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MASSIVE DATA CAPTURE MODELING FOR THE REFURBISHMENT OF EXISTING BUILDING STOCKS

David Infantes-Lopez, Albert Sanchez-Riera, Jordi Casals-Fernandez, Oriol Pons-Valladares
Universitat Politècnica de Catalunya, Barcelona, Spain

Abstract

The rehabilitation of buildings is a pressing global requirement that could contribute to reduce the negative economic, environmental and social impacts of the construction sector. Current documentation on existing obsolete building stock is missing or outdated. Therefore, digital models need to be generated, such as creating building information models from scratch. However, this has limitations, for example that the resulting model is an abstract theoretical version that cannot reproduce the geometric singularities of the real building, which has implications for structural performance among others. Thus, the automation of this digitalization is an interesting solution that has been investigated for years. This research paper presents a novel approach for the digitalization of non-heritage buildings that reduces data capture timings but is precise enough for retrofitting applications. The new approach uses laser scanner, thermal infrared sensing, high quality pictures (HQP) and automatic frame extraction (AFE) from video. Data preparation for the 3D reconstruction is the main novelty, which has been applied to obtain the surroundings and building information model (BIM) of the reference building for Barcelona schools. Findings coincide with previous projects regarding the high accuracy of the laser scanner and the broad coverage of photogrammetry. New results qualify HQP as a highly efficient method. Its combination with AFE increase the coverage to high levels. The proposed approach is part of the project "Waste-based Intelligent Solar-control-devices for Envelope Refurbishment" starts, of "Ecological Transition and Digital Transition Projects" of the Spanish Ministry of Science and Innovation (MICINN) with reference TED2021-130155B-I00, funded by MCIN/AEI/10.13039/501100011033 and by the European Union "NextGenerationEU"/PRTR. This proposal surpasses the manually modeled BIM errors and enables digitalizing architectural clusters to generate urban digital twins to enhance the proper future management of urban stocks.

Keywords: photogrammetry survey, laser scanner, retrofitting, high precision coverage, urban digital twin.

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1. Introduction

The construction sector negative environmental impacts are not diminishing rapidly enough although all the efforts made by many parties involved. For example, 34% of global energy demand and 37% of related CO2 emissions was caused by the construction, use, maintenance and end of life of buildings in 2022 [1]. To reverse this situation, numerous initiatives promote the refurbishment of existing obsolete buildings. This is the case of international working groups [2], conventions [3], directives [4], [5]; and refurbishment projects [6] among others. An important lesson learnt by these initiatives is the need to move from addressing isolated edifices to consider whole building clusters.

These rehabilitations aim to highly improve the buildings' performance from a holistic approach, including acoustic, light, thermal… comfort as well as structural behaviour among others. Thus, the professionals involved use digital tools that simulate on models like building information modelling (BIM). However, the current documentation of the building stock in need of rehabilitation is scarce, non-existing in some cases and just in paper format in others. One solution is to create the digital model from zero, which has limitations because the obtained BIM is a theoretical version that omits particularities of the

Corresponding author email address: oriol.pons@upc.edu

existing construction that could oversimplify the simulations [7]. Another solution is the automation of the digitalization process that has been considered for decades [8]. Automatic capture of geometric, scale and shape data has been carried out for numerous construction projects by using computer vision technology and three-dimensional (3D) data capture. Nevertheless, at present there are still interoperability limitations between BIM and optical data capture technologies (ground penetrating radar (GPR), photogrammetry, terrestrial laser scanning (TLS)). Overcoming these limitations would enhance the optimization of the surveying processes of the existing buildings in needs of refurbishment.

Several research gaps are detected when looking at the most recent similar applications [9]. Firstly, most focus exclusively on heritage applications, which is beyond the present research project that focuses on non-heritage obsolete buildings. Second, most focus on a single building, without including the urban context, which applies also to the only previous retrofitting project. Moreover, most predecessors focus on using TLS, which is highly precise as well as time consuming. These features are optimum for heritage applications in which the maximum detail is required and have no tight timeframes. Otherwise, obsolete building stocks in need for rehabilitation would benefit more from agile and medium precise alternatives. In this sense, this congress paper presents a novel data capture approach within the Wiser project [10], that solves the aforementioned necessity. Section 2 presents this new approach, Section 3 describes the case study and the following sections present the results, analyse them and draw conclusions.

2. Methodology

The new approach presented in this paper follows the following 4-steps: S1) data capture, S2) data processing, S3) mesh optimization and S4) BIM model preparation. Figure 1 summarizes this approach (adapted from [9]).

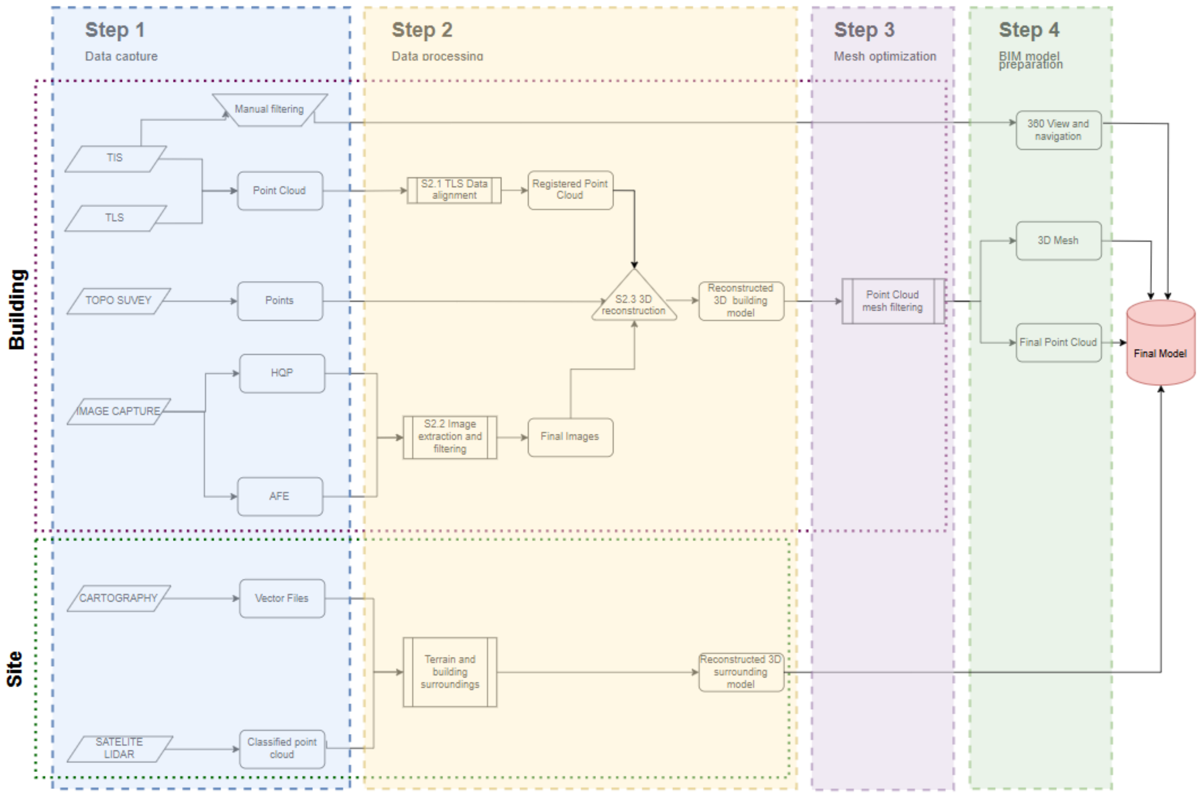

Fig. 1. Framework of the new approach presented in this paper. Adapted from [9].

Step 1 captures data separately for the building and the site combining thermal infrared sensing (TIS) [11], TLS [12], topo survey with total station, real-time kinematic (RTK) positioning and global navigation satellite system (GNSS) [13]; and image capture for photogrammetry using high quality pictures (HQP) and automatic frame extraction (AFE) from video, both with unmanned aerial vehicle (UAV) [14]. The main novelties of this step are: a) no need to plan topographical control points because the data obtained from the TLS is joined to the georeferenced data from LiDAR; b) ability to control occlusions and the full coverage of the building during the UAV flight; c) AFE's automated acquisition of a larger data-volume by means of an algorithm that correlates the video frame number with its corresponding position. This step results are point clouds from TLS and TIS, control point coordinates from the data survey, and video and pictures files from the drone.

Step 2 processes data independently for the building and its surroundings in three sub steps. The first two align, extract and filter the data from TLS/TIS and images from pictures and video recordings. The third sub-step reconstructs the space using the Reality Capture tool [15] to merge the photo with the TLS. The second sub-step contains the main novelty of this approach, which is the data preparation for the 3D reconstruction. Specifically, the novel are the filtering and frames extraction from the video recording of the building. This process has been automated by means of new own-developed algorithms based on the Open Source Computer Vision Library (OpenCV library) [16]. An algorithm iterates through all the video frames to compute a blur quantification from the Open CV library, and extracts the frame when the quality value reaches the required threshold level. Then the frame is named by ordered number so that it becomes correlated to a time stamp and a space position. Another algorithm filters the frames by name using logic gates, considering the required coverage, and applying the position calculated according to the drone velocity and the name of the video frame. To sum up, these new own-developed algorithms achieve automatization, great precision and fast results of data processing [9].

Step 3 focuses exclusively on the analyzed building and applies the last steps of the method previously developed by the authors' laboratory Virtual Innovation in Modeling the Architecture and the City lab (VIMAC), which modeled for 3D printing Gaudi's Dragon Door in Finca Güell [17] and filtered façade surfaces in surveys in the Sagrada Familia Cathedral [18]. In this specific case of building stocks, the mesh optimization deals with the point cloud noise caused by instrumental error and ambient conditions. Therefore, it uses the CloudCompare tool [19] and the Poisson Reconstruction algorithm [20]; which allows meshing at 1 cm to preserve the main surfaces while avoiding the incorporation of useless elements in the final point cloud, in this case of non-heritage obsolete building stock. The point cloud is filtered comparing the distance between the temporary mesh and the unoptimized point cloud, deleting the points at a greater distance from the threshold and avoiding open meshes, inverted normal, etc. Then, the final meshing exclusively incorporates the optimized clean point cloud with the final resolution, which is suitable for the final BIM model.

Step 4 combines building and site information to prepare the final BIM model. To merge all the information, each model is georeferenced or includes reference points from the 3D reconstruction sub step. The aforementioned optimized point cloud mesh results with the building exterior, which is already georeferenced. A 360 view and navigation plus a simplified point cloud from the TIS – available from numerous market applications [21] – provide the building interior model. The reconstructed surrounding model from step 1 provides the site definition. After merging the models using a BIM software tool, if there is any model part without georeferencing, it is placed in a provisional location. At the end, the positions of all model parts are controlled and improved considering the precision required for the specific model.

3. Case study

The presented approach was applied for the first time to Bellvitge school, which is a real case study representative of the educational stock in need of refurbishment within the Barcelona Metropolitan Area. These are public schools constructed from 1960 to 1979, before the first energy code in Spain. They are mostly buildings with concrete frames, slab floors and cavity brick uninsulated envelopes. They define a sample of more than a hundred schools, some of which were discarded for being planned to be demolished or lacking information. The clustering k-means algorithm divides the sample in three typologies. Bellvitge school is the real-reference building of the second cluster, which was confirmed considering its annual energy consumption. The schools of this cluster are mid-rise linear schools with single-side circulations and a high window-to-wall ratio. Figure 2 shows Bellvitge school and its cluster.

Fig. 2. Bellvitge school and other buildings from the second cluster. Adapted from [22].

The case study is an elementary school in a mass housing area of Barcelona Metropolitan Area. Built in 1972 for 250 pupils has an H-shaped plan, the main front block 3-stories high and the main rear block 4-stories. The main front block has important direct solar gains because it faces south-west on a large open playground; while the main rear block faces a 10-story housing block. The case study, as well as the second cluster, has energy and comfort renovation needs to solve the winter overheating, the summer hot temperatures, the glare and the non-uniform daylight among others. In this sense and within the project WiSeR a digital modeling was needed to simulate the classrooms with new facades from a holistic point of view, to optimize its acoustic, mechanical, fire safety, lighting and sustainability behavior.

Thus, a georeferenced digital model with controlled precision was required for Ansys Mechanical, Design Builder, Dialux, Energy Plus and FDS software tools among others. This model was obtained following the approach presented in the previous section and using the specific sources and tools presented in Table 1.

Table 1. Specific sources and tools used in the application of the new approach to Bellvitge School.

Step	Source, tool	Device	Description
1	TLS	Focus3D X 330 HDR	Laser Class 1 (UNE EN 60825-1/A2), reliable for the expected usage conditions, range focus from 0.6 to 330 m, ranging error of ± 0.1 mm; ± 0.4 mm at 25 m.
1	TIS	Camera 3D Matterport Pro2	Infrared 3D sensor, maximum range of 4.5 m with 3D scanner measurements, 99% accuracy. Lens 4k full glass, exportable images up to 8092 x 4552 px for position.
1	HQP + AFE	UAV DJI Mavic 3	Constant flight speed of 1.5 m/s, video recording 30 frames per second, 20 MP resolution, Hasselblad camera, 5 cm variation of sensor's position between frames.
1	CAD cartography	N/A	Available CAD cartography from the Cartographic and Geological Institute of Catalonia (Institut Cartogràfic i Geològic de Catalunya [ICGC]).
1, 2	LiDAR	N/A	Georeferenced terrain model information from point clouds from ICGC.
4	Revit	N/A	The study used Revit software tool, Blender BIM and Blender GIS.

4. Results and discussion

The main result is the BIM model of the building with its surroundings depicted in Figure 3, from joining 181,553,907 points, associated data and 22 reality capture alignment points; after 220 minutes processing time and 170 minutes capture time.

Compared to former similar approaches [9], this novel proposal:

- Defines appropriate timeframes for non-heritage obsolete stocks in need of rehabilitation, which require agile data capture with a time-precision relation that obtains appropriate BIM models.
- Includes the urban context and, therefore, enables broader meta-analysis, comparative evaluation of modelling performance, and inclusion of urban data into future research, public reports, etc.
- Optimizes data capture by reducing the required time and preparation on site combining TLS and UAV based photogrammetry.

- Optimizes data processing precision, response time and automatization with the own-developed algorithms.
- Optimizes the quality of the mesh optimization final results with VIMAC's algorithms.

Fig. 3. Resulting BIM model of Bellvitge school and its surroundings.

The real case study application enables the authors to compare the data capturing technologies applied to build school model in Table 2. This table compares 7 parameters: 1) number of generated points, 2) capturing time, 3) data processing time, 4) total time, 5) coverage (number of points in relation to the total surface area of the building), 6) effectiveness, lack of errors of each technology (percentage of the number of generated points that are within 1 cm, compared to the TLS model) and 7) efficiency of each technology (number of points captured per unit of time).

Table 2. Comparison of the technologies used to capture data for Bellvitge school.

Parameter	TLS	HQP	AFE	HQP+AFE	TLS+HQP	TLS+AFE	TLS+HQP +AFE
1) Generated points (number)	$5,9*10^6$	$1,1*10^8$	$7,6*10^7$	$1,6*10^8$	$1,1*10^8$	$7,4*10^7$	$1,6*10^8$
2) Capture time (minutes)	50	60	60	120	110	110	170
3) Data processing time(min.)	0	40	150	200	60	180	200
4) Total time (minutes)	50	100	210	320	170	290	390
5) Coverage (number/m^2)	**$1,46*10^3$**	$2,68*10^4$	$1,86*10^4$	**$3,86*10^4$**	$2,72*10^4$	$1,82*10^4$	**$3,81*10^4$**
6) Effectiveness (%)	**100%**	21%	**5%**	20%	19%	18%	21%
7) Efficiency (number/minutes)	**$1,2*10^2$**	**$1,1*10^3$**	$3,6*10^2$	$4,9*10^2$	$6,5*10^2$	$2,6*10^2$	$4,0*10^2$

From this comparison the following discussion arises:

- TLS outstands by far as the most effective and precise alternative as expected, though it reaches the lowest coverage and efficiency. Moreover, when combined to HQP or AFE it lowers their efficiency while not improving significantly the coverage or precision.
- HQP offers the best coverage when combined with AFE or alone if only one alternative is required, as reported by previous studies. Its efficiency is also the best and its effectiveness is the second best though far from TLS.

- AFE achieves much better coverage and efficiency than TLS but the worst precision, as expected.

The high precision of the final BIM model has enabled the researches to detect geometry singularities of the structure that the manually modelled BIM had not found. To sum up, this approach has been successful for the case study and it is chosen for the next steps of the research project. Therefore, it is chosen to be used to model the rest of the clusters' reference buildings, all buildings of the cluster, a digital twin of the building and the entire clusters. Obtaining a complete twin digitalization of the cluster would permit the study of each building in depth. This digitalization could be useful for the maintenance works on these public schools because it incorporates the urban context and it would enable the optimization of the management of the building stock energy performance among others, as reported previously in other studies [23].

4. Conclusions

The novel approach presented in this conference paper is a step forward in the optimization of surveys of obsolete building stocks and their urban surroundings. The main novelty of the new approach is the 3D reconstruction model. These novelties have been successfully validated by the automated generation of a BIM model of a real case study. The approach differs from previous solutions for heritage because it aims the refurbishment of non-heritage buildings. Therefore, the precision and timeframes of the novel approach are optimized for the refurbishment of non-heritage building stocks, being more agile than heritage-aimed proposals but more precise than manual built BIM. Moreover, it also differs from previous solutions because the resulting BIM incorporates the building context and is georeferenced. The development and first application of this new approach draws the following specific conclusions:

- Agreeing with the results from previous studies and practical applications: a) the most precise data capture alternative is TLS, which has the lowest coverage; b) HQP photogrammetry obtains good precision and medium coverage; c) roofs coverage is highly improved by drone captured HQP or AFE while good façade's coverage is already achieved by TLS; d) adding TLS to drone capture HQP and/or AFE achieves high precision.
- To the author's best knowledge this validation has found out that video photogrammetry obtains the best coverage enough precision and, combined with AFE, high precision is achieved. This combination is the most cost-effective alternative in the case of large datasets.
- In cases with limitations regarding the flight of drones, for instance due to legislation, the best combination would be AFE photogrammetry and TLS.

These findings can be useful to improve the efficiency and accuracy of future surveys of existing building stocks in need of rehabilitation. The proposed standardized procedures could enhance the automatization of ambitious workflows such as the generation of twin buildings incorporating their urban surroundings. This could move forward related research, institutional and industrial projects. This project considers as pillars of future actions both the incorporation of standardized procedures and the balance between data capture and processing loads, the quality of the obtained models and the precision and timeframes required in each case. Future works will use the obtained model to carry out the aforementioned simulations and escalate the results to the cluster. Researchers also expect to apply the novel approach to other types and sizes of buildings, as well as entire clusters, in order to further advance towards an optimized massive data capture for the refurbishment of existing building stocks.

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