The application of a 3D laser scanner in contemporary education of civil engineering students

E Szafranko and J A Pawłowicz
University of Warmia and Mazury in Olsztyn, Faculty of Geodesy Geospatial and Civil Engineering, Institute of Building Engineering, ul. Heweliusza 4, 10-724 Olsztyn, Poland
E-mail: elasz@uwm.edu.pl

Abstract. The programs of study in field of civil engineering include a number of objects, which concern with details of the planning, design and realization of buildings. These are buildings and structures such as, roads, bridges, tunnels, viaducts. Most of these objects are located far from university and it was difficult to show them on the lessons. Discussing the structure based on the description of the object, photographs or drawings do not always allow to imagine the actual shapes and sizes of buildings, roads, bridges and viaducts. In such a situation, terrestrial photogrammetric technology could be helpful. One of them is 3D laser scanning technology. Measurements performed with a laser scanner allows to introduce selected objects in the form of spatial models. They give you the ability to rotate and zoom them in order to know the details of construction of the object. The article presents the possibility of using a 3D laser scanner in teaching.

1. Introduction
The profession of an engineer is a public trust position. It is an occupation governed by legal regulations, which in practice manifests itself by the obligation to obtain relevant permits in order to perform the work of a building engineer and to hold independent technical functions in the construction industry. Several requirements must be fulfilled prior to assuming the role of a building engineer, including completing an appropriate course of education, internship and examinations which test the knowledge of legal regulations and the ability to combine the theoretical knowledge with practice. Depending on specialities ascribed to the permits acquired, an engineer can participate in making plans of buildings and structures, conducting and supervising construction works of various building structures, and in the manufacture of construction elements. The tasks involved in the work of a civil engineer carry a large burden of responsibilities. The safety of building structures and their future users depends on the quality of engineering work. Thus, the education gained by university graduates is fundamental to the professional experience they will earn during their careers. Meanwhile, the subsequent reforms of higher education have generated many undesirable effects, leading to some reduction in the scope of curricula.

2. Problems in teaching civil engineering programmes at higher schools
The profession of an engineer enjoys great popularity. For years, college and university entrants have expressed much interest in civil engineering and even recently, when the number of students has been declining, college and university faculties which offer ‘Civil Engineering’ as a course of study have full enrolment. Unfortunately, an assessment of the education process at several higher schools in Poland conducted by the Polish Chamber of Civil Engineers has revealed some negative trends. One group of
problems is generated by the implementation of the Bologna Process, which has brought about a three-tier division of the educational process. Another source of difficulties is the shortage of funds at higher schools, which forces them to cut down the number of teaching hours allocated to many basic subjects, including the ones that form the foundation for acquiring the rights to practice the profession of a civil engineer [1, 2].

The principal obligation expressed in the Bologna Declaration is to create a general qualifications framework [3]. It is presumed that having completed higher education in civil engineering, graduates will be prepared to operate on the national and European labour market, they will become active citizens, they will have developed their personality and will have had an instilled desire for further development, education and maintaining their level of technical knowledge. Pursuant to this obligation, National Qualifications Frameworks have been developed, which define the learning outcomes and qualifications of graduates. The concept of obligatory minimum curricula has been discontinued. This change has strengthened the autonomy of higher education institutions, in terms of both curriculum design and the content and form of teaching, meaning that the structures and programmes of education can be more diverse [2, 4].

A question arises how to ensure diversity and comparability of education at the same time. The answer lies in the structure of qualifications, which should be modified so that generic learning outcomes rather than syllabuses (content) of education serve as points of reference. Thus, it is necessary to assure international transparency of qualifications. The Bologna scheme of qualifications should enable us to translate qualifications earned in one country to qualifications earned in another country. However, for the Bologna process to work properly, it is essential to ensure adequate quality of education. The quality of education at higher education institutions in Poland is assessed by the Polish Accreditation Committee. It analyses the appropriateness of learning processes with regard to the binding Qualifications Frameworks. It needs to be remembered that because of the further professional development of graduates and the obligation to obtain building permits, syllabuses and curricula in civil engineering schools are additionally evaluated by commissions affiliated with the Polish Chamber of Civil Engineers [1, 3, 4].

Results of analyses of the curricula in Polish schools of higher education demonstrate considerable differences between the defined requirements concerning building construction design courses, with a decreasing tendency regarding the number of designs produced by students. It has also been noticed that the number of teaching hours allocated to such subjects as reinforced concrete and steel constructions, brick, timber and composite constructions has been decreasing steadily. Certain issues related to these problems are absent in some curricula. The most common reason is cutting down costs. By reducing the number of teaching hours conducted by a teacher in a classroom, schools reduce possible payable overtime of their staff or eliminate the need to hire outsourced teachers, which leads to budget savings.

In such a complicated situation as sketched above, modern multimedia techniques and technologies may help to ensure the expected level of education and the achievement of pre-defined learning outcomes.

3. Possibilities of using 3d laser scanning in education of civil engineering students

For many years, in the teaching process at higher education institutions, emphasis has been laid on improving the quality of education and associated transfer of knowledge. Academic teachers participate in training sessions dedicated to contemporary teaching methods, whose aim is to resolve problems. Multimedia presentations, educational films or computer visualizations can accelerate the transfer of information. Worth attention are the possibilities created by terrestrial photogrammetric methods. 3D laser scanning offers many options and an image obtained from a scanner can be rotated or magnified, which means that students can learn numerous construction details even during a single lecture. There are many possibilities of supporting the teaching processes with this technology. Some will be discussed underneath.
3.1. The application of laser scanning in construction design courses

Construction design courses, because of the extensive scope and versatility of problems raised during the classes and lectures, are extremely challenging for students. Presentation of various constructions, such as made of reinforced concrete, steel, timber and brick, and discussion of various cases of work, loading and damage to construction components takes many hours of lessons. As mentioned before, less and less time is being scheduled for such courses.

In order to show students the whole diversity of constructions, details of buildings and elements made from different materials, 3D images of moving objects can be used. A 3D scanner is a device which - while measuring a building it is set to scan - analyses the shape, surface and texture of the object and its environment. Measurements made with a 3D scanner, if made correctly, allow us to process the data and generate a fully digitalised, three-dimensional model. Figures 1, 2 and 3 show examples of scanned objects.

![Figure 1. Fragment of a 3D model of a building – brick construction with visible structure of exterior walls.](image1)

![Figure 2. A three-dimensional model of a wood girder.](image2)
3.2. Application of laser scanning in the subject: technical drawing and general civil engineering

With a laser scanner used for making measurements, it is possible to visualise buildings and other building structures with high precision. When both the external shape and the interiors of an edifice have been measured, the composite results of the survey provide a complete set of information about the measured object. Once a model of this object is developed, it can be submitted to further processing, e.g. it can be used for the mapping of this object in projections and cross-sections. It can also serve for making inventories of buildings [5, 6]. Projections and cross-sections can be created quickly with the aid of a software application called ‘Limit Box’, which generates a three-dimensional box with cutting edges. They can cut a model of a building at any point, producing ‘a plaster’ (fig. 4), which can be used for developing vertical or horizontal cross-sections of the building (fig. 5). Based on such sections, we can determine dimensions: straight and diagonal, diameters, lengths of arches and any angles, etc. [7,8].

Data achieved by 3D laser scanning allow us to make axonometric projections of a building and visualizations of its external wall patterns. To this aim, it is possible to use a cloud of points, obtained from field measurements, which creates a model of a measured object directly by connecting data from individual stations.
Figure 5. A three-dimensional model of a steel girder.

Figure 6. A three-dimensional model of a building – a ‘raw’ point cloud.

An image can be shown as a ‘raw’ point cloud or a cloud with superimposed photographs, which gives an insight into the object’s colour pattern and texture. Objects scanned with a 3-D laser scanner can be analysed very quickly, hence making an inventory of objects does not take many days of measurements. Moreover, during a class with students, a teacher can discuss and analyses various building structures, showing their 3D models. This will certainly expand the scope of issues presented in the classroom, especially in a situation where the number of teaching hours is reduced.

3.3. Application of laser scanning in road and bridge construction engineering

While teaching civil engineering students who specialize in road and bridge construction, a teacher can be faced with a problem such as the absence of model structures in the vicinity of the school. Discussing issues connected with the construction of roads in a variety of specific conditions, while being unable to demonstrate examples of discussed solutions makes it more difficult for the teacher to present questions associated with road planning, design, construction and future use [9, 10]. The same problem arises when various construction solutions applied to the building of road and railway bridges are discussed. Here, same as in the previously mentioned circumstances, images generated by a 3D laser scanner can be helpful. During a one-hour class it is possible to visit different objects so as to show a variety of material and structural solutions, and to make cross-sections of these building structures that will demonstrate interesting engineering details [10,11]. Some possibilities that this technology offers are illustrated in figures 7 and 8.
Figure 7. A three-dimensional model of a building – a stone bridge.

Figure 8. A cross-section through a bridge’s construction with the clear span.

A cross-section can be made in different planes in order to show construction details that we find interesting at a given moment. The cross-section shown in figure 8, for example, enables us to calculate the clear span of a bridge.

Figure 9. A profile of an embankment seen in a cross-section of a construction.

In the engineering practice, we are often interested in earthwork, the shape of embankments and foundation trenches. Having an image produced with the laser scanning method, by making an adequate cross-section (figure 9), we can obtain a profile of an embankment on which a traffic concourse is built.

4. Possible applications of a 3d laser scanner for stimulating students’ interests outside the classroom
The cutting-edge technologies are highly popular among students, who may have an opportunity to test them when participating in student clubs. Students who belong to the Club of Young Architects and Urban Planners ‘Kreska’ at the University of Warmia and Mazury in Olsztyn, helped by the club
supervisors, dr eng. Joanna Pawłowicz and dr eng. Elżbieta Szafranko, are eager to test and make measurements with a laser scanner ScanStation C10 manufactured by Leica. The achievements of the club members include surveys of various objects, such as the university swimming pool, some (listed as monuments of architecture) buildings on campus of the UWM in Olsztyn-Kortowo, a historical church in Klewki or a palace and manorial buildings in Mortęgi. They also try to use scanning applications for other coursework. In the construction practice, engineers are frequently faced with various tasks. Students have become interested in the possibility of using the scanning technique for measuring masses of earth moved during earthwork. They were eager to test the TLS technique for monitoring volumes of earth mass in embankments and removed from trenches. The objective was to determine the accuracy of measurements of excavated earth mass. The study was conducted at the Concrete Technology Laboratory of the University of Warmia and Mazury in Olsztyn. To achieve the research aim, an amount of 0.005m³ of medium-grain aggregate was measured and formed into a mound. Afterwards, a high resolution scan was made. The higher the scanning resolution, the more dense and detailed the resulting cloud of points. The study proceeded in two steps. First, high-resolution scanning was performed at three stations. After that, during the control step, medium resolution scanning measurements were taken at four scanning stations. Data were obtained from both measuring series, and a model of the mound was generated in the form of a point cloud [8].

The volume became measurable when the point cloud was converted into a ‘Mesh’ model, which was obtained by overlaying the so-called TIN (Triangulated Irregular Network) layer. This is a network consisting exclusively of triangular facets, whose end tips connect with points of the cloud, generating a surface. The programme produces results in m³ – figure 10.

![Figure 10](image)

*Figure 10. Measurement of a mound’s volume based on a ‘Mesh’ model [8].*

Based on the completed study, the students determined the smallest volume difference for the mound model in relation to the amount of aggregate used at 0.0000013m³, which corresponds to 0.026% deviation from the reference value. The mean deviation was calculated for all variants of possible configurations during the data processing, and it equalled 0.274% for the first measurement and 2.749% for the second one. Having completed this study, it became obvious that the 3D laser scanning technique is suitable for measuring volumes of earth masses, which can largely facilitate the work of an engineer. Moreover, we noticed that a higher resolution scanning approach generated the results by one order of values more precise than the observations made at a lower resolution.

5. Conclusions

Issues associated with the education of civil engineering students are discussed by numerous groups of interested parties. Both professional associations, which group engineers, and representatives of the higher education system often raise the question of the quality of teaching at Civil Engineering courses. Assessments of curricula at higher education institutions demonstrate high diversity in the requirements
regarding construction design courses, with a decreasing tendency both in the number of designs made by students and the number of hours allocated to these courses.

Examples of applications of laser scanning for the sake of improving the teaching process show how modern technologies can help us familiarise students with many problems, accelerate the learning process and add to syllabuses the issues unattainable through traditional methods. It can be stated rather firmly that 3D laser scanning is useful in each of the presented cases. It is a uniquely helpful technology, with countless applications, including a wide range of applications in civil engineering, which are limited only by our imagination. However, using modern technology, we should keep in mind the traditional approach to design such as 2D drawings that are still popular in many countries in Europe.

References

[1] Grabowski Z. 2009. Problematyka kształcenia zawodowego inżynierów w aspekcie uzyskania uprawnień budowlanych, 55 Konferencja Naukowa Komitetu Inżynierii Lądowej i Wodnej PAN oraz Komitetu Nauki PZiTB – KRYNICA 2009.

[2] Kawecki J. 2009. Jakość kształcenia na kierunku Budownictwo w ocenie Państwowej Komisji Akredytacyjnej”, 55 Konferencja Naukowa Komitetu Inżynierii Lądowej i Wodnej PAN oraz Komitetu Nauki PZiTB – KRYNICA 2009.

[3] Łapko A. 2009. Realizacja Deklaracji Boloniańskiej w obszarze Inżynierii Lądowej – Porównanie z innymi krajami UE”, 55 Konferencja Naukowa Komitetu Inżynierii Lądowej i Wodnej PAN oraz Komitetu Nauki PZiTB – KRYNICA 2009.

[4] RAPORT: 2010. Analiza programów nauczania wyższych uczelni kształcących dla budownictwa, Polska Izba Inżynierów Budownictwa, Krajowa Komisja Kwalifikacyjna, 2010.

[5] Pawłowicz J. A., Szafranko E. 2015. Recording and analysis of anomalies appearing in structures of wooden construction objects using the 3D laser scanner. International Scientific Publication, Materials, Methods & Technologies 9 (2015), pp. 178-184.

[6] Pawłowicz J. A. 2014. Analiza dokładności i przydatności danych z pomiaru metodą TLS do oceny bezpieczeństwa obiektów budowlanych, Logistyka (5), pp. 1233--1239.

[7] Bojarowski K., Dumalski A., Kamiński W., Mroczkowski K., Trystuła J. 2008. Possibilities of using laser scanner scanstation from Leica to research deformation of building structures, Technical Transaction, 2-Ś/2008, Kraków, WPK, pp 139-147.

[8] Pawłowicz J. A. 2013. 3D laser scanning in measurements of volume of earth masses; The 2nd Virtual International Conference on Advanced Research in Scientific Areas (ARSA-2013) Slovakia, December 2 - 6, pp. 438 – 440.

[9] Boehler W., Marbs A. 2004. 3D scanning and photogrammetry for heritage recording: a comparison; Proc. 12th Int. Conf. on Geoinformatics – Geospatial Information Research: Bridging the Pacific and AtlanticUniversity of Gävle, Sweden, 7-9 June, 2004, pp: 291-298.

[10] Dubik A., 1991. Zastosowanie laserów, Warszawa, Wydawnictwo Naukowo-Techniczne.

[11] Szafranko E., Pawłowicz J. A. 2015. Inventory of agricultural building objects based on data obtained from measurements by laser scanning. Engineering for Rural Development. Jelgava 20-22.05.2015, Pp.190-194