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Non-destructive approach for the generation and thermal characterization of an as-built BIM

S. Lagüela, L. Díaz-Vilariño *, J. Armesto, P. Arias

Close Range Photogrammetry and Remote Sensing Research Group, University of Vigo, Rúa Maxwell s/n, Campus Lagoas-Marcosende, 36310 Vigo, Spain

HIGHLIGHTS

- Methodology for generating as-built BIMs with descriptive data of building elements.
- Non-destructive techniques applied to thermal and geometric inspection of buildings.
- Automatic point cloud processing for the generation of the geometry of BIM.
- Quantitative thermography approach for the calculation of *U*-values of the enclosure.

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ABSTRACT

Building Information Models are being increasingly accepted as containers and managers of data during the lifecycle of buildings, given their capacity of associating the descriptive data available, such as the physical properties of the materials, with the 3D representation of the building. In the case of existing buildings, as-built BIMs have to be created, and non-destructive techniques are required to acquire all the information needed provoking no disruption or change to the building. In this work, the as-built BIM of a facility is created through the semi-automated processing of a laser scanning point cloud and enriched with the different *U*-values of the enclosure. This thermophysical property is obtained for the construction as-is through an energy balance using temperature values measured with a thermographic camera. The resulting as-built BIM is defined according to the gbXML language, which was especially created to be used in analysis of the performance of the building.

1. Introduction

Building Information Models, BIMs, stand as an optimal solution for the combination of all the information needed in the analysis of a building, coordinating and associating the geometric representation on a 3D domain with descriptive data, such as physical and thermophysical properties [1]. As an example of its applications, the use of BIMs in energy modeling of existing buildings is established and supported by several institutions such as Statsbygg [2], the National Agency for Enterprise and Construction [3] in Europe, and the General Services Administration in the USA through its National 3D-4D BIM Program [4]. What is more, this application was reinforced by the creation of an informational infrastructure in order to facilitate the transfer of the building properties stored in CAD to energy analysis tools, called green building eXtensible Markup Language, also known as gbXML [5].

The geometric representation can be extracted from a laser scanned point cloud [6], improving the accuracy of the final Building Information Model regarding the as-built reality. The main reasons for the choice of a Terrestrial Laser Scanner (TLS) for the acquisition of the geometric reality of the building, are: (1) the manual generation of the 3D model of a building is time-consuming, and the final result can be substantially different from the reality of the building as-is [7]; (2) as happens with the thermal properties of the construction, the plans of the building, which are usually the input data for the generation of the 3D model, are often not available, and if they are, their representation of the reality is usually distorted, missing information about changes from the design and the repairs in the building; (3) TLS are providers of fast and accurate representations of the facilities [8]; (4) in the comparison with other methods such as a total-station or photogrammetry, these are too time-consuming or inaccurate to be practical on a large scale [1]. Although the last techniques have suffered an important improvement in the last years by increasing their level of automation and speed, laser scanning still presents the highest speed and automation for the registration of different scan

* Corresponding author. Tel.: +34 986813499.
E-mail address: lucia@uvigo.es (L. Díaz-Vilariño).

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positions into the same coordinate system [9], in such a way that a complete point cloud is obtained through a simple process of only two steps: points referencing and position matrix computation.

Apart from the geometric data, the generation of a complete BIM requires the introduction of descriptive data of the materials, elements and systems of the building. A simple-to-measure but equally important property for a complete description of the building useful for many types of analysis (steady-state thermal analysis) is the overall-heat transfer coefficient of the construction elements. The calculation of the overall-heat transfer coefficient of existing constructions usually implies a complex task of data compilation, since it is a function of their composition (materials and their thickness [10]), which are values usually not accessible or available, especially in old buildings, where their age and the great quantity of actors involved imply the performance of a high number of modifications regarding their original state [11]. The common approach is to calculate the *U*-value of the construction using the nominal values for the different materials, supposing their nature and thickness within the walls of the building [10]. However, for these values to be accurately representative of the reality of the elements of the buildings, a non-destructive method stands as an optimal solution for the characterization of the existing construction, needed in energy simulation. Infrared thermography has been proven as a reliable technique for the evaluation of the performance of building materials [12] in a qualitative approach, and for temperature measurement if a quantitative approach is taken [13]. In the latter, temperature values can be used in the computation of thermal construction parameters such as the overall heat transfer coefficient (*U*-value) and the thermal diffusivity [14,15], and for the analysis of thermal bridges, as in [16]. In all these studies, infrared thermography is used as a mere measurement technique, and its temperature values are used as input in energy balances and thermal models in order to obtain the desired value. These goes in contrast with works such as [17,18], in which thermographies add visual information to the 3D model of the building, and even with [19,20], where temperature values are incorporated to each point in the point cloud, but no further analysis is done with these values measured by the thermographic camera for giving more attributes to the model. In [21] the thermal resistivity value, R-value, is obtained from the temperature value per point of the point cloud. This value is essential for the performance of energy studies in buildings, but its introduction in energy software needs to be "per wall" instead of "per point" format.

However, thermophysical properties can only be included in energy studies if the geometry of the building is known, since the 3-dimensional reality of the building is required for the calculation of heat losses and thermal inertia. This fact is evidenced by the increasing interactivity between simulation software and 3D modeling software such as Google SketchUp©, which gives importance to the generation of 3D models of buildings, as in [22]. What is more, [23,24] have developed different software tools either to allow the storage of energy data in the BIM or to support data exchange between design and energy applications.

This paper presents a methodology for the highly-automated generation of an as-built Building Information Model including the thermal characterization of the construction obtained after a thermal essay in which temperatures are measured with a thermographic camera. It is organized as follows: Section 2 presents the methodology developed for the combination of geometric information obtained with a laser scanning device and the thermophysical data computed after a thermal essay; Section 3 shows the results obtained after the application of the proposed methodology to a sample building, a Building Information Model with thermal data of the building components, further called energy BIM; finally, Section 4 includes the conclusions of the study.

2. Methodology

The methodology presented in this paper involves geometric and thermographic data acquisition and processing, as both are needed for the generation of the as-built BIM: geometric data provides support to the information included in the BIM, whereas thermographic data represents the real state of the construction, from which as-is values can be extracted for their introduction as descriptive data in the BIM. The proposed workflow is shown in Fig. 1 in which both thermal characterization and geometric modeling are performed simultaneously, given that the outputs of each process are independent inputs to the final BIM generation.

This methodology is presented through its application to a case study, a building with simple geometry (Fig. 2) made of brick that houses an electrical transformer. This building is chosen due to its simplicity and to the knowledge of its composition, which allows the verification of the method, especially for the thermal analysis, prior its extrapolation to more complex buildings with components of unknown configuration, such as air spaces and thermal insulation.

2.1. Geometric modeling

As the final purpose of the as-built Building Information Model is its incorporation to energy analysis software, a simplification of the geometry is carried out to be used as an input of simulation software. Energy simulations are usually carried on in simple models because of the computational time required for simulating more complex geometrical models. In this case and despite the simplification of the geometry, the model provides an accurate representation of the reality of the building, and consequently energy consumption and energy efficiency results are more accurate and realistic. Simplifying the geometry implies that the extraction of the boundary points that define each surface, such as wall, ceiling or floor, from the acquired point cloud is enough information for the complete representation of the building. This is developed through a process which includes data acquisition, pre-processing and segmentation for the identification of the planes that define the structure of the construction.

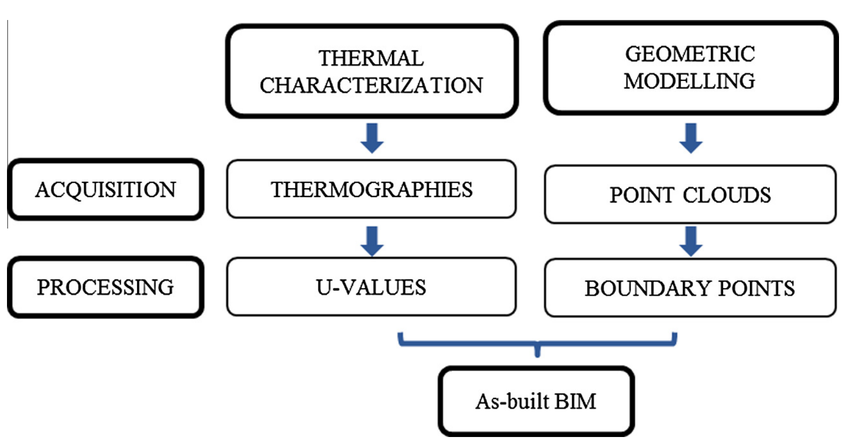

Fig. 1. Workflow of the proposed methodology for the generation of an as-built BIM including thermal information.