Budownictwo i Architektura 18(2) (2019) 21-30 **DOI: 10.35784/bud-arch.552**

Comparative analysis of the inventory process using manual measurements and laser scanning

Piotr Gleń[1], Karol Krupa[2]

[1] Faculty of Civil Engineering and Architecture, Lublin University of Technology
Corresponding author: p.glen@pollub.pl, ORCID: 0000-0002-2975-408X
[2] Faculty of Civil Engineering and Architecture, Lublin University of Technology
k.krupa@pollub.pl, ORCID: 0000-0002-7313-4080

Abstract: Laser scanning allows the acquiring of spatial data about existing objects. It is used as a modern inventory technique, most often in the creation of archival or conservation documentation. It gives the opportunity to obtain a very large amount of spatial data of the facility thus helping to improve operations in the field of conservation but also reduces the margin of error in the inventory and then design documentation. It is useful due to the growing BIM technology, through which three-dimensional models of existing objects of various scales are obtained. This article presents research comparing the traditional measurement method and the modern one with the use of a laser scanner. The research is a compilation of the duration of architectural inventory techniques as well as the accuracy of the measurements made and of the following architectural drawings. The result of the research is a relative percentage ratio showing the acceleration of inventory works with a simple construction object using modern assistive techniques compared to the traditional method.

Keywords: Architectural inventory, historic objects, laser scanning, point cloud, measurement methods

1. Introduction

Architectural inventory of existing facilities is a key element in the preparation of comprehensive project documentation. The inventory process itself concerns both measurements in the object as a whole as well as specific dimensioning of architectural details [1]. Computer support in the inventory process is a helpful tool that greatly speeds up the work [2]. The specificity and accuracy of the inventory depends on its subsequent use but also on the measured object itself. Classical inventory methods most often presented the study in the form of paper 2D plans (projections, sections, views and photo plans) [3]. The development of computer technology results in additional capabilities for documenting objects measured in numerical form of CAD [4]. The currently growing measurement technology, most often used in the study of historic objects focuses on creating a three-dimensional computer model. With the use of the right software, BIM technology in which we obtain an inventory model can be extremely useful for planning conservation work (renovation works, incorporation of new elements into historical fabric or even for virtual reconstruction of the object) [5]. The results of BIM measurements can also be presented in the form of a 3D model printout or a virtual walk [6]. Creating documentation in the form of a point cloud not only results in better measurement capabilities but also creates a documentation of sorts allowing the improvement of other research methods on existing objects [7].

In this article, two measurement methods will be compared. One method is traditional measurement using a measuring tape and a laser rangefinder. The other method is a measurement through scanning the building with a laser scanner. The duration of the entire process as well as the accuracy of the results of the part related to the in-situ test and the processing of the acquired data up to obtaining the final architectural documentation will be verified. Laser scanning is a modern measurement method and currently the most popular method of inventory [8]. The measurement accuracy depends on the type of device, but also on the material being measured or the distance from the measured component [9]. If the collected data in the form of a point cloud provide sufficient material, laser scanning can be treated as a direct measurement method [10]. In this study, however, laser scanning functions as an inventory note and is therefore regarded as an indirect measurement method. This method involves the collection of spatial data describing the geometry of the measured object and the assignment of its radiometric values. The so-called point cloud forming the three-dimensional object model created with this kind of measurement serves as an inventory note in the further development of drawing documentation in AutoCad software.

A small and simple construction object was selected for the study. It was important for the studied building to be a small and two-story object - with emphasis on the importance of the measurement problem most often created by wooden staircases due to its irregularity in the dimensions of individual elements - with visible damages in the structure of external and internal partitions. During the inventory using both traditional and laser techniques, each stage of measurements was described, and measured over time. Then, after obtaining drawings in the form of CAD files, the accuracy of the measurement and the duration allocated to individual elements were compared.

2. General characteristics of the studied object

The object undergoing inventory works is a residential building located on the premises of the palace and park in Snopków in the commune of Jastków (Fig. 1). It has a simple body with a gabled roof, two symmetrically located northern entrances, windows on each external wall and additionally two roof windows on the south side. Small ventilation openings to the basement from the front, located symmetrically at ground level. It is a two-story building made of solid brick with wooden window and door joinery, with no visible decorations, both outside and inside the building.

There was no information or conclusive traces of any interference (repairs, renovations, reconstructions) in the facility over the years. The building, owing to its simple architectural form and significant degradation, is an interesting research element.

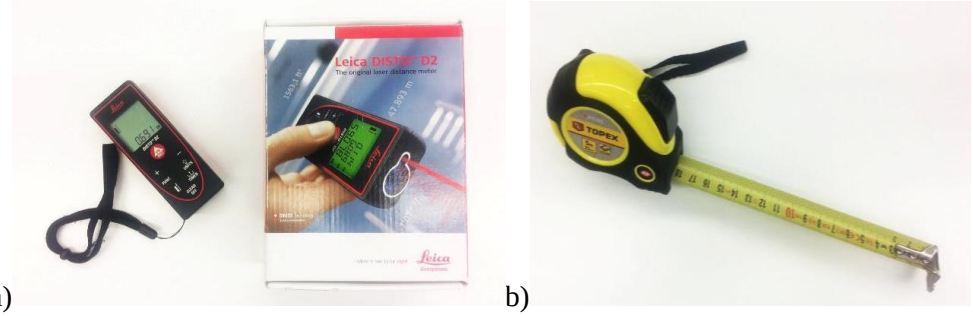
Features of the object relevant to the experiment:

- A simple geometric form in the outline
- Small cubature
- Gabled roof
- Deformation of the geometry of both the internal and external partitions
- Numerous defects and damage in the body of the building
- Wooden staircase with irregular steps.

Fig. 1. Building covered by the study, Snopków 102 - photo by the author

3. Description of research

Basic available equipment used during architectural inventory was used for research on the site. In the traditional method, a laser rangefinder and measuring tape were used (Fig. 2). In the case of laser technology, the Leica C10 laser scanner was used (Fig. 3) [11]. The research method focused on the basic measurements carried out on this type of buildings in traditional and laser inventory (Table 1). The aim was to create a comprehensive measurement documentation taking into account the dimensioning of the building's facade, indoor enclosures, roof truss, staircase and finally marking the damage in the object's structure.



a) b)

Fig. 2. Measuring instruments a) laser rangefinder b) measuring tape - photo by author

Fig. 3. Leica C10 laser – photo by author

Table 1. List of materials and measurement techniques - compilation by author

Details	Traditional measurement	Laser measurement
Stage 1 preparing measuring equipment		
Laser scanner	-	X
Laser rangefinder	X	-
Measuring tape	X	-
Papers	X	X
Pens	X	X
Photo camera	X	X
Stage 2 in situ research		
Sketch of building plan	X	X
Facade sketch	X	-
Facade measurement	X	X
Enclosure outline measurement	X	X
Enclosure height measurement	X	-
Stairs measurement	X	-
Attic slants measurement	X	-
Roof truss measurement	X	-
Window opening measurement	X	-
External partition thickness measurement	X	-
Roof slope angle measurement	X	-
Supporting photographic documentation	X	-
Stage 3 measurement digitalisation		
Placing posts in a point cloud	-	X
Redrawing measurements to CAD format	X	X
Additional measurements of missing data	X	-
Correcting measurement errors	X	-

- **Traditional technique:**

In the traditional technique, after preliminary preparation of foundations illustrating the schematic layout of the rooms and the façades of the measured building, detailed measurements were implemented. Two people participated in the measurement (one performing the measurement, the other noting the dimensions onto sheets of paper). Laser rangefinder and measuring tape were used for this task. The building heights and total as well as detailed lengths of the walls were checked. Door and window openings as well as their joinery were measured separately. The next stage was the documentation of internal rooms including window and door carpentry, room heights in at least 3 places (due to the likelihood of ceiling deflection). Subsequently, measurements were made of two wooden staircases. It was necessary to check the differences between each of the stair steps in detail, because they showed significant deviations from each other. After reaching the habitable attic, the procedure was repeated, and supplemented with additional measuring aspects related to the slants present in each floor space. Subsequently, the plumbing installations, ventilation openings, manholes for the basement and the unused attic were marked.

After applying of all inventory information to the drawing pad (Fig. 4), the researchers proceeded to describing the structure of the building partitions.

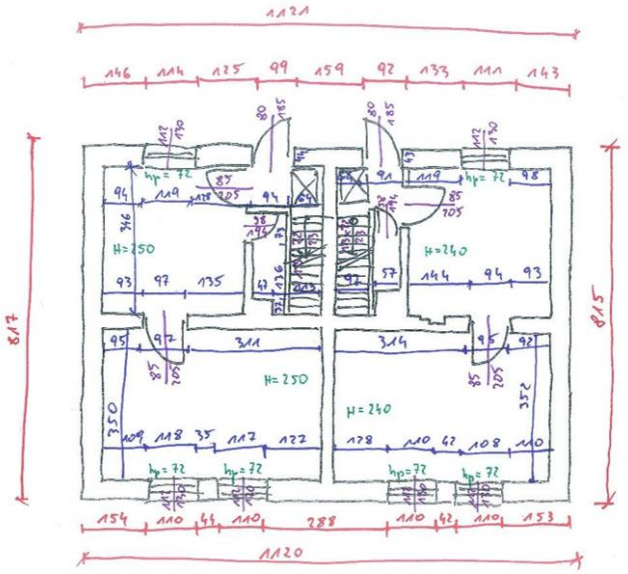


Fig. 4. An example of a manual sketch layout with dimensions

- **Laser technique:**

After preparing a schematic (and simplified compared to the one used in the traditional technique) functional system of individual storeys of the object, as the measuring proceeded, only an approximate location of the placement of the scanning device was applied (Fig. 5.). Photographic documentation was then made, the duration of which was 30 minutes. The measurement was carried out by two people due to the need to carry measuring equipment and a tripod. For each measurement, the scanner was placed on a tripod. The device was then

leveled manually and the scan was started. The first stage of the measurement was the placing of the scanner in each of the 9 stands outside the studied object for the inventory of the elevation. The number of stands resulted from the necessity of interlocking of the consecutive planes of external walls. Subsequently, the places where the scanner was placed were transferred on plan.

The average time of equipment transfer, tripod setting and leveling was 7 minutes. The average duration of one scan was 7 minutes. 20 individual workstations were set up during work on the site. The entire duration of the scanner operation was a total of 280 minutes. To the measured time, an additional 20 minutes were added which accounted for the first start of the scanner and a manual sketch of the object layout needed to apply scanning spots. The total duration of in-situ work was 330 minutes.

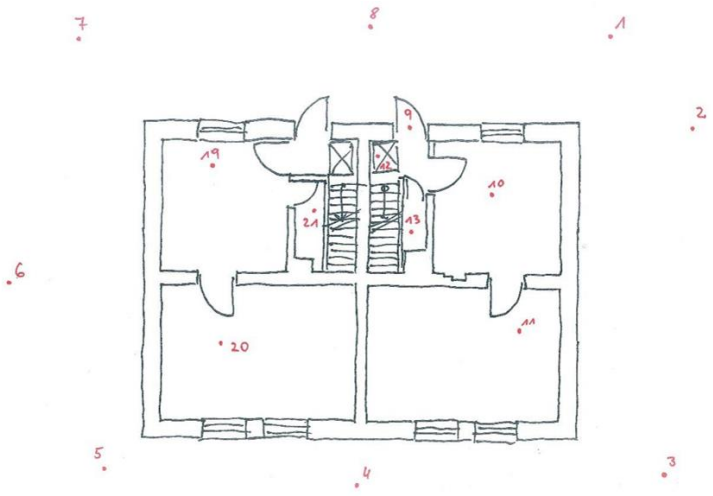


Fig. 5. An example of a manual layout sketch with marked points

4. Result summary

The detailed measurement procedure and processing of the obtained data in both developed techniques are presented below (Tab.2.). The time measurement was given in minutes.

A summary of data comparing each stage in detail with regard to the duration of carrying out inventory activities is shown in Fig. 6. A comparison of the duration of the measurement with the time of its digitalisation is shown in Fig. 7.

After the measurement processes were concluded, two drawings were made in the AutoCad software in order to compare the measurement accuracy. Below are the drawings of the conducted inventory in both measuring techniques. (Fig. 8.) (Fig. 9) The difference in wall plastics is already visible in the drawing showing the basement. The result of manual (traditional) measurement was the simplification the geometry of external and internal walls, while the measurement using a laser scanner allowed to map out the exact geometry of the walls. The significance of the measurement differences is also noticeable when tracing wooden staircases which have been distorted over the years and each of the stair steps differs significantly from the previous one.

Table 2. List of performed measurement activities - compilation by author

Performed action	**Description of performed action**	
	Traditional method	**Laser method**
Preliminary drawing note	Schematic drawings needed for dimensioning walls, window and door openings, functional layout, building elevations, staircase	Schematic drawings of story plans on which laser location positions are marked (not required)
Duration: minutes	**36**	**20**
Photography	Drawing up a diagram of the functional system on which the locations of taking pictures of the object were marked	Drawing up a diagram of the functional system on which the locations of taking pictures of the object were marked
Duration: minutes	**30**	**30**
Measurement stage 1	The length and width of the object, the rooms inside, the width of the partitions, the height of the window sills, the width and height of the door and window joinery, dimensioning of stairs between storeys, room heights, roof slope angle, structural arrangement of the roof truss (Fig. 2)	Placing the laser scanner first around the building and then entering the inside moving in such a way that the performed scans intersect each other.
Duration: minutes	**540**	**360**
Digitalisation of measurements, stage 1	Based on the manual measurements made, preliminary drawing documentation was prepared using AutoCad software	After the measurements made, single stations were connected to obtain a point cloud to generate ready inputs (projections, elevations, cross-sections, etc.) (Fig. 3.)
Duration: minutes	**600**	**120**
Measurement, stage 2	After transferring the measurements to the CAD format, the drawings were printed in order to mark the degraded places in the building on precise inputs (plaster losses, defects in the masonry structure, salinity, moisture, damage of the roof truss and roofing).	Does not apply
Duration: minutes	**300**	**0**
Digitalisation of measurements, stage 2	Marking the damage in the documentation	The tracing of inputs generated from the point cloud in JPG format in the AutoCad software. Visible in the prepared inputs are the losses, damage, moisture and salinity in the structure of the object, which at this stage are applied to the drawings.
Duration: minutes	**300**	**600**
Measurement, stage 3	Applying additional measurements of missing data from stages 1 and 2	Does not apply
Duration: minutes	**300**	**0**
Digitalisation of measurements, stage 3	After the damage measurements are made and additional measurements of missing data is performed, it is drawn onto the earlier inputs using photographic documentation.	Does not apply
Duration: minutes	**300**	**0**
Printout	Ready CAD files are printed	Ready CAD files are printed
Duration: minutes	**60**	**60**

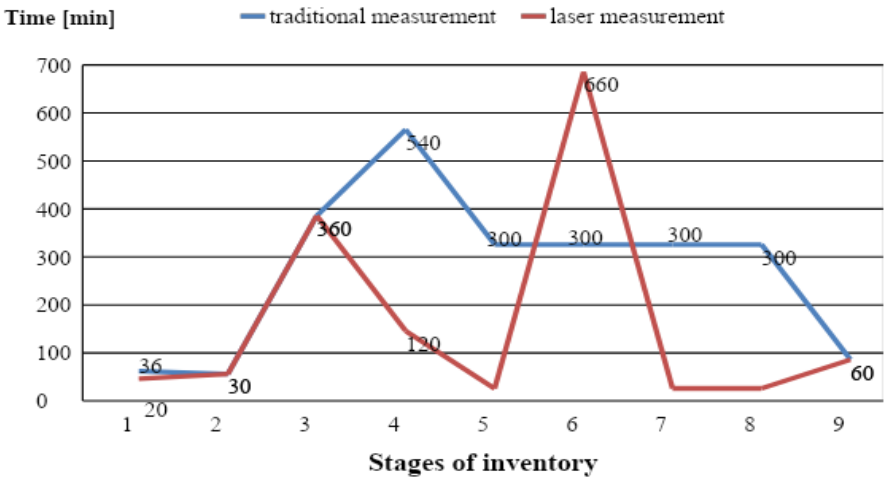


Fig. 6. Diagram of the comparison of the duration of measurements of individual stages - compilation by the author

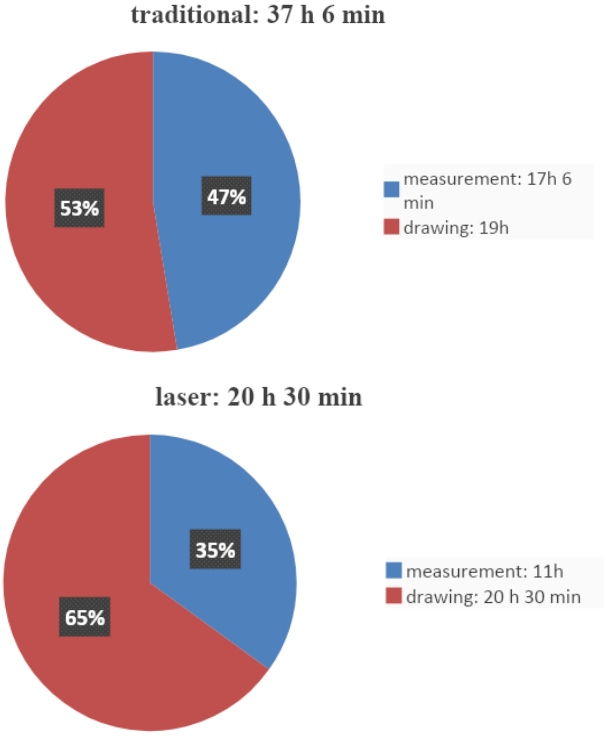


Fig. 7. Percentage comparison of measurement duration with drawing duration - compilation by the author

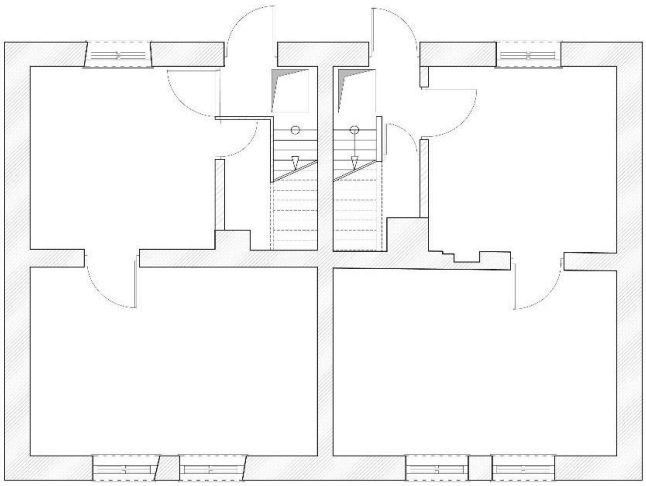


Fig. 8. Object outline based on manual measurement - compilation by author

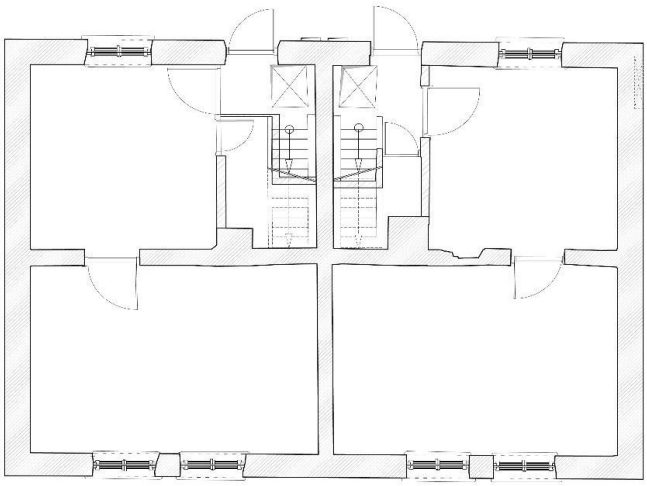


Fig. 9. Object outline based on scanning- compilation by author

5. Conclusions

During laser measurements, a decrease in the time at the measurement and offset stages as well as a shorter time of digitalisation of the measurement data can be noted. This is due to the fact that a single measurement using a 3D scanner allows to obtain the maximum amount of data needed to prepare later documentation in the 2D version. The research on a specific construction object presented in this paper clearly illustrates the advantage of laser inventory over the traditional one. Experience has shown that the difference between the two methods is twice as fast in favor of laser technology. Moreover, the inventories made differ considerably in terms of accuracy. The traditional method produces a much larger measurement error, and thus the accuracy of the drawings is significantly varied. The laser measurement technique allows to obtain a measurement representing the actual state [12], whereas the traditional technique contains a substantial measurement error.

References

[1] Uchański J., Falkowski P., Sörensen L., "The problem of standardization of terrestrial laserscanning techniques for architecture inventory purposes", Archiwum Fotogrametrii, Kartografii i Teledetekcji, vol. 18, 2008, pp. 633-641

[2] Chodorowski F., "Inwentaryzacja architektoniczna od Villarda de Honnecourt do komputerowego wspomagania", in Zeszyty Naukowe Politechniki Białostockiej. Architektura, 1999, Tom Z. 18, p. 79

[3] Boroń A., Borowiec M., Wróbel A., „Rozwój cyfrowej technologii inwentaryzacji obiektów zabytkowych na przykładzie doświadczeń zakładu fotogrametrii i informatyki teledetekcyjnej agh" / „The development of digital technology concerning surveys of heritage objects based on experiences of agh department of photogrammetry and remote sensing informatics", in Archiwum Fotogrametrii, Kartografii i Teledetekcji, Vol. 19, 2009, p. 13

[4] Boroń A., Rzonca A., Wróbel A., „Metody fotogrametrii cyfrowej i skanowania laserowego w inwentaryzacji zabytków" / „The digital photogrammetry and laser scanning methods used for heritage documentation" in Polskie Towarzystwo Informacji Przestrzennej, Roczniki Geomatyki 2007, tom V, zeszyt 8, p.129

[5] Sztwiertnia D., Ochałek A., Tama A. & Lewińska P., "BIM (Heritage Building Information Modell) of The Wang Stave Church in Karpacz (Poland)" – case study, International Journal of Architectural Heritage, 2019. https://doi.org/10.1080/15583058.2019.1645238

[6] Kulig A., Nassery F., Filipowski Sz., Zieliński R., "Wykorzystanie technologii BIM w nowoczesnej inwentaryzacji i analizie zabytków architektury" / "The use of BIM technology in modern methods of inventory and anlysis of architectural monuments", Wiadomości Konserwatorskie (Journal of Heritage Conservation) vol. 42/2015, pp. 39-42.

[7] Gleń P., Krupa K., "The use of secondary build-up in historical fabric based on the donjon of Kłodzko Fortress", E3S Web of Conferences 49, 00031 (2018), Solina 2018, p. 3

[8] Głowienka E., Jankowicz B., Kwoczyńska B., Kuras P., Michałowska K., Mikrut S., Moskal A., Piech I., Strach M., Sroka J., „Fotogrametria i skaning laserowy w modelowaniu 3D" pod redakcją Sławomira Mikruta i Ewy Głowienki, Rzeszów 2015, p. 73

[9] Boroń A., Rzonca A., Wróbel A., „Metody fotogrametrii cyfrowej i skanowania laserowego w inwentaryzacji zabytków" / „The digital photogrammetry and laser scanning methods used for heritage documentation" in Polskie Towarzystwo Informacji Przestrzennej, Roczniki Geomatyki 2007, tom V, zeszyt 8, p. 133.

[10] Filipowski Sz., „Skaning laserowy w inwentaryzacji architektonicznej – stosowane rozwiązania i propozycja udoskonalenia" / „Laser scanning in architectural surveying – popular solutions and proposal for improvement", PUA 1/2018, p. 97.

[11] Lewińska P., Zagórski P., "Creating a 3D database of Svalbard's historical sites: 3D inventory and virtual reconstruction of a mining building at Camp Asbestos", Wedel Jarlsberg Land, Svalbard, Polar Research; ISSN 0800-0395. — 2018 vol. 37 art. no. 1485416, pp. 1-9. https://doi.org/10.1080/17518369.2018.1485416

[12] Remondio F., "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning", Remote Sensing, 2011, vol. 3(6), pp. 1104-1138. https://doi.org/10.3390/rs3061104