
An integrated laser and image surveying approach in support of model-based information technology for inventory of campus historic buildings

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Abstract

In the past few years, buildings design and construction processes have benefited from novel building information modeling (BIM) functionalities. However, these benefits have mainly reached the new buildings. The historic buildings, in turn, due to their exceptional maintenance, conservation and restoration requirements, have barely benefited from the new Information and Communication Technologies (ICTs). The primary purpose of this paper is to evaluate available solutions and main problems addressed to data capture and modeling efforts to generate digital as-is model. The secondary purpose is to describe the concept of a comprehensive inventory for supporting conservation and rehabilitation works of historic assets. Two university buildings have been used to compare different remote sensing technologies and its fusion in a hybrid 3D geometrical model. Different software packages have been used in an attempt to streamline this process. The results revealed that factor as scale; complexity and location have direct impact in the selection of surveying technologies.

Keywords: Built Heritage Management, reality-based surveying, Building Information Modeling, data integration, data comparison

1 Introduction

The recent history of Architecture, Engineering and Construction (AEC) industry has shown that design, construction and maintenance phases of new buildings have been highly benefited from the features introduced by the new Information and Communication Technologies (ICT), such as the Building Information modeling (BIM), particularly buildings with complex architectures. In the cultural heritage field, accurate and detailed data capture and as-is model may consider the peculiar maintenance requirements of these buildings.

Beginning with the need for maintaining, enhancing performance, improving functionality and quality of historic assets to new standards of sustainability, efforts have been made by different research communities, in the process of surveying and creating rich representations that reflect the buildings in their as-is conditions (Arayici 2007, Penttilä et al 2007, Chevrier et al 2010, Fai et al 2011, Manferdini & Remondino 2012).

This paper presents a methodology to create a Comprehensive Historic Inventory (CHI), based on Building Information Modeling technology, providing an overview of the first and second steps for CHI: data collection and modeling. To accomplish these objectives, two historic buildings at the University of Southern California were surveyed to investigate the integration of multiple reality-based technologies, as well as the processing of the point cloud raw data that allows the creation of a

3D geometrical model. The case studies are the Mudd Hall of Philosophy, built in 1929, and the University Religious Center, built in 1965.

2 Comprehensive Inventory

Over the past few years, the building of a reliable 3D model from historic assets has become increasingly usual for the purpose of maintaining and improving architectural valued building stock to its functional level and safeguarding its outstanding historic value.

In order to provide a holistic approach of the historic asset, the authors propose the concept of a Comprehensive Historic Inventory (CHI). The CHI is a semantically oriented three-dimensional model which should work as the main information's depository of the building in its life cycle. In addition to the shape, construction details and architectural performance of the building, this depository should include information related to the historical context of the building (e.g. pictures, blue prints, historic documents, texts, videos, and other medias). The historical context is the key part of the historic asset dossier and a guiding element to define precise conservation, renovation and rehabilitation works. Thus far, these documents are decontextualized from the building, making the reading and the connection to each architectural element a difficult task.

The concept of the comprehensive inventory, which comprises the integration of physical and historical context of the building in the 3D BIM model, is summarized in the Fig. 1.

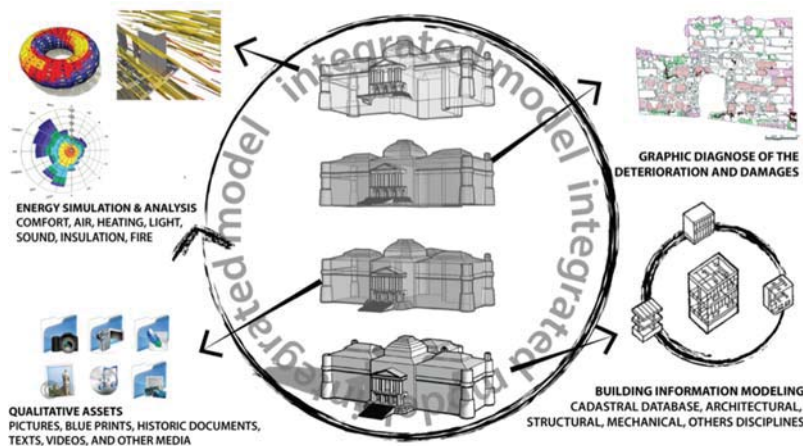


Figure 1 Concept of the Comprehensive Historic Inventory (CHI)

Creating a CHI of historic assets requires three major steps: (1) capture of their as-is conditions; (2) usage the data obtained in the first step to create the geometrical and tridimensional representation; and (3) integration of relevant semantic and historical information about the life cycle of the building into the 3D model. Each step is a different task and faces considerable challenges and technology gaps.

Fai et al. (2011) state that accurate documentation from historic assets might cover qualitative (historic data) and quantitative (geometric and performance data) aspects in an integrated approach based on heterogeneous datasets.

Object-related semantic information plays an important role in the comprehensive inventory in order to give meaning and properties to the objects and coherence on their representation. The Building Information Modeling (BIM) technology has proven to be an effective tool for describing building components with respect to their geometrical attributes, topological relationship and semantic information.

Eastman et al (2011) outlined that the main benefit of the BIM-enabled method for recording as-built information, for facilities maintenance and management, is the creation of a central database containing information that can be easily accessed, visualized and shared.

3 Overview of data capture and data modeling for existing buildings

3.1 Remote sensing assessment for existing buildings

According to De Luca et al (2006) in a building two essential points should be considered: (1) the perfect ideal conceived by the architect and (2) the real, imperfect and concrete realization of the plan. Concerning to the historic assets, the difficulty to obtain both the as-designed and the as-built reference documentation makes the surveying starting from the real object, in a reverse engineering process.

The reverse process still relies heavily on manual surveys for the development of drawings and 3D models. The Verification of as-is conditions of the buildings, including dimensions, materials and state, are carried out by means of in local surveys using direct measurement, image-based and range-based technologies. These data are used to update as-built drawings and/or 3D models, and to generate digital documents in the case of lacking prior as-built drawings. Conservation and Restoration works are a complex task and require a high level of detailed data, furthermore, traditional methods of survey by direct measurement, though simpler, end up making it an expensive and time-consuming method, as well as, it is unable to record the peculiarities of all architectural components of the building in a faithful way.

According to Scott et al (2013) there are many approaches to survey historic asset and the adoption of the appropriate technology depends on three key factors: (1) data accuracy, (2) asset scale and (3) equipment affordability. In the same direction, El-Hakim et al. (2004) listed eight requirements to create accurate and complete 3D models of historic buildings and objects: high geometric accuracy, capture of all details, photorealism, high automation level, low cost, portability, application flexibility and model size efficiency. The goal of the 3D models (e.g. restoration and reconstruction, educational, virtual tourism or visualization purposes) dictates the order of importance of these requirements. However, the authors point out that satisfying all requirements with a single system is something for the future. The author purposed workflow combined different techniques (laser scanning, photogrammetry, image texture and reflectance models, panoramas from aerial images), and met most of the eight requirements, except low cost due to laser scanning.

The use of remote sensing technologies, to collect the spatial information of the buildings, has been popularized in the last decade. Although very different in terms of equipment costs and detection process, range-based and image-based are three-dimensional acquisition systems, automated, non-contact with the analyzed object, using sensors based on light waves to measure, directly or indirectly, points of the scene scanned or photographed.

Previous researches, concerning to the use of range-based systems (i.e. Laser Scanning technology) for built heritage, pointed out that this technology provides high data acquisition rate, high spatial data density, high level of detail and a high metric accuracy (Arayici 2007, Scott et al 2013). In spite of its potential, some issues (e.g. portability, cost) associated with laser technology are still a limitation.

On the other hand, image-based survey has long been used for historic assets documentation according to its low cost. Nowadays computer vision software packages have speeded up the dense point clouds extraction from pictures, with evident benefits for surveying process (Garagnani & Manferdini 2013). Besides these benefits, in the last few years several affordable and/or free close-range photogrammetric software packages with computer vision algorithms have become available as open-source applications or as web services. These offer cheap and easy-to-use 3D capture solutions for different users and specialists (Kersten & Lindstaedt 2012).

In the data collection process for as-built/as-is documentation, choosing the best reality capture method has proven to be challenging to address (Beraldin 2004, Remondino & El-Hakim 2006, Moussa et al 2012).

According to Moussa et al (2012), such an issue is due to the lack of a suitable ideal approach for all applications and their demands. The terrestrial laser scanning (TLS) deals directly with 3D object points via a set of coordinates with precise geometric and spatial information but with RGB data and texture in low resolution. Photos contain RGB information and texture in high resolution, but do not contain any explicit metric information without additional processing steps.

Additionally, some difficulties in choosing the capture method were observed by Remondino & El-Hakim (2006) due to the specific requirements for each object and place. Thus, selecting the most appropriate remote sensing technology, or the fusion of different methods, depends on the size and

complexity of the scene or object, precision and level of detail required and budget constraints. The authors point out that satisfying all requirements with a single system is still in the future.

Beraldin (2004) corroborates the hybrid approach by stating that to model complex environments, those composed of multiple objects with different characteristics, it is essential to combine data from different sensors and information from different sources.

The range- and image-based technologies have been widely compared in the Computer Vision and Engineering community. Table 1, organized by Klein et al (2012), highlighted the advantages and limitations of both technologies.

Table 1 Comparison of range-based and image-based technologies. Source: Klein et al (2012)

Technology	3D laser scanning	Photogrammetry
Accuracy	Millimeter	centimeter
Resolution	Millions of points	Hundreds of points
Equipment cost	Tens of thousands	Hundreds
Required skill	Medium-high	Low
Portability	“bulky”	Hand held
3D data generation	Automatic capture	Post-processing
Commercial software	Yes	Yes
3D modeling	Automatic meshing & shape extraction	Manual Modeling
Environmental challenges	Reflectivity, surface texture, weather, target movement, edges, line of sight	Feature repetition, surface texture and material, view angle, line of sight

3.2 BIM approach for existing Buildings

The concept of Building Information Modeling (BIM) has been established more than forty years ago, and due to the rapid development of information technology in the past few years, BIM has been widely studied and adopted for new buildings.

According to Akcamete et al. (2010) BIM for FM is a new way of analyzing building behavior/deterioration over time, providing as-is facility information in addition to history of previous maintenance and repair (M&R). For the authors, BIM has capabilities, e.g. information about the whole system integrated to 3D spatial model, those may not be easily performed with traditional data representation formats.

As many researchers point out, an as-built model will be more suitable for facilities management than the original BIM model (Eastman et al 2011, Huber et al 2011, Lagüela et al 2013).

The potential benefits to using BIM in buildings management and operation seems to be significant in several areas, such as the improvement of project management and information flows, risk mitigation, heritage documentation, space and energy management, retrofit planning, monitoring, tracking and controlling dimensional compliance in construction (Becerik-Gerber et al 2012, Volk et al 2014, Bosché 2010).

Arayici (2007) proposed a semi-automated approach for the development of as-built BIM with the purpose of remodeling of existing buildings, based on two case studies (Jacint House in Manchester and Peel Building on the campus of University of Salford). For the author the as-built BIM model resulting from laser captures is an important document in the decision-making process regarding interventions in historic buildings.

Fai et al. (2011) go further by placing emphasis on the potential of BIM, as a multi-disciplinary knowledge database, in the life-cycle management of growing heritage buildings stock. The authors underline the prospective contribution from this technology to the collation of the complex relationships between tangible (*building itself*) and intangible heritage (*such as historical images and texts, multi-language story telling, and music*).

4 Case Studies

The focus of this paper is on describing the first (capture the as-is condition) and the second step (modeling of geometric 3D representation) to create the proposed CHI. With this objective, and within the integrated range-based and image-based technologies context, two buildings at the University of California Park Campus were selected as case studies. These buildings range in scale and complexity. Both buildings granted the Historical Cultural Monument status in 2013, and have significant value in the context of the campus architectural history.

4.1 Case Study 1: Mudd Hall of Philosophy

Ralph Carlin Flewelling designed Mudd Hall of Philosophy in 1929 in Romanesque revival style, combining elements of Tuscan, Byzantine and arabesque decoration, similar to the other University buildings completed under the first university master plan from 1919. Mudd Hall of Philosophy was awarded the American Institute of Architects' Gold Medal for America's Most Beautiful Building in 1931 and the AIA Southern California Chapter Honor Award in 1934.

The building is clad in brick and cast-masonry, also composed of three wings and an open cloister surrounding a courtyard that encloses a water fountain. A 146-foot clock tower with a pyramidal roof is located in the corner of the north and west wings of the building (Fig. 2). The tower is an imposing architectural element, which characterizes the Mudd Hall of Philosophy, as well as such building has a vast amount of intricate detail, ornate sculptures, reliefs and mosaics that adorn it. The building still retains a high degree of integrity and has been upgraded following the 1994 Northridge earthquake. Its landmark tower suffered several damages, which have been repaired, including replacing finials and missing decorative features, patching and repointing brick and low cast stone walls. The originals drawings were used to the repairing work. Also the building underwent extensive structural and decorative restoration in 2003 and since then no more updating of the as-built drawing was undertaken.

The two-story plus basement building has a net area of 17,465 sq ft, gross area of 27,703 sq ft and a footprint area of 11,759 sq ft.



Figure 2 – Mudd Hall of Philosophy. [Left] Trousdale Parkway Façade, [Center] Courtyard and Fountain. Right, Clock Tower and the arched colonnade walkway at the east façade of the building

4.1.1 Survey methodology

Mudd Hall of Philosophy is located on the corner of Trousdale Parkway (Campus main street) and Exposition Boulevard. This condition and the presence of vegetation (trees of different size and height), hedges, fences and the proximity of others buildings surrounding it were a great limitation for the surveys (Fig. 3). Another difficulty was the capture of the roofs and the tower with the range-based approach.

For this reason, the survey campaign started by focusing only on the courtyard and the fountain, in order to set up the general workflows for surveying the whole building.

The used pipeline for the 3D geometrical reconstruction of the courtyard consisted of: (1) data capturing using photogrammetry and laser scanner technologies; (2) processing the raw data; (3) testing the accuracy comparing the meshes from the different software using the laser scanner point cloud as reference and; (4) fusing the reality data from laser scanner and photogrammetry to generate a hybrid model.

The Terrestrial Laser Scanner (TLS) used in this survey is a time of flight Riegl VZ-400, based on echo digitization and online waveform processing. The Riegl VZ-400 has a maximum range of over 600m with a 360 x 100° field of view, a scanning rate of 122,000 measurement per second, and a measurement precision of 3mm @ 100m. The Scanner is integrated with a digital camera, Nikon D700 SLR (capable of HDR), which allows the scanner to capture high quality color data (10 megapixel).

The scanner is connected to a 12V battery. The VZ-400 provides stand-alone data acquisition via the built-in user interface, or remotely using the software RiscanPRO on a notebook either connected via LAN interface or integrated WLAN.

The scanner was controlled by RiscanPRO software and by display. The use of software allows the operator to store and convert data while data acquisition. The software enables the registration in the field as well as the full control and visual check of the capture. It is important to mention that

the field registration of scanings show two inconvenients: the laptop battery level runs out quickly and the scanner operation is slower.

On the other hand, when the scanner is controlled by display, the use of a laptop computer and cables in the field can be avoided. As well as, the operation is faster, but there is no way to control the visual check of capture.

A field methodology for operating and handling the 3D scanner was planned in order to speed up the surveying process. The scanner automatically proceeds the calibration and alignment of its own coordinate System (SOCS) based on measurements of the magnetic field and detailed information of its internal GPS receiver. This functionality aids the data alignment (registration) from multiple scan positions. The scanner proceeds first with a panorama scan (360°) for each scanner position. Image acquisition starts directly after the panorama has finished.

The acquired data can be exported to different file formats to be passed to post-processing. The post-processing was conducted in various software packages. The standard registration process for target scan is in RiscanPRO software from Rieggl, which is based on corresponding tie points (fine scanned reflectors). For target less scans the authors used the Recap PRO from Autodesk. The registering scans workflow in Recap PRO is only the process to match 3 points in the XYZ axes between two different scans. The software provides a summary of the results and a quality chart, which one can either approve and finalize the registration or reject and re-select the matching features.

TLS data were acquired from 24 scan positions in a polygonal framework (fig. 3), in order to overdo the limitations and to cover the whole exterior of the building including the cloistered courtyard and the arched walkway. The surveying was performed in a first moment with several 5-cm-flat-reflective tape target specified by Rieggl (scanner location numbers 1-3), and in a second moment without target (scanner location numbers 4-24).

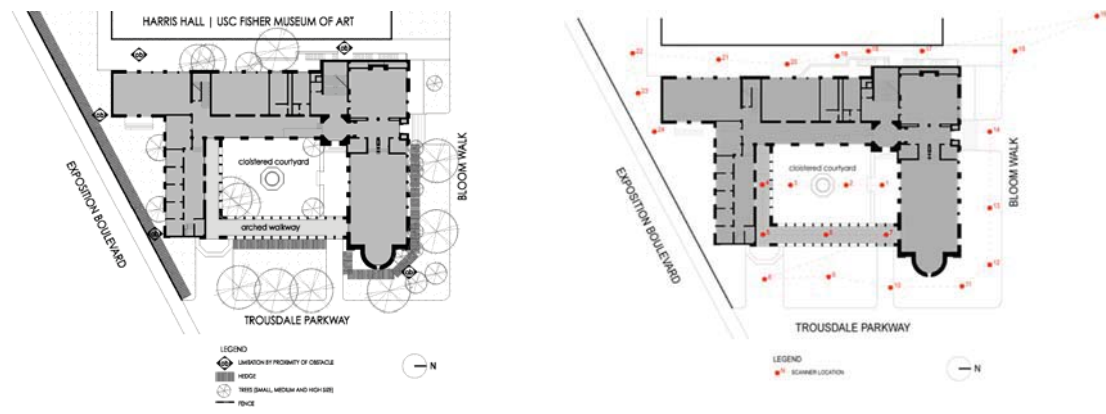


Figure 3 Site Plan of Mudd Hall showing [Left] the obstacles to the 3D scanner survey and [right] Scanner position to survey the exterior of the building.

The first set of scans was performed using different resolution set-ups, based on the level of detail of the architectural element to survey. The first scan acquisition was carried out using a sampling step of 0.025 degrees (42mm point spacing @100m). The second was carried out at 0.035 degrees (58mm @100m) and the third at 0.05 degrees (83mm@100m). The time surveying with 0.025 degrees resolution was high and overloaded the computer. The density of point cloud resulting from the 0.035 degrees sampling was enough for cover the very intricate detail and this was the resolution chosen to perform the scanning.

For the image acquisition, a non-professional equipment was used. The photographs were taken using an Apple iPad Air, whose iSight camera has resolution of 5MP, five-elements lens, hybrid IR filter and fixed aperture of $f/2.4$. The selected photographs were uploaded in three different photogrammetric cloud-based service from Autodesk: (a) 123D Catch – a free web-based service; (b) Autodesk Labs Project Memento – technology application preview; and (c) Autodesk ReCap 360 – a web-based service that needs subscription.

The processing of the three different software is fully automatized, and the time processing depending on the object's dimensions, shape and morphology.

A set of circa 70 photographs have been acquired of the courtyard fountain in order to rasterize its whole shape and morphology. The first sequence of images has been taken perpendicularly, at same distance from the object, and with a 50-70% overlap, in order to avoid holes in the final point cloud. Another group of images has been taken to cover the up side of the fountain.

To cover the roof and the clock tower a low-cost UAV (Unmanned Aerial Vehicle) quadcopter DJI Phantom was used, equipped with a GoPro. Due to its wide-angle, the GoPro camera provides high yield of distortion, requiring its calibration and wide overlapping to reduce the distortion. The authors used the video functionality of the camera to capture roofs and tower.

4.2 Case Study 2: University Religious Center (URC)

William Pereira and Associates developed the third master plan for the USC campus in 1961, and under this plan, more than twenty buildings were constructed using modern and innovative architectural language, complying with USC vernacular style.

The University Religious Center (URC) is one of them. This building was designed in 1966 by Killingsworth, Brady and Associates using the basic design principles of the International Style, which include rectangular massing, exposed post-and-beam steel structure, brick and cement plaster cladding, floor-to-ceiling glazed windows walls and flat roof. This architectural agency was among the influential group of architects practicing the Modernist style in California during the 1960s.

Compared with the Mudd Hall of Philosophy, the URC presents low complexity due to its exposed steel structural system, repetitive floor-to-ceiling fenestration, lack of exterior ornamentation, and prevailing geometrical forms. URC is also smaller than Mudd Hall, it has a gross area of 11,170 sq ft, as well as, URC presents less obstacles to scan than Mudd Hall, as showed in fig. 4.

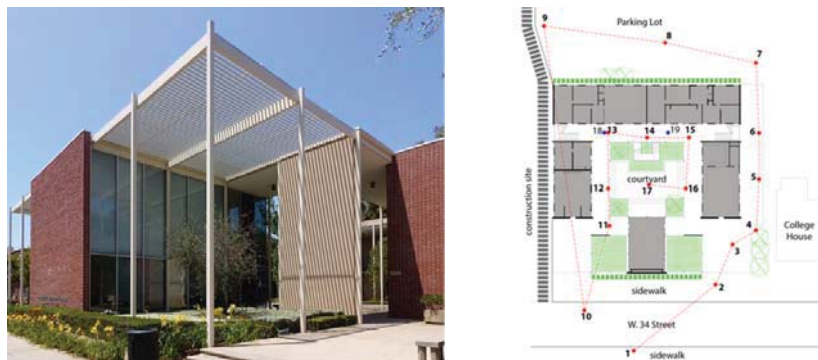


Figure 4 [left] URC view from W 34 Street and [right] Site Plan and Scanner position to survey the exterior of the building.

4.2.1 Survey methodology

URC was scanned using the same equipment as was used at Mudd Hall. After all lessons learned at the Mudd Hall, the authors could performed all the 20 scan positions in less than 3 hours. For the post-processing of the data (registration), Recap PRO from Autodesk was used, and after eight hours of computer work, a good registration was achieved according to the software algorithm, considering the balance, the overlap points and the percentage of points less than 6mm.

To cover the blind spots of the laser scanner survey (the roof area in this case study), the authors used images taken with an Apple iPhone 6 plus built iSight camera. This camera has resolution of 8MP, optical and digital stabilization, five-element lens, hybrid IR filter and fixed aperture of $f/2.2$. Approximately 700 photos were taken from the roof with 50% minimum overlap. To increase the crispness and quality of the pictures, backlighting was avoided by taking photos earlier in the morning. Blurry photos were manually eliminated later.

Several commercial and open source software tools were tested with the collected images. The authors initially used Autodesk Recap for the 3D reconstruction of this case study. Autodesk Recap is a free online service provided by Autodesk to generate 3D point clouds from images. The service provider limits the maximum number of images to 250, thus images were manually selected from the total image set. During the 3D reconstruction process, the quality properties were set to ultra, and .rcs file format was chosen as the output format. After the first submission, a resubmission process was carried out because reconstruction process failed to take into account 18 uploaded images; these

images were stitched by manually selection of homologous points. During the resubmission process, dimension was also added to the point cloud using information from laser-scan data. The result point cloud is not satisfiable via visual inspection; data were missing in several locations and some objects were distorted due to reduced image set.

The second software package tested was VisualSFM, which is an open source structure from motion (SFM) software for 3D reconstruction using 2D images. The SFM method mainly consists of four steps: (1) Feature detection detects features from each image; (2) Feature matching matches features from different given images; (3) Sparse reconstruction calculates camera positions, orientations, and distortions; and (4) Dense reconstruction was finally carried out to generate the complete 3D point cloud (Wu 2011). Like any other open source software, the user has the flexibility to plug in their own code and adjust the parameters. VisualSFM also provides options for users to increase the performance such like “specify your pair-list for matching” which allow users provide image paths txt file for feature matching. The main limitation of using VisualSFM is that it is easily run out of memory during dense reconstruction phase with large amount of images. In the case study, system was crashed during 3D reconstruction due to the large image set.

Smart 3D capture was the third software package tested. This is a commercial software that out performs all other software previously mentioned. With the advanced edition offered by the software provider input imagery dataset can be up to 10 gigapixels, which is equivalent to 1250 images taken with 8 megapixels camera. Smart 3D capture also provides a unique feature called tiling, in which the system divided the computation in several parts specified by the user during the dense reconstruction process to avoid memory crashes. For URC case study, an Apple MacBook Pro was used, equipped with Intel® Core i7 processor, 16 GB RAM memory, and Intel HD Graphics 4000 graphic card. Total imagery dataset were provided to the software, GPS information was used to facilitate camera positions, orientations, and distortions calculation. The software eliminated 42 photos before dense reconstruction phase since there are not enough features matching from them. The authors created 20 tiling blocks to reduce the maximum RAM usage during dense reconstruction phase. Point cloud generated from images is shown in figure 5 (A).

Imagery point cloud and laser-scan point cloud are registered using CloudCompare, an open source project for 3D point cloud and mesh processing. The authors used CloudCompare build in function register entities. Four points were selected in both point cloud as common points and the software automatically registered the two-point cloud. Final registered point cloud is shown in figure 5 (B).

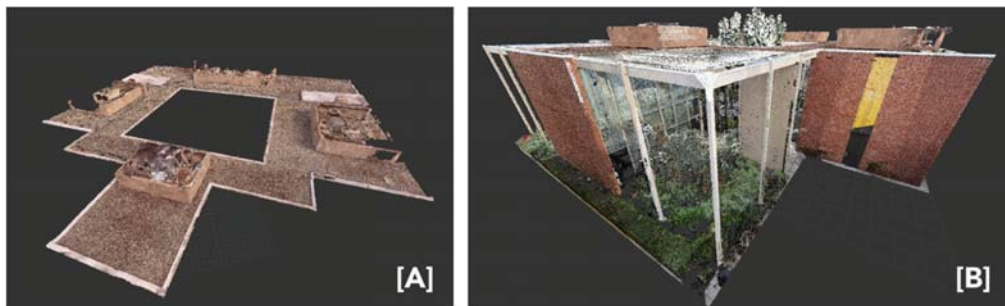


Figure 5 – [A] Imagery point cloud generated by Smart 3D Capture software. [B] Hybrid point cloud model aligned by CloudCompare software

5 Comparison results between the case studies

Scanning and pictures have been taken from the both case studies in order to generate an accurate as-is 3D geometric model. The different complexity and scale of the buildings has determined the scan and image approach. Lessons learning from the case study 1 (e.g. time of scanning and post-processing, capture completeness, use of target, capture resolution) have influenced the scan locations in the case study 2, determining the most suitable positions for capturing critical cluster. A comparison of registration data report provided by Recap PRO, considering the balance, the overlap points and the percentage of points less than 6mm, from the both case studies, is showed in Table 2.

Overlap represents the amount of scan data that can be used for registration. ReCap Pro recommends at least 30% of overlap between each scan in order to process the registration properly.

The scans from Mudd Hall have an average overlap of 33.5% and those from URC presented best results with 39.2%.

Balance represents the quality of the features (or surfaces) used for registration. Features with surfaces that face in all x, y and z directions will produce better results than surfaces that face in one or two directions. Analyzing the outcomes from the two buildings studied the fact that the shape of URC is more regular than those from Mudd Hall have influenced the results, as showed in the table 2.

The points less than 6 millimeters inquiry section tracks how many points in the unregistered scan are within 6mm of the registered data. Data in this range indicate a consistent match between scans. In our case studies, most of the results on this category is higher than 98%.

The outcomes lead to the conclusion that using a target less registration have speed up the data post-processing without loose accuracy.

Table 2 Comparison of registration data from the two case studies

Case Study	Mudd Hall	URC
Number of scan positions	24	19
Total time of scanning	2:54 hours	2:36 hours
% of the building surveyed with 3D laser scanner	65%	80%
Average of overlap	33.5 %	39.2%
Average of balance	27.5 %	30.3%
Average of Points < 6mm	99.1%	98.2%

The registered 3D point cloud resulted from Recap PRO is showed in fig. 6. The percentile covered by the scanning is different in both case studies and it depends on the obstacle presents in each building. URC has few obstacle (e.g. the construction works at its west side), for this reason more than 80% of its surfaces have been covered by the laser scanner. The Mudd Hall has more obstacle (vegetation, proximity of other buildings, higher elements and inclined roofs) and the total of the surfaces covered by the scanning was 65%. On the other hand, URC has more glass surfaces than Mudd Hall, resulting in gaps in the laser point due to the material reflectivity.

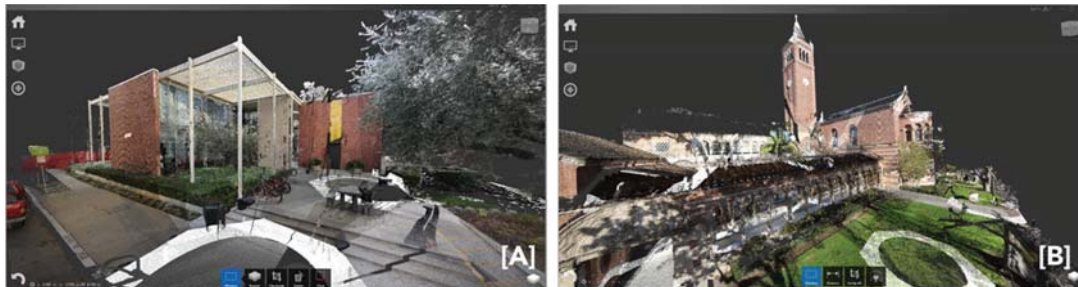


Figure 6 Point clouds aligned output from Recap PRO: [A] URC and [B] Mudd Hall

6 Conclusions and Future Works

The main question in this research was how to speed up the data capturing and the point cloud processing, with the possible lowest number of software solutions, in order to create a methodology aiming to complete the two first steps of the proposed CHI reasonably. The goal was to simplify the fieldwork and data processing. Such goal was influenced the choices of post-processing software and the option to work without targets.

The outcomes of the two case studies have demonstrated that a high-resolution 3D Geometrical model can be obtained by fusioning scan and image data. As well as, the pictures taken with the mobile apparatus (e.g. tablets and cell phones) showed to be good enough to generate a high-resolution and high-density imagery point cloud.

This research has a preliminary nature. The next step is to work in the automated object extraction from the hybrid point cloud model and its classification in order to create the BIM model. In such model heterogeneous data types could be unified, which represents the proposed CHI third goal: integration of relevant semantic and historical information about the life cycle of the building.

Acknowledgements

The authors would like to thank the São Paulo Research Foundation (FAPESP) for the support, grant # 2014/02951-5

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