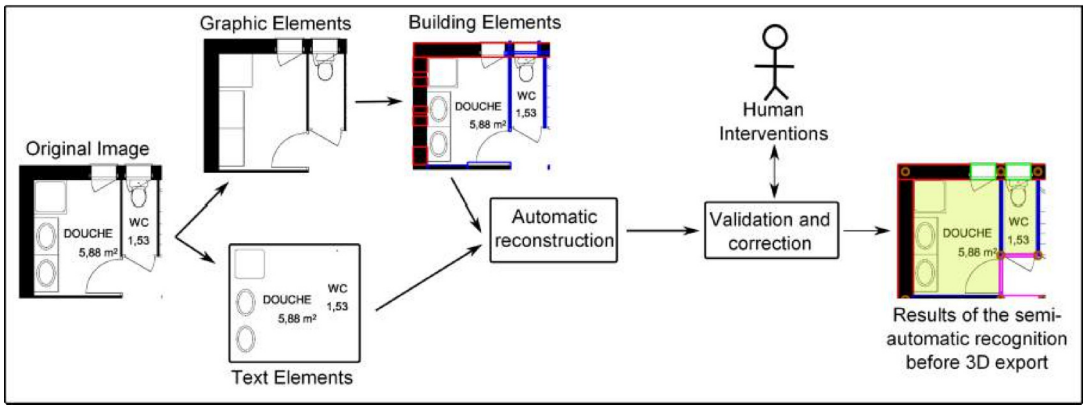


Figure 1: General process to convert semi automatically a 2D scanned plan into a 3D building model

During the recognition, a validation stage aims to detect automatically inconsistencies in the generated building model. Theses inconsistencies have been defined by creating an exhaustive taxonomy based on the geometry, topology and semantics using the most common errors found after a series of automatic tests. For example, confusing a door with a window is a semantic error while an intersection between two walls is a topological and geometrical error. Each detected error is stored in a specific file and an impact score is calculated according to its impact on future applications of the 3D building model like simulation purposes.

The system uses the impact score to determine the priority order of corrections. The highest priority is given to errors with a high impact level. For each error, several choices for correction are proposed to the user through a dedicated interface. He can then select the most appropriate correction, which is applied to the model.

At the end of the process, the building model is exported to a standard BIM 3D building model (namely the IFC – Industry Foundation Classes). This methodology significantly enhances the results of recognition while not requiring significant time to correct the model. The time to reconstruct a 3D building model is reduced compared to a manual conversion and gives better results than an automatic reconstruction, which would in any case be impossible given the vast variety of drawing and representation conventions that one may encounter.

**Extension of the toolkit for enhanced genericity**

The main limitation of the previous work was the lack of genericity to face a large variety of graphic representation for architecture symbols. Indeed, we have tested the first version of our prototype, with plans from a single database, which follow similar drawing conventions (see Figure 1). In order to evaluate the flexibility capacity of our approach, we have decided to develop an extension of the toolkit to enhance genericity and to perform additional tests with plans from other sources, featuring different drawing conventions. The evaluation has specifically been focused on recognition of walls, which can be represented differently depending on the plan (black, white, or hatched).

The rationale is to keep the algorithms tested with the initial set of plans and to add some preliminary processing to the source plan in order to generate a plan compliant with the initial conventions. In the specific case of walls representation, this consists in applying preliminary treatments that generate an image in which walls are represented by black pixels. This intermediate image is used during the conversion of graphical elements into building elements to validate candidate walls. Two additional types of wall representation have been considered: walls filled with white pixels or hatchings.

For walls filled by white pixels, contours are extracted in the original image. The drawback of this method is that all contours in the image will be identified, resulting in possible redundancies. It is therefore necessary to select those contours that are likely to represent a wall and to delete those corresponding to other elements, likes spaces. Our approach is to calculate the area of each generated contour and, to be considered as a wall and be filled with black pixels, the area has to be lower to a specific value. This specific value corresponds to the minimum room area of the building and can be set by the user.

The Figure 2 represents the different steps of the process for a wall filled with white pixels.

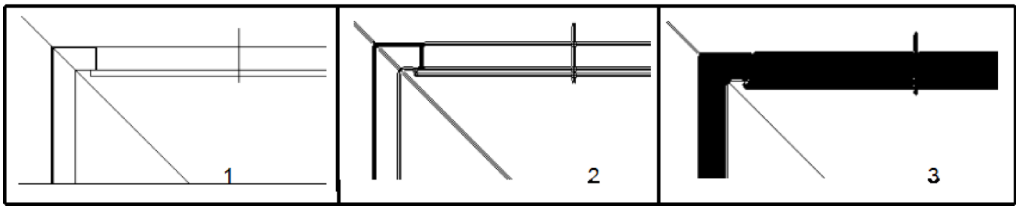


Figure 2: (1) Original image, (2) edges, (3) Final image

For walls filled with hatchings, the first step is to remove hatchings from the original image. A method is to analyse extracted segments from a previous vectorisation (Lladós *et al.*, 1997). The aim is to compute for each segment the couple (θ, L) where L is the length of the segment and θ the slope. Hatches are usually small and θ is around 45°.

Then, the method we propose is to identify in the set of remaining segments those that are parallel and close to each other (according to a predefined distance threshold). The region defined by the couple of segments is then filled with black pixels to comply with the constraint of our generic wall representation. The Figure 3 represents the different steps of the process for a wall filled with hatching.

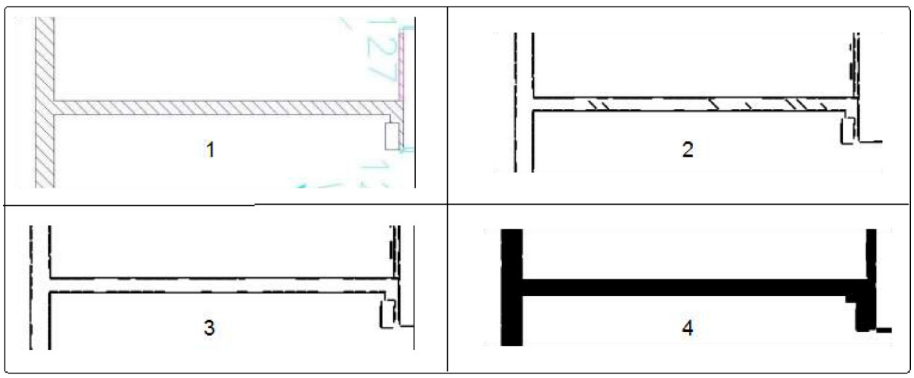


Figure 3: (1) Original image, (2) segments extracted with a Hough Transform, (3) Image after removing hatching, (4) Final image

This method has the advantage to be fast to run and easy to modify in order to be extended or improved when new representations will be encounter without modifying the entire prototype. However, the intermediate image cannot be used to identify precisely walls because of the large number of resulting artefacts. It only allows validating candidate walls and avoids the creation of graphical artefacts that do not correspond to any actual building element and that would be, in the subsequent steps, difficult to detect.

## Experiments on existing buildings

To test and validate this extension, we have lead experiments on existing buildings thanks to floorplan images provided by a French real estate agency specialised in the sale of Haussmann style apartments in Paris[5]. Plans have been sometimes manually enhanced for a better quality with a low definition. In this article, the results obtained with two different plans are presented. The original images are shown in Figure 4.

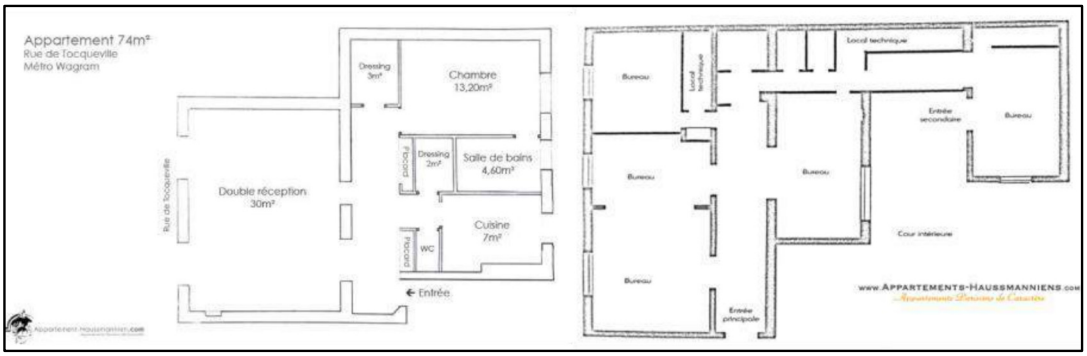


Figure 4: Two original floorplan images

The method applied to create an image with black pixels allows creating images for the two plans and resulting images are represented in Figure 5. These images are used to validate candidate walls by testing the density of black pixels for example. It cannot be used to find precisely walls because they are composed of artefacts and some walls are missing due to the constraints on the area of the contours detected.

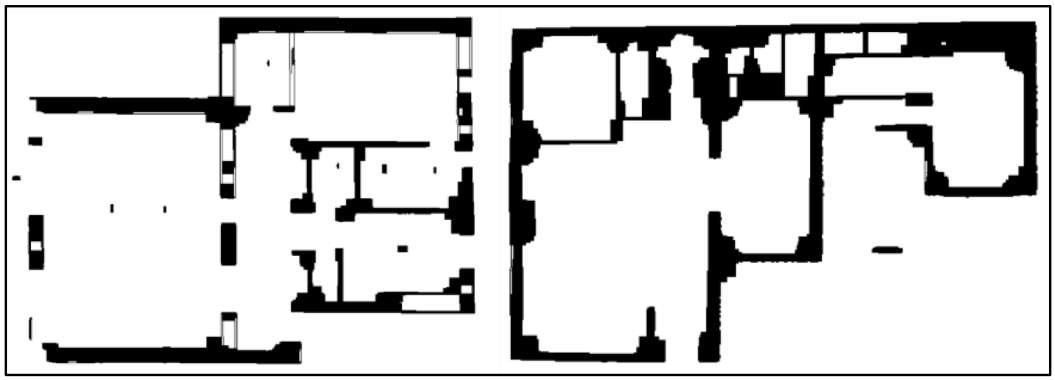

Figure 5: Images resulting of the process to identify pixels of walls

Results on the footprint reconstruction of the building and outdoor openings are displayed in Figure 6. In the left image, the reconstruction is good and all openings except one door have been well identified. In the right image, the reconstruction is less successful. This is partly explained by the low quality of the source, which globally impacts the recognition performance.

[5] http://appartement-haussmannien.com/

This process allows reconstructing a 3D building model in less than 10 minutes, including the automated reconstruction and the guided human corrections. It presents the advantage not to require any data acquisition on site using e.g. laser telemeter or laser scanners. Only little human intervention is necessary. Further tests have been performed using plans from additional sources, representing a complete building composed of two levels, which allows to reconstruct all the outdoor and indoor elements (walls and openings).

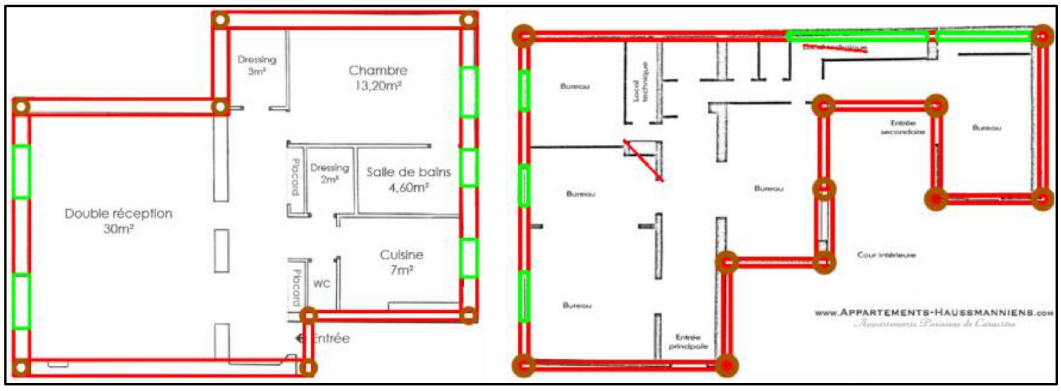


Figure 6: Semi-automatic recognition of outdoor elements. Red rectangles are outdoor walls and green rectangles are openings

## Discussion

The improvement of our existing methodology allows to convert 2D scanned plans from various representations and qualities to 3D building models by combining automatic process with punctual and guided human interventions.

Our approach is able to identify walls with various graphical representations. However, there are other building elements whose representation can vary, such as doors. In the Figure 1, doors are represented with small black points but the quality is too low to be certain and to automatically find them especially if the image is filtered during the preprocessing. No representation is dedicated to opening in plans of the Figure 2, so it is almost impossible to detect automatically or manually doors.

Even if images resulting from the extension of the prototype are just used to validate candidate walls, the precision is dependent of the quality of the original plan. This method could be improved by selecting more precisely contours corresponding to walls to avoid the generation of artefacts

Tackling the diversity of representations in architectural plans remains a research challenge. By now, our work has been focused on walls because they are the most important components of buildings' geometry. However, other components, like doors, could be processed in a similar way.

A last issue concerns the third dimension such as height of the building and openings. There is often no information related to this point in architectural floor plans. To get the exact measurements, a solution could be to use results from façade images segmentation which allows recognizing building elements such as openings or balconies and approximating measurements using an object in the image which size is known (Ok *et al.*, 2012).

## Conclusion

This paper describes a methodology to semi-automatically convert a 2D scanned plan into a 3D building model. The approach is characterized by a blend of automation and focused manual intervention in order to reach the best trade-off between the efforts spent on 3D models creation and the resulting quality. An extension of the prototype has been also presented to various floorplans representations in order to make our methods generic. One added value of the solution is an enhanced flexibility through the easy parameterization of 2D plans drawings conventions.

Future works will be focused on the improvement of the prototype extension to include others architectural representation types of building elements and to expand the 3D building models by integrating additional sources of data in the process.

***Acknowledgements***

*The work presented in this article was supported by the European Community's Seventh Framework Programme under Grant Agreement No. 609138 (Project HOLISTEEC).*

*The authors of this document also thank to Christophe Bouchet for providing and authorizing the use of floorplan images.*

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