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CLASSIFICATION OF DATA CAPTURING AND BUILDING SURVEYING TECHNIQUES IN THE CONTEXT OF SELECTING THE OPTIMAL METHOD OF CREATING 3D BIM AND HBIM MODELS OF EXISTING BUILDINGS

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Abstract

When creating a BIM information model of an existing building, a number of surveying techniques may be applied. The choice of particular technique depends largely on the budget of the investor commissioning the task and, on the specialist, commissioned to do it. Methods of conducting very accurate architectural survey and creating a digital 3D model are still fairly expensive due to the need of using specialist equipment. On the other hand, more common and affordable methods often lack the accuracy in the final model. This paper attempts to present a new classification of data capturing and building surveying techniques for creating 3D BIM models of existing buildings. The authors discuss optimal ways of applying particular methods and combining them so as to reduce the overall cost of the commissioned task and to achieve high accuracy of the final model at the same time. The analysis presented in this paper allows to introduce some order in the methods of creating BIM models of existing buildings by offering a new classification adjusted to standards currently used in architectural surveying.

Keywords: *BIM modelling; Modern architectural survey; Digital surveying methods; Classification of surveying techniques*

Introduction

Architectural survey, the aim of which is creation of a complex BIM or HBIM model may be conducted on the basis of existing archival materials or by means of using various measuring methods [1]. The techniques and tools applied depend to a large extent on the budget of the investor, qualifications of people involved in measurement process, level of complexity and the historical value of the surveyed building. The methods which allow for very precise architectural surveys in the form of a digital model are still fairly expensive due to the need to use specialist equipment. However, some simpler, less expensive and, consequently, more affordable tools may be applied for creating a working model with a lesser degree of accuracy, one which will require more work and time at later stages to become fully complete.

The aim of the article is to develop a current classification of measurement methods in the context of BIM modeling of existing and historic buildings. The classification takes into account the latest available technologies and devices used for precise digital registration. The article also presents future directions for the development of measurement techniques. The authors of this article present a new classification showing methods of data capturing and survey measurements

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in the context of using this data to create BIM digital models of existing buildings and particularly in reference to digital models of historical buildings (HBIM). The suggested division of survey techniques results to a large extent from the professional experience gained by the authors when dealing with buildings of varying degrees of complexity and being under various types of conservation protection. The classification presented below is intended to help when having to choose the most appropriate tools which will allow for optimal application of equipment and software and, consequently, lower the cost of the surveying process while maintaining the required accuracy of the final model.

Current State of Research and Research Methods

Research Methods

The main research method apart from comparative analyses and drawing on the available bibliography on the subject was taking advantage of the professional experience of the authors [2]. When selecting professional literature, it was important to expand knowledge related to topics such as laser measurements of buildings, heritage BIM, and the application of BIM in existing structures. Due to the rapid development of laser scanning and other modern measurement methods, the authors paid attention to research materials from the past few years.

The main interest focused on the issues related to the survey of existing and historical buildings. The authors conducted measurements of buildings of various sizes, displaying varying degrees of complexity and being under various forms of conservatory protection (among others, complex of historical buildings in Oświęcim, the facade of Łobzów Palace in Kraków, modernist Polskarob office building in Gdynia). Additionally, it was decided to take advantage of the cooperation with other architectural design offices specializing in laser scanning methods and structural engineers. The experience gained as a result of applying various techniques of architectural surveying has facilitated greatly the creation of the classification presented below. It should be pointed out here that the previously mentioned buildings were in everyday use and the created information models will be used in further design and modernization works. The article references examples of buildings with varying scales of complexity and size, whose documentation was developed during the authors' professional practice. In the research analysis, the authors considered parameters such as the age of the building, the level of complexity of the structure, the number of details, and the surface area.

Current State of Research

In 2009 U.S. agency General Services Administration published a coursebook entitled GSA Guide to Building Information Modeling [3], in which technologies of 3D imaging were presented. The book contains a detailed description of creating a model thanks to using laser scanning and a brief yet very important comparative analysis of traditional technologies. The authors point out numerous factors that influence the decision behind choosing a particular architectural survey technique for creating o model of an existing building. A list of factors begins with the specific requirements of the investor and they include such things as the level of detailing of the model, requested resolution and degree of permissible inaccuracies in relation to the actual state of the building. Furthermore, it was concluded that high cost of very accurate scanning influences largely the choice of methods and measuring tools. At the same time attention was drawn to the potential wide range of applications for using point clouds during later stages of design work as well as during the everyday use of the building. The authors believe that the possibility of utilizing the effects of the scanning for building maintenance and for preparation of installation plans in the future should be taken into consideration when calculating the measurements costs. The book also gives an observation regarding uncomplicated buildings with simple structures. The authors believe that "For jobs involving simple geometries and readily accessible work sites, 3D imaging systems may not be the best choice. However, even if the alternative is less costly, 3D imaging may still be a better alternative depending on the expected use of the information" [3].

This very sentence suggests that not every BIM model has to be created on the basis of a cloud point and the decision lies with the investor and the contractor commissioned for the task. This concerns in particular buildings displaying rather simple, repetitive structure and uncomplicated architectural form.

In 2008 Yusuf Arayici and Joseph Tah were one of the first to present the application of laser scanning in BIM modelling. In their publication the authors analyse a case study of revitalization project of a residential building [4]. The model was created using Microstation Triforma program on the basis of a point cloud generated by Riegl LMS Z210 scanner. Polyworks IMEdit was used in the recording process and the final effect was recorded in IFC format. Arayici and Tah offered a full workflow analysis of the scanning, beginning with the appropriate positioning of a point cloud in x, y, z coordinate system, then generating cross-sections and finally arriving at creating a 3D model. Similarly to the authors of GSA Guide, Yusuf Arayici and Joseph Tah emphasize a wide range of possible applications of point clouds in various types of simulations, monitoring and integration with GIS systems, even in registering and analysing the effects of natural disasters or construction disasters.

The issue of classifying measuring methods used in creating BIM models has also been discussed in literature on this subject. Nouha Hichri and others in their publication *From Point Cloud to BIM: A Survey of Existing Approaches* postulated dividing data capturing techniques into three categories: topometric, photogrammetric and lasergrammetric [5]. In the first group the authors decided to include methods based on a traditional angle measurement pointing out the fact that despite being very accurate, they may be too time-consuming and uneconomical when dealing with more complex structures. By contrast, photogrammetry is a much faster method while lacking high precision and accuracy. In the context of building BIM models, the authors consider lasergrammetric methods (laser scanning) as the most effective ones pointing out, however, that the process of integrating point clouds is fairly complicated. At the same time the authors emphasize advantages resulting from combining various measuring methods and decribing such approach as 'hybrid'.

It has to be mentioned, however, that since the time of publication of the above study considerable technological progress has taken place. Contemporary laser scanners often feature the function of preliminary registration of the generated point cloud while conducting the measurements.

Another classification of measuring techniques has been suggested by Rebekka Volk and others in their *Building Information Modeling (BIM) for existing buildings – Literature review and future needs* [6]. The authors postulate the main division into contact and non-contact techniques (Fig. 1). The first group comprises image analysis, non-contact methods using barcodes or RFID systems (Radio-Frequency Identification), analysis of preexisting documentation (drawings, photographs) as well as using GPS data (Global Positioning System). Image-based techniques include photogrammetry and videogrammetry, whereas the group of range-based techniques includes scanning and laser measuring. The contact methods included measurements conducted using traditional tools such as measuring tape or laser rangefinders. The authors also point out the main considerations when choosing a particular measuring techinque, which include the overall cost, time, degree of detailing and accuracy of the digital model and the environmental conditions during the measuring process (such as lighting, the weather and surrounding vegetation or even if the place was cluttered or not).

The authors also conclude that 'it is a common practice to combine various measuring techniques in order to eliminate drawbacks that each of them may have.' Both of the above-mentioned classification attempts date back to almost a decade ago and therefore the authors of this article have decided to review and update a list of the currently used measuring methods and suggest a new division that reflects the choice that we have when conducting architectural building survey to create its BIM model. It is particularly relevant when dealing with historical buildings (HBIM models) as with such buildings more complex and multi-factor analysis of their structure may be required.

It has to be pointed out here that one of the major problems encountered during the measurement process is capturing all necessary information to create a functional BIM information model. According to Jennifer McArthur, irrespective of measuring technique applied, it is hard to avoid some degree of uncertainty regarding the accuracy of the data captured during the surveying process. Even with very careful and detailed onsite work, there is still a risk of human error. McArthur believes that when managing uncertain data in BIM models there are three possible approaches: verification, acceptance and avoidance [7].

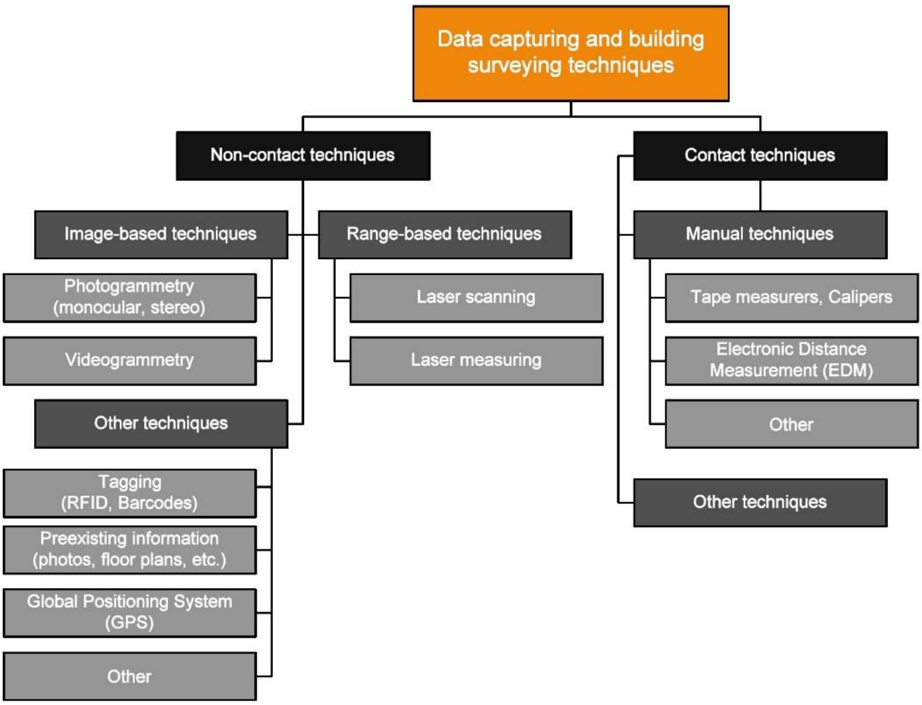


Fig. 1. Review of techniques of obtaining data and measuring to create BIM models, based on: [6]

The first method – verification – is based on direct onsite verification of all the data that is unclear or unknown. This is by far the most expensive but also the safest method – with the lowest margin of error. The acceptance method is based on making individual estimates of the accuracy of the information expressed in percentage. A good example here could be excavating foundations on one side of a building and then making a 50% probability estimation of the positioning of the opposite wall. It should be assumed that when using this method, the data which is below a certain level of probability will not be entered into the digital model. The third method, i.e. avoiding the verification of uncertain data, is clearly the cheapest solution. There exists, however, a considerable risk of making an error which is likely to influence the coherence of the model and which will no longer reflect faithfully the actual state of a building.

Results and Discussion

To begin with, a classification of the architectural surveying techniques used to create BIM models was proposed. Thus, after analyzing the specialized literature and based on their own experience, the authors of this study propose the introduction of a new classification, which divides the techniques/methods used in architectural lifting into two categories: basic techniques and additional ones (Fig. 2).

The adopted division illustrates the options for the designers are given and have to choose from while working on a particular building. It has to be mentioned here that some methods were included in both groups (e.g. laser manual measurement). The supplementary techniques group was further subdivided into traditional (manual) techniques, which are more affordable and accessible and automated techniques, which usually require hiring external professionals. Using supplementary techniques is practically indispensable because none of the methods on its own, as shown in the publications mentioned above, can provide all the necessary data for creating a BIM model of a building. One of the examples could be laser scanning. Although it is a very precise method of measurement and a source of great deal of data regarding external geometry (e.g. dividing walls, interior elements and features), it does not provide any information on types of materials used, their layers or internal structure of a building. The missing information has to be completed by resorting to another technique (e.g. analysis of archival materials or onsite exposures)

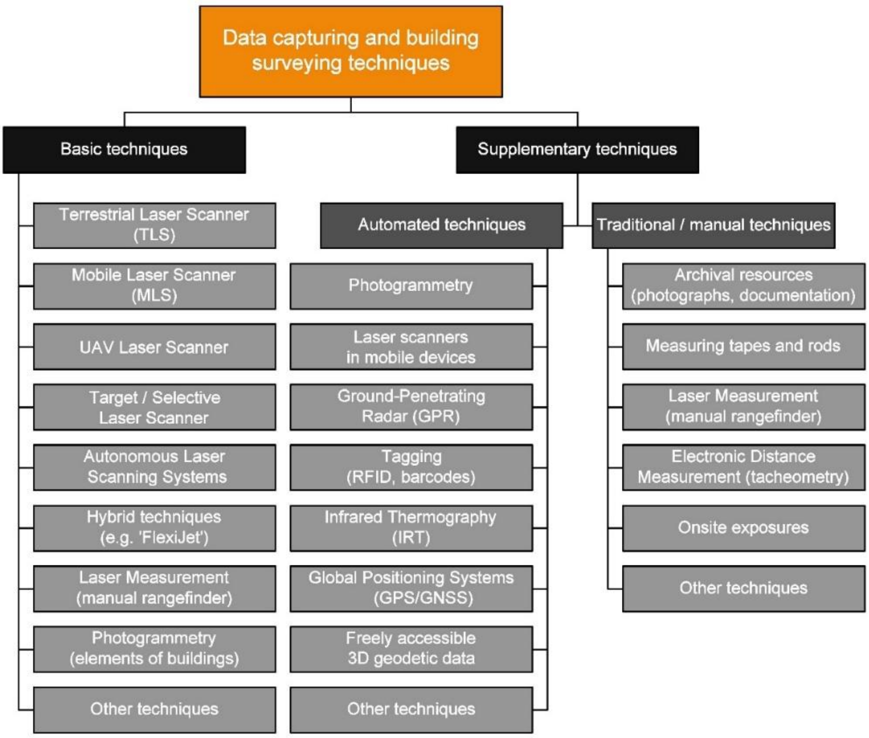


Fig. 2. Review of techniques of obtaining data and measuring to create BIM models

Basic techniques

One of the more frequently used methods used in architectural surveys of buildings is the method of *manual laser measurement* with laser rangefinder. Despite a very intensive development and widespread use of laser scanning, manual measurement still remains one of the most accessible methods of architectural survey and one that guarantees high accuracy of a single measurement. One of the major drawbacks of this method, however, is having to draw manual survey sketches which only later become digitilized and lack of possibility to merge spatially particular measurements. For this reason, this method is applied mainly in the case of smaller buildings with fairly simple shapes and also as a supplementary technique.

Laser scanning is particularly useful in historical buildings and details or modern buildings with complex structure and form. An example is the building of the Palace in Łobzów, which, after many reconstructions, gained its final form in the 19th century. The building can be classified as complex due to its architectural details and 110 m long façade. Such objects often feature a large number of details and complicated spatial structures and therefore conducting an architectural survey using traditional methods would be either impossible or it would mean having to repeat measuremnts many times (Fig. 3). Furthermore, the obtained data would have to be first recorded or provided with sketches and later begin creating a 3D model. Historical objects are frequently complicated when it comes to the geometry of structural partition elements. The walls of rooms may not be positioned at the right angles and the thickness of the partition walls may also vary throughout the length of one such wall. All these factors contribute to the fact that in this type of buildings laser scanning and the resultant point cloud is the only method of obtaining information for creating a 3D model, which would be very precise (with accuracy of up to ca. ± 5 mm with larger objects), time-efficient and providing relatively easy material for modelling (after appropriately conducted process of merging individual scans and optimalization).

Fig. 3. The laser scan of the historic architectural detail, Łobzowski Palace, Kraków.
The point cloud was registered, simplified and imported into the architectural software ArchiCAD

Creating BIM models based on point clouds is becoming more and more popular with researchers [8-12] and designers One example of the application of such computer techniques can be found in the model of a tenement house created during the student workshops at the Cracow University of Technology (Heritage in Progress) held in 2020-2021. The Renaissance building, which currently houses part of the Faculty of Architecture, is characterized by a complex form with a large number of details, various types of vaults, and a complicated functional layout. Despite its relatively small area (4000m²), creating a BIM model was technically challenging (Fig. 4). Also, the number of firms on the market which offer their scanning and modelling services is growing. Another thing worth noting is the rapid progress in technological advancement of scanners and their additional features. Infrared cameras integrated with measuring devices allow to formulate conclusions regarding the structure and technical condition of dividing structural elements and [13]. GNSS modules, which have become standard nowadays, not only allow a precise location of the device on site, but also support effectively the process of recording cloud points. It is worth mentioning in this context devices, which thanks to being fitted with their own computational module, carry out this process automatically already at the stage of conducting measurements. Modern scanners are less affected by unfavorable weather conditions or green vegetation surrounding the surveyed buildings. Partial penetration through the vegetation and conducting measurements in adverse weather conditions such as rain or fog [14] is possible now in ground devices thanks to applying the technology of laser beam splitters already known from airborne laser scanners.

Fig. 4. HBIM model of the building in ul. Kanonicza 1 in Kraków, the seat of the Chair of History of Architecture and Monument Preservation at the Faculty of Architecture of PK (Cracow University of Technology), created on the basis of architectural survey conducted using laser scanning (prepared by Anna Marek, Piotr Pikulski)

In case of buildings with poor accessibility, resorting to drones (UAV – Unmanned Aerial Vehicle) proves very useful. Their application in *photogrammetry* has been widely discussed in literature [15–17], but there also exist laser scanners which can be mounted on various types of aerial vehicles [18] or they form integrated solutions for UAV scanning [19]. Apart from measuring objects which are difficult to access, these devices offer a wide range of possibilities when it comes to automatization of the scanning process. It is possible to plan the sequence of measurements, which are conducted automatically by the device (similarly to scanners mounted on robots working on the ground). Laser scanners mounted on both drones and planes are also used in finding and measuring objects hidden in thick vegetation [20] or when looking for traces of historical events [21].

Manual mobile scanners constitute another group of devices, which have evolved intensively recently. A distinction has to be made here, however, from scanning modules which appear in mobile devices used in everyday situations (they have been described below in the group of supplementary techniques). Professional scanners differ substantially when it comes to measuring accuracy as they use more advanced algorithms analysing the points captured earlier and comparing them with the following scans in real time. One of such technologies is SLAM (Simultaneous Localization and Mapping) which is based on detecting orientation points and tracking their localization in consecutive measurement frames [22]. Scanners of this type are becoming more and more accessible on the market [23, 24] and are suitable for architectural measurements in which very high precision is not always necessary.

The solution which combines the two previously mentioned techniques and which might well be the future of architectural surveying is *autonomous scanning*. It is based on combining a laser scanner (mobile or stationery) with a robot that follows a predefined route. Currently different configurations of these types of devices are being tested, which use both ground-operated devices and drones as carriers [25]. Experimental prototypes are also being tested on historical buildings [26]. Thanks to such solutions the participation of a human being in the measuring process could be minimized as the device, having completed the predefined route, could automatically send the merged point cloud to the design office server. Another advantage of autonomous scanning is the possibility of conducting measurements in buildings which are used intensively throughout the day (measurements can be contucted outside regular working hours). All that has to be done is to set the time when a robot is supposed to begin its measurement operations. A very interesting example showing autonomous scanning, which can be found on the Internet, is the testing of Faro and Riegl scanners mounted on a quadruped robot produced by Boston Dynamics [27].

Before autonomous scanning became a commonly used technique, however, it is worth mentioning the existence of devices which could be called *hybrids*. They combine the advantages of laser scanning, as they operate in an automated way, but they generate less measurement data and they are more accessible. A good example of such a device is FlexiJet laser tachometer. Its greatest advantage is the possibility to export directly each measurement to appropriate engineering software and to the tools connected to it. The points measured manually are recreated in digital 3D environment. The measurements can be interpreted by the user as BIM objects, e.g. walls, beams or windows. Therefore, the process of creating a BIM model is semi-automatic, the preliminary model is already created at the stage of conducting measurements. The effects and methodology of using FlexiJet tachometer have been discussed in, among others, publications by Anna Kulig, Farid Nasser, Szymon Filipowski, Rafał Zieliński and Maciej Wójtowicz [11, 28, 29]. Based on the practical application of this device by the authors it can be concluded that it is especially useful with simple buildings with repetitive geometry or historical buildings with uncomplicated architectural details and geometry.

Another example of a hybrid technique is targeting scanning. Architect Szymon Filipowski from the Chair of Descriptive Geometry and Digital Technologies at the Faculty of Architecture of Cracow Technological University devised a type of laser scanner for conducting specifically architectural measurements. The device produces ready contours of rooms which are recorded in dxf format (the device is protected by patent P224847 covering the method of conducting measurement and shape recognition). It is equipped with technologically advanced functions such as automatic shape recognition and creating contours while measuring. As for the method of obtaining data, some analogies to traditional methods of conducting architectural surveys can be noticed, yet in the case of Szymon Filipowski's scanning device the extracted information from a surveyed location is fully digitalized and provides greater precision in shorter period of time. So, this measuring tool can be described as a sort of hybrid device optimized for the needs of conducting an architectural survey as it combines precision and fastness of laser scanning with no overload of information data typical of traditional methods.

Supplementary techniques – traditional (manual)

The starting point for conducting an architectural survey is usually conducting *search and analysis of archival materials*. The availability of archival records depends to a large extent on the age of the building, its function and also, very frequently, on its legal status. These materials are available in most cases in paper form and do not always reflect the actual state of the building.

This means that conducting architectural and installation surveys is necessary during each investment task related to project documentation. This is a costly process which slows down the design stage of an investment. Despite their varying quality, archival materials constitute nevertheless a very valuable source of information for architects and designers and may have considerable influence on their decisions. Furthemore, in the case of historical buildings a thorough search of archival records should be one of the main elements at the preliminary stage of designing due to the aspect of legal conservation protection.

Resorting to *onsite exposures* is the most common way of verifying archival records. It is a fast and inexpensive way of verifying the inner structure of dividing structural elements in a building. Appropriate entering of material types and layers into a BIM model is of crucial importance when it comes to its future usefulness at the stage of planning renovation works as well as in the context of current maintenance of a building. A good example of using onsite exposures and the analysis of historical records for the purpose of verifying conducted measurements is the surveying (conducted in 2016) of an army barracks building no. 27, built in 1942 in Oświęcim (945 m^2). It is located within the parameters of the former Nazi KL Auschwitz Concentration Camp (Michał Banasik, Maciej Wójtowicz and Rafał Zieliński were the authors of this 2016 renovation project). In this case archival records proved to be an extremely valuable source of information. The search and analysis of documents in the Archives of Auschwitz-Birkenau Museum (APMA-B) complemented greatly the information gained during the measurement process (Fig. 5) and provided detailed information on the damage sustained by the studied building, which were the result of war activities (case study described in detail in [29]).

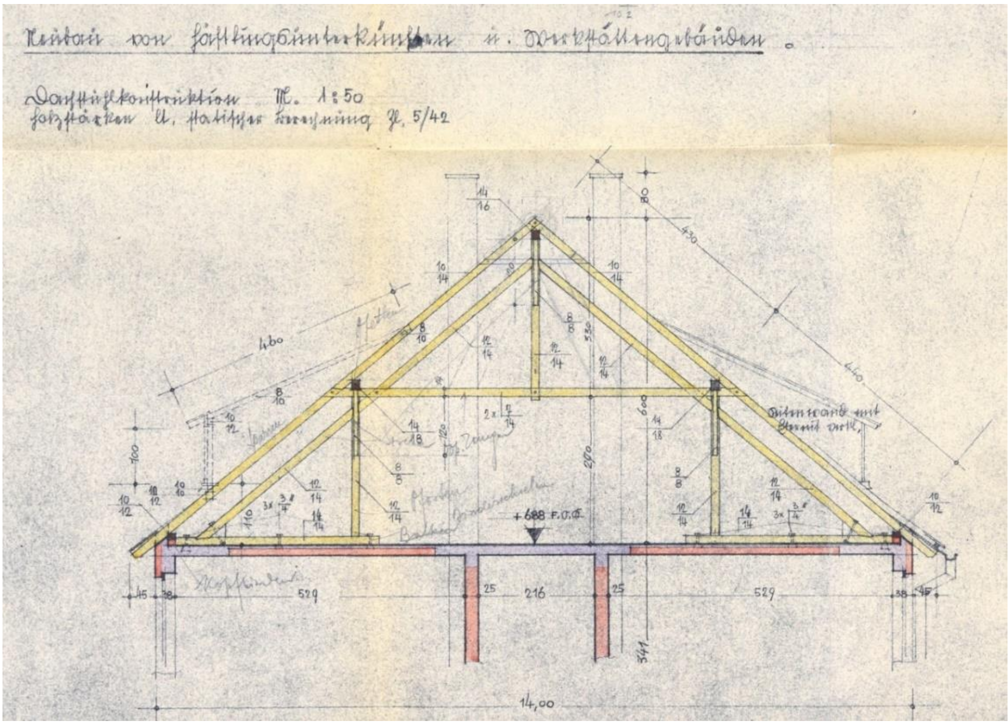


Fig. 5. Scan of the original cross-section of timber roof truss, typical of the buildings in Lagererweiterung area; worth noting is remarkable precision of the drawing including colour-coding of construction materials: yellow – timber, red – ceramics, grey – concrete and ferroconcrete; source: APMA–B.

One of the supplementary techniques that has already been mentioned (see: Basic techniques, figure 2) is *manual laser measurement*. The method relies on obtaining firstly the general geometry of the building and its characteristic parameters by using tools which allow precise relocation (e.g. *geodetic surveying* using a traditional tacheometer). Then these measurements are complemented with precise measurements conducted with manual devices. This method proves to be a good solution for objects with repetitive and ucomplicated geometry because frequent repositioning of tools and devices is not necessary in such cases. As for measuring smaller elements of the building, interior features and installations (e.g. jambs, windowsills and ventilation shafts) a traditional measuring tape appears to be the best choice.

It is worth mentioning that manual laser measuring is used less and less frequently as a basic surveying technique of existing objects and therefore the authors included it in the group of supplementary techniques. It still happens, however, that with buildings which have uncomplicated form and when less costly methods of conducting measurements are recommended, architectural surveying is done using laser rangefinders only. One has to remember that in such situation creating a BIM model is also possible. This can be achieved using equipment which is compatible with software which records all the measurements and tranfers them immediately to a digital environment. In this way ready images are generated which can later be edited in BIM modelling programs. The picture below is of a simple commercial building with retail and service function on ul. Marcika 14a in Kraków (Fig. 6) may serve as a good example of conducting architectural survey using this very technique. The building, classified as a low-complexity structure, was constructed in the 1970s and was intended as a production hall for fittings – an inventory was prepared for its demolition plan.

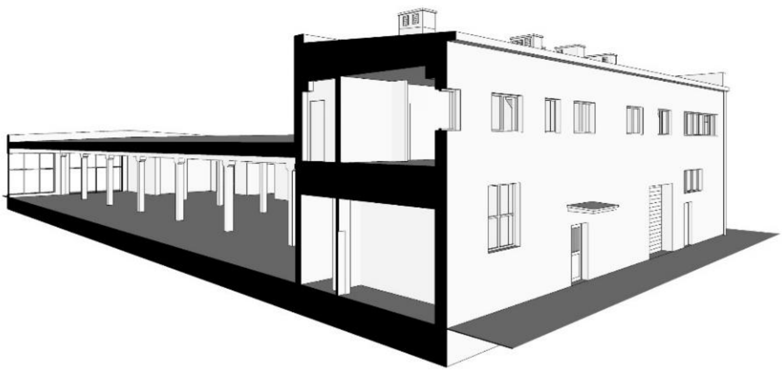


Fig. 6. Architectural survey of a commercial building on ul. Marcika 14a in Kraków conducted with a laser rangefinder and software which enables transferring measurements to BIM model

Supplementary techniques – automated

One of the more frequently used supplementary techniques is *photogrammetry*. While creating an information model, the technique is based on generating a point cloud from a series of photographs of a given architectural object which were taken at different angles. This process can be automated thanks to using appropriate software, such as Agisoft Metashape. One of the advantages of this technique is the possibility of generating colourful point clouds, which can be very useful during the later stages of working on the model (e.g. when verifying the technical state of construction materials or separators). Photogrammetry is less expensive than laser scanning, but it is also less accurate. Another problem is precise merging of particular clouds in space (the so-called process of recording). It is especially noticeable while conducting the surveys of the interior of buildings, when a well-organized process of repositioning and marking particular measuring points is very important.

One of the applications of photogrammetry used as a supplementary technique is the creation of the so-called inspection models, which are often used to monitor progress of construction works. This method, described by Sebastian Tuttas, Alexander Braun, André Borrmann and Uwe Stilla [30], involves taking a series of photographs of a current stage of construction works and generating point clouds based on them. This material is then compared with the project design BIM model of the object under construction. This analysis allows us to establish the actual progress of construction works. It needs to be mentioned here that for this type of applications laser scanning [31] and automated laser total stations are often used; they are equipped with software which is integrated with BIM models [32].

GPR (Ground-Penetrating Radar) technology is another supplementary technique used for creating BIM models of existing buildings which has been singled out by the Authors. The operating principle of GPRs is fairly simple. These devices emit high-frequency radio signals and measure the time needed for the signal to be reflected by an object and registered back by the receiver. In *BIM for Existing Buildings: Potential Opportunities and Barriers* two ways of using this method were described, one of which is surveying underground infrastructure [33]. The information regarding the network of underground installations is crucial at the stage of conducting survey of the area surrounding an existing structure. It is not uncommon that positioning of underground objects differs considerably from what is shown in plans and documentation used for design purposes. GPRs may also help to reveal some other structural objects such as, for example, ruins, shelters, bunkers or drains. This information is not only vital when designing installation routes outside the building, but also when estimating engineering costs involved in potential dismantling of the building and managing earth masses. GPR technology may be applied successfully in surveying historical buildings. Such application was presented by Fabian Welc, Kamil Rabiega, Izabella Brzostowska and Adam Wagner on the example of the remains of the castle in Wyszyna [34]. The authors of the study proved that, despite some interference caused by the debris buried underground, the GPR method was a successful non-destructive way of surveying historical architecture which remains hidden underground. It is worth mentioning that the authors combined GPR surveying with research of archival materials and formulated conclusions based on comparative analyses of both sources.

One of the so-called NDT (Non-Destructive Testing) techniques used in architectural survey is *IRT (Infrared Thermography).* The tremendous usefulness of this technology in relation to existing buildings was pointed out by Norbert Szmolke in his publication *Diagnostyka obiektów z wykorzystaniem kamery termowizyjnej* [35]. The author presents advantages of using this method, notably fastness and the non-destructive nature of this testing method, yet he concludes by saying that IRT testing should constitute one element of a more comprehensive process of diagnostic survey of buildings.

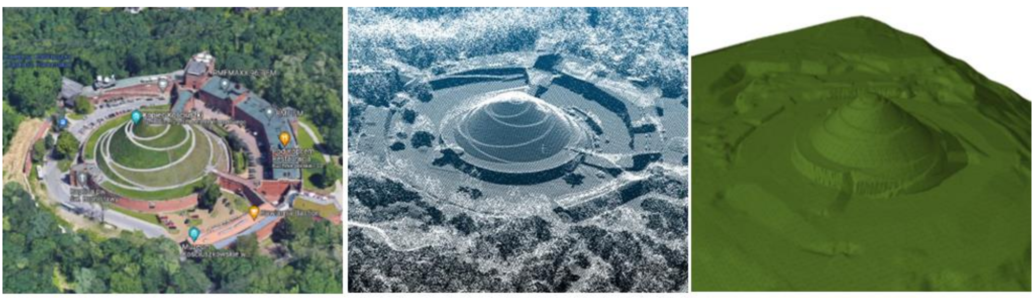
As for the application pf IRT technology in BIM models, it may be used in non-destructive testing of building materials thermal conductivity [36]. This is absolutely crucial information in the context of constructing 3D energy performance models, especially for buildings which are being renovated and modernized.

Another example showing the application of infrared thermography in historical buildings is the survey works conducted in the Baroque-style Church of Annunciation in Sessa Aurunca (built in the late 15th century), which was presented in *Architectural Survey Techniques for Degradation Diagnostics* [37]. This case study presents the application of several architectural survey techniques. The first one is laser scanning, which allows for obtaining 3D reflection of the interior of the whole church in the form of a point cloud. During one of the stages of the survey process, a careful analysis of the point cloud allowed us to detect a problem with dampness of the main dome of the church. In order to enhance the accuracy of the obtained measurements, two separate photogrammetric tests were conducted: one from the ground level and another one using unmanned aerial vehicle (UAV). The images were then transformed using Agisoft Metashape software into thick, colourful point clouds. The next step involved using infrared thermography to identify construction materials used, inhomogeneities in finishing layers, presence of dampness and thermal bridges. The results of all measurements were compiled creating in this way a complete picture of the technical state of the structure.

In conclusion the authors observe that an integrated approach based on combining together various techniques of architectural survey is very valuable as it allows us to fill in information gaps related to each technique. Laser scanning and photogrammetry allows for obtaining precise geometric reflection of studied buildings and thanks to infrared thermography a surface thermal map of the structure can be created. Consequently, it is possible to detect anomalies resulting from structure degradation, which are not visible on the surface. At the same time an integrated point cloud is created, with every element carrying information not only about its geometric location, but also a specific colour.

Among methods of obtaining data for constructing BIM models Rebekka Volk and others [6] mention also *global positining system* (GPS) which constitutes part of global navigation satellite systems (GNSS) together with Russian GLONASS (Globalnaia Navigacionnaia Sputnikova Sistema), European Galileo, Chinese BeiDou and Japanese QZSS (Quasi Zenit Satellite System). This technology on its own does not play a role in the process of architectural survey, yet it constitutes a key element in numerous devices and processes in which measuring data is generated. Modern total stations use GPS/GNSS and by supplying land surveying reports they support the process of registering point clouds and, consequently, support creation of BIM models. Also, modern laser scanners rely directly on GPS/GNSS systems during the initial process of recording scans at the stage coonducting measurements. Thanks to this solution the merged point clouds can be retrieved from the memory of the scanning device, which reduces considerably time needed for editing the data.

The issue of global positioning systems is also related to geographic information systems (GIS). During the process of conducting an architectural survey, this technology proves to be very useful when modelling the surroundings of existing buildings. The range of possibilities and using open geographical databases, including the ones with 3D information, is becoming wider and wider. One of such possibilities is free access to digital models of terrain based on airborne laser scanning (ALS) and accessible to everyone via Polish Geoportal [38]. Geoportal offers two types of digital models: elevation models and surface models. Both types of models are point clouds based on a 1.0 x 1.0 metre mesh. It is worth pointing out here that BIM software not only makes it possible to download this type of file but also to interpret and convert automatically the data into the parametric elements of a 3D model (Fig. 7).



a b c

Fig. 7. a. Bird's eye view – Kościuszko Mound built in 1822-23 in Kraków (source: https://www.google.pl/maps); b. Digital elevation model of the terrain - Kościuszko Mound in Kraków (source: www.geoportal.gov.pl); c. 3D model created in ArchiCAD software based on the digital surface model (prepared by the Authors)

Among supplementary techniques *mobile devices equipped with a laser scanning module* are particularly worth mentioning (iPhones 12 PRO and some of iPad's PRO produced from 2020). Their advantage is the low price considering the range of functions they offer. Inadequate measuring precision does not make it possible to include them in the group of basic techniques

(Fig. 8), yet they are very useful for creating control point clouds and supporting manual laser measurements. It is worth pointing out here that in this type of device the way of conducting scanning process is of crucial importance. The smoother the workflow of the scanner, the greater the ultimate precision of the conducted measurement. Users also seem to be in agreement that fitting the device with a stabilizator enhances considerably the accuracy of the generated point cloud.

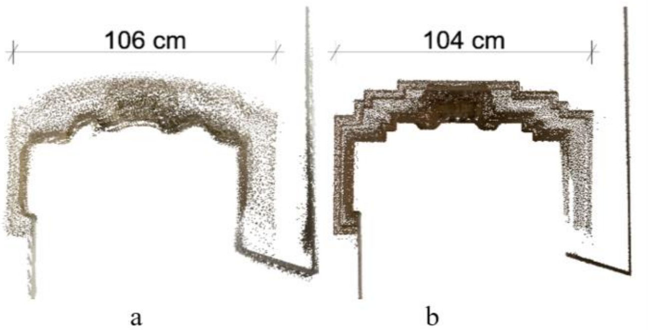


Fig. 8. Historic architectural detail, Łobzowski Palace, Kraków. Comparison of data obtained from laser scanning (b) and mobile device equipped with a laser scanning module (a). The difference in precision is noticeable

Conclusions

The Authors of this article believe that current study works and publications regarding methods of conducting architectural surveys of buildings and their subsequent digitalization in the form of BIM models need to be complemented with a new classification which would reflect the rapidly changing situation on the market of new technologies.

The suggested classification allows to organize clearly measuring methods used for creating architectural 3D BIM models of existing buildings. The proposed division of techniques facilitates the choice of a particular architectural survey task. This division results from the need for preparing more and more precise survey documentation (particularly in case of historical buildings or the ones with very complex forms) and also from the fact that advanced measurement techniques (e.g. laser scanning or photogrammetry) are becoming more and more accessible for medium-size and small companies and investors. This is the result of rapid technological progress and the fact that using specialist tools and software has become more affordable.

From the above analysis it transpires that in the context of BIM modelling the main (basic) method of aggregating data should be adjusted primarily to the type of the building and the character of the requested order. It has to be remembered, however, that none of the techniques, when used alone, can provide us with all necessary data required for building a model of an existing structure. In a number of publications quoted in this analysis the Authors emphasize the importance of combining various measuring techniques in order to minimize or eliminate the shortcomings of each of them.

Laser scanning constitutes nowadays the basis for creating BIM models of existing buildings while remaining still a relatively expensive method (e.g. when compared with traditional methods or photogrammetry). Laser scanning proves to be very successful when dealing with historical buildings. When it comes to buildings with simpler structure and form, it is possible to use less expensive techniques combined with proper verification of data obtained thanks to the application of supplementary methods. With less complicated buildings a laser rangefinder can be applied successfully as the accuracy of measurements is sufficient enough for creating a digital model. Precise external dimensions of an object can be obtained by means of surveying its characteristic points using tacheometry techniques and reliable information regarding, for instance, horizontal and vertical dividing structural elements can be recreated in a model thanks to the information gathered from onsite exposures. Hybrid methods are also worth mentioning here as they are very precise and generate a smaller amount of preliminary data when compared with laser scanning.

It is also worth mentioning that research and academic institutions seem to be focusing on developing autonomous measuring systems combined with mobile scanning technology.

In the context of creating BIM models, it is also important not to forget about the information content of the surveyed object while focusing on the geometry of the building. The information content is supposed to serve as a data base of the building – about its construction structure, interior features and technical condition the building is in. In each case this data base will constitute a different set of information. In some cases, it will have only a supporting character in a design process, but principally it should reflect the needs of the user of the building. In that case the diversification of the information content follows the regulations of ISO 19650 norm [38], which defines EIR (Exchange Information Requirements) for every construction investment as a set of three project requirements: OIR (Organizational Information Requirements), PIR (Project Information Requirements) and AIR (Asset Information Requirements). In this context it is necessary to choose individually a particular method of obtaining data taking into consideration the user's needs, available budget and the general characteristics of the building.

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