Safety in measurement activities of buildings done with different methods and equipment

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Abstract. In this chapter, methods and measurement equipment was described, which have been used by man since the beginning of history. Their accuracy and minuteness depend on the needs and goals of making measurements and the advancement of technology at the disposal of a user. The paper focuses mainly on the most modern method of building measurement i.e. laser scanning. A different aspect of making measurements with a scanning device and the principles of its safe use were presented. Building measurement activities are always connected with the risk of an accident, especially of falling from a height. The 3D laser scanner eliminates this problem, and additionally, we get a result which surpasses the accuracy of other described methods.

1. Introduction
Buildings that we find in our surroundings are diverse in their geometry, shape, cubature or details. There are these older and those younger, these more handsome and those less interesting. Yet, each element of infrastructure and terrain is physically measurable, the only problem is to apply an appropriate method and instrument to make it possible. A stocktaking of a building is one of the activities which enable to learn about its measurements, surface or cubature. Additionally, this activity provides a re-created building documentation, which is indispensable for making repairs or modernization of a building. Collecting data on a building may be done with different methods, with the aid of less or more technologically advanced devices. But measurements in situ are usually labour-intensive and time-consuming and moreover, they are connected with doing dangerous activities which may lead to a work accident. A choice of an appropriate method may influence not only the time and accuracy of obtained results, but also the safety of measurement activities.

2. Buildings inventory methods throughout history
Since the dawn of mankind, people have tried to measure everything that they have found in their environment, and thus, the notion of measurement has come into existence. In their effort to communicate what they have meant, people have still invented new samples and references, which have resulted in a better understanding of their message. The most frequently used devices were those easily available. Hence cubits were lain, steps were added up and in this most simple way, a length was measured. For example, the Sumerians used the length of a finger as the smallest measurement unit, then a palm, a foot, four fingers or a cubit. A distance was determined as the number of days needed to travel it, and as the weight units, they used talents equal to ca. 30 kilograms. The ancient
Greeks measured objects by comparing them to the human body parts. Before the 7th century BC, these units, independent to each other, were unified. As the basic unit, the length of a foot was applied, which was divided into four width of a palm and sixteen widths of a finger.

In ancient Egypt, the basic unit was a cubit. Its length was determined from the elbow to the tips of fingers and it was divided into 2.5 feet. It is an interesting fact that a separate cubit was used for measuring fabric, it was so-called weaver’s cubit – presently 0.385m. In the case when a foot proved to be too little to determine a given measurement, its increments and so e.g. 600 feet were described as a distance which could be run with a maximal speed without a rest, whereas after 100 feet oxen should be given a rest during work.

Thus, the development of measuring techniques was a significant achievement of the ancient civilizations. However, in the course of time, the needs arise for more advanced measurement methods, which would enable to delineate a localization of a stronghold or a course of defensive walls. The development of exact sciences helped in this, i.e. mathematics and astronomy. As the time went by, people started to accept more and more new matters, other designations that were useful in the everyday life. But customs and norms accepted in one part of the world were not necessarily identical to those common on the different geographic latitude. Therefore, more universal models were accepted [1]. Hence, people began to use measurement methods, which simplifies a layout of buildings and a preparation of design drawings.

In the Middle Ages, the most commonly used methods were geometric methods ad quadratum and ad triangulum. Thanks to them, the work was done on paper, parchment, a board and directly on a building site, where projections, facades and details were drawn most often, and very seldom cross-sections as well. Those plans did not have any scale, but only proportions. In the initial stage of a drawing, a geometric lattice was made by drawing a few squares, and to obtain an octagon, a square was drawn in a square turned by 45°. In such a way, an architectural plan of a building, in which the wall thickness was not included, was made. All the lines were of the same thickness, even windows and details in designs of facades.

The next stage was a localization of a building in a parcel. The geometric method was applied here, too. The square lattice and the building plan had to be proportionally enlarged. The work was initiated by finding a centre, which was marked with a stake, delineating the north-south axis, thanks to a compass with a degree calibration, and then the perpendicular to that axis. After determining these two axes, parallel lines were delineated in both directions with poles, steel squares and plumb lines. A string attached to a nail was a tool to draw a circle, used also today on building sites. For measurements, compasses, dioptometers with sights and two vanes as well as strings and measurement sticks were used (Figure 1) [2].

At the beginning of the 17th century, the so-called measurement table was constructed, which was used to draw angles on a design in an appropriate scale on a squared paper sheet. Later in 1606, the field glass was invented, in which a crosshair was included in an ocular. Such a set of tools enabled to draw strictly accurate city panoramas and architecture. The next innovation was the level enabling to mark angles horizontally and vertically. This level was more accurate because it measured with the accuracy of 1 centimetre for the distance of 1 kilometre. Such geodesic instruments are also used today, but the technology and precision were improved. Measurements with customary methods were labour-intensive, and they had defects resulting from rounding.

However, measurements with these different tools were connected with overcoming terrain obstacles, which influenced the safety of measuring teams. For instance, a measurement of a tall
building required climbing a ladder easily provoking a fall accident. Moreover, sometimes it was impossible to place a platform, so people contrived ways to obtain the expected data.

Figure 1. Medieval measurement tools [2]

These days, facilitation in measurements of hard-to-reach objects are laser telemeters. Making a measurement with such a device has many advantages: the in-situ work may virtually conduct one person, there is no need for physical approaching to each element being measured, it is enough that a laser beam reaches the place (even in the distance of 200m). Another advantage is the possibility of making an indirect measurement. This function uses the Pythagorean theorem to determine the height of difficult-to-reach elements which increases the safety of performing the work – there is no need to climb a ladder or scaffolding, from which someone can easily fall. In comparison to the traditional methods using e.g. a measuring tape, the use of a telemeter surely facilitates and accelerate the work and enables to obtain results with the accuracy up to ±1,5 millimeter. Additionally, the device can calculate the surface and cubature, which enables to estimate quickly e.g. the cost of a repair.

3. Photogrammetric methods
Presently in engineering measurements, there is a tendency to obtain real images as detailed as possible.

Figure 2. The general division of photogrammetry [3]
Telemeters and tachometers were introduced, both to facilitate the work of measuring staff. Modern, more precise methods are more suitable for constructional and architectural measurements. The first attempts to use photogrammetry go back to the second half of the 19th century. It enables to obtain information of objects in a contactless and non-invasive way. Photogrammetry can be divided into 2 groups – aerial and terrestrial (Figure 2). [3]

The one-picture terrestrial method involves stocktaking of flat objects as for example elevations and paintings with the aid of a camera with a high resolution. The camera should be placed parallelly to the photographed surface. The distance between the place of a photographer and the object depends on the object-lens and its focal length, because the longer distance, the lesser imperfections of a picture.

The two-picture method is used for an object of a complicated, dimensional structure with the aid of so-called stereogram that is a pair of stereo pictures. They are made with a stereometric camera consisting of two cameras fitted to a tripod (Figure 3) or of one camera from two places. Digital cameras are reflex digital cameras with matrices of a very high resolution and with lens of a constant focal length.

During the processing of individual photographs as well as of stereoscopes, photopoints are needed, that is the point of known coordinates (X, Y or X, Y, Z) in the reference system, which is marked on an object, most often on noticeable details. These points are measured with electronic tachometers, using a mirror-free distance measurement. The method of terrestrial photogrammetry is relatively safe in use. Thanks to the measurement, a rich set of data is obtained abort vertical and horizontal objects without the risk of falling from a height [4].

4. 3D laser scanning
The photogrammetric method which is utilized in the measurement of a laser beam is a 3D laser scanning. It is a technology of great possibilities and accuracy. Also, the swiftness of work and the possibility of making contactless measurements are very important.
Laser scanning was defined in the decree of the Minister of Domestic Affairs and Administration from 9 November 2011 on technical standards of making geodetic situational and height measurements and processing them and sending to the state of geodetic and cartographic (Journal of Laws 2011 no 263 item 1572). According to this document, it is a method of terrain surface imaging, consisting of measuring the distance between the object being measured and the device (scanner) installed on a plane, car or a stationary site, emitting and receiving laser impulses reflected from this object and at the same time marking dimensional coordinates (X, Y, Z), determining the position of this device and directions of a laser beam at the moment of sending an impulse [5].

This technology enables to collect information on the geometry of an object being scanned and is based on the principle of a laser measurement of a distance from a site of determined dimensional coordinates to the point being measured, and then to determine their position in the established coordinates’ system of the scanner. A user obtains automatically raw data in the form of a 3D cloud of points, which is a dimensional representation of the surface of an examined object. Laser scanning may be divided into the following categories:

- TLS – Terrestrial Laser Scanning,
- ALS – Airborne Laser Scanning,
- MLS – Mobile Airborne Laser Scanning.

In a building inventory the method of terrestrial laser scanning is used most often. A scanned object is localised in the defined dimensional system of coordinates X, Y, Z, through measurement with scan density adjusted to the needs (e.g. every 1 mm, 1 cm). The defined density of scanning results in an increase of the values of vertical and horizontal angles. The polar coordinates (angles and inclined distance) are calculated into rectangular coordinates X, Y, Z. The measured point is represented by three coordinates X, Y, Z in the local scanner system or any coordinates’ system determined in the device and the fourth coordinate I – standing for the reflexion intensity [6].

Making measurements with a 3D laser scanner (Figure 4) requires a solid preparation for in situ investigations. It is especially vital to learn not only about the object itself, but also about its surroundings. In order to obtain the 3D data, an element must be measured from at least three positions situated in such a way that the object is seen from each side. The range of some work enables sometimes to make a measurement from a singular position. But when we want to do it from a few positions, we must remember to refer to the earlier established characteristic points. During the measurements, different kinds of disks can be used e.g. a paper printed black and white flat disks, 10 cm spherical disks (Figure 5) or 6-inch incline-revolving HDS disks (Figure 6)
5. Safety of people, devices and an object during measurements

During measurement activities, it is important to pay special attention to the issue of safety of both the measuring team and the examined object itself. The use of the photogrammetric methods and of the 3D laser scanner, in particular, enables to collect data from a considerable distance because the range of a laser beam reaches up to 300 m. Thus, there is no need to set a scaffolding or to use a ladder for measuring highly localized elements. Making measurements of a roof, using direct methods (e.g. with a measuring tape), presents the risk of falling down. To increase the safety of such a work, the workers would have to be qualified for such activities and should be fitted with additional safety equipment, such as nets and straps.
Making inventory measurements on heights with a tape or laser telemeter may result in the damage of the measured object. It pertains mainly to the mechanical damage of walls connected with a scaffold setting and fixing. Some objects have ornaments and details which might be damaged in direct contact with a ladder or scaffolding [7]. Therefore, a great advantage of the contactless methods, such as the laser scanning is the fact that they are non-invasive and have no direct influence on the object.

Measurement work done by a group of people presents a certain kind of danger. People moving with tapes or other measuring devices should observe safety principles particularly in little known surroundings. It is especially important in the case of objects in bad repair or these with rubble. During the work in a tumbledown building, each movement can result in the damage of the static balance of the construction and end up with a building collapse. Such a situation may result in injuries and casualties of the people working there. Sometimes, measurements must be made on rubble or in a place where the heavy building machinery worked. It can derange the integrity of the ground and uncover e.g. wells invisible under debris. A man walking on such a surface can fall down in this opening and meet with an accident.

Each work performed in a place with heavy traffic calls for a special indication for the measuring staff and their devices. Reflective vests and similar elements on the devices increase the visibility of the measuring team. It gives the advantage that the traffic taking place in the site of measurement does not threaten the people and the devices, which are visible from a distance.

Measurement with a laser scanner requires on the part of an operator to pay attention to passers-by. A laser beam, contrary to the producer’s warning, is not harmful to eyesight, but a direct exposition to it should be avoided.

6. Conclusions
The safety of doing all the activities connected to the measurement of buildings is an important issue. Buildings may be in different technical conditions and of a different degree of complexity, therefore such measuring methods and devices should be chosen, which enable not only to make an inventory and to obtain needed data, but also to facilitate the work of the measuring team and result in performing the task according to the rules and principles of safety. The result of this consideration indicates that the photogrammetric methods are not only very precise and allowing to measure complicated structures, but also relatively safe both for the people and the object. It is especially important while mapping objects of a special historic or cultural value.

References
[1] M. Gruca, J. Grzelka, M. Pyrc, S. Szweja and W. Tutak, „Metrology and measurement systems”, 2008.
[2] M. Brykowska “Measuring and examination methods of ancient monuments”, Publishing House of the Warsaw University of Technology, Warsaw 2003.
[3] M. Gałda, E. Kujawski, S. Przewłocki, “Geodesy and building metrology” Eugeniusz Romer Polish Company of Cartographic Publishing, Ltd., Warsaw-Wroclaw, 1994.
[4] W. Francuz „Performing measuring work”, Institute of Operational Technology-State Research Institute in Radom, 2005.
[5] Decree of the Minister of Domestic Affairs and Administration of 9 November 2011 on technical standards of making geodetic situational and height measurements and processing them and sending to the state geodetic and cartographic (Journal of Laws 2011 no 263 item 1572).
[6] J. A. Pawłowicz, “3D modelling of historic buildings using data from laser scanner measurements”, Journal of International Scientific Publications: Materials, Methods and
[7] B. Van Genechten, L. Schueremans, “Lasers-canning for heritage documentation”, Conservational News, No 26, pp. 727-737, Cracow. 2009.