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CIVIL ENGINEERING

BIM implementation in urban infrastructure design and education

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Abstract. This paper presents the significant impact and progressive trends of using building information modelling (BIM) technology in planning and designing urban areas and their infrastructure in accordance with sustainable development goals. It draws attention of the scientific and educational community to the need for consistent implementation of BIM in education of future architects and engineers. Major capabilities and high potential of this innovative approach are introduced in the paper by showing achievements of inter-disciplinary digital designing as part of the Erasmus+ project. As comprehensive benefits of this international collaboration, the main effects of the adopted training methods and modified university curricula are indicated, including the bachelor and master levels of education. Exemplary results of current research works focused on the integration of 3D scanning technologies into BIM for bridge structures are presented as well.

Keywords: BIM; digital technology; urban development; innovative technical solutions; AEC sector.

1. INTRODUCTION

The dynamic development of urban areas and building or modernization of their infrastructure require modern approach and new effective tools that support the planning, designing, construction and managing for all parties involved in these processes (Fig. 1). In order to meet these challenges, the building information modelling (BIM) technology has already become the current design standard in many countries [1, 2]. Anglo-Saxon and Scandinavian countries are among the leaders. Poland follows the countries most developed in the application of BIM techniques in the particular stages of building engineering structures. The interest in BIM technology in Poland and the beginning of its continuous development dates back to 2016 – i.e. the time of organizing first conferences and publishing first collective studies in Polish dedicated to this topic [3, 4]. In Portugal, the implementation of BIM has been progressive and driven by several initiatives at technical and legislative level [5]. One of the key elements of this change is the introduction of the mandatory presentation of architectural, structural and other projects according to the BIM methodology, in an open data format, from January 1, 2030. This measure aims to promote the adoption of BIM as a standardized practice in construction and urban planning projects in public and private works.

BIM as a fully digital process allows to create comprehensive three-dimensional (3D) models of buildings and infrastructure (with different levels of detail), which can be evaluated and updated in real time during subsequent phases of the project. It provides the possibility to go beyond 3D modelling by incorporating particular types of additional information into a BIM model (data base) and expanding it with further dimensions in the lifecycle of a facility (see Fig. 1). The collaborative profile of BIM ensures a common space for more efficient workflow – more convenient access to information and faster updating of the changes introduced, which improves coordination between disciplines. In addition, it helps to visualize the architectural, engineering and construction components of the project before the executing stage of the investment begins. Besides clearly recognized benefits, BIM technology also poses potential challenges related to its successful implementation. This involves changes in collaboration practices, solving interoperability issues in terms of the standardization of BIM processes and data formats (e.g. industry foundation classes (IFC)), establishing applicable procedures for sharing information within an integrated BIM platform, storing and protecting large amounts of data (including backup and recovery), a comprehensive training program and initial investment in software.

This transformation also entails the necessity for professional education to align with current and progressing requirements. Therefore, higher education needs to keep exploring these innovations, provide up-skilling in the application of collaborative digital tools and common data environment (CDE), and practice inter-disciplinary methodologies to be kept up with changes and future-proof [6].

This article focuses on the introduction of new BIM standards into the next levels of education and training of future engineers, which requires adapting teaching methods and preparation of new subjects at higher education institutions (HEIs). The effective implementation of BIM is highly supported by the exchange of experiences between HEIs, discussions on new and potential

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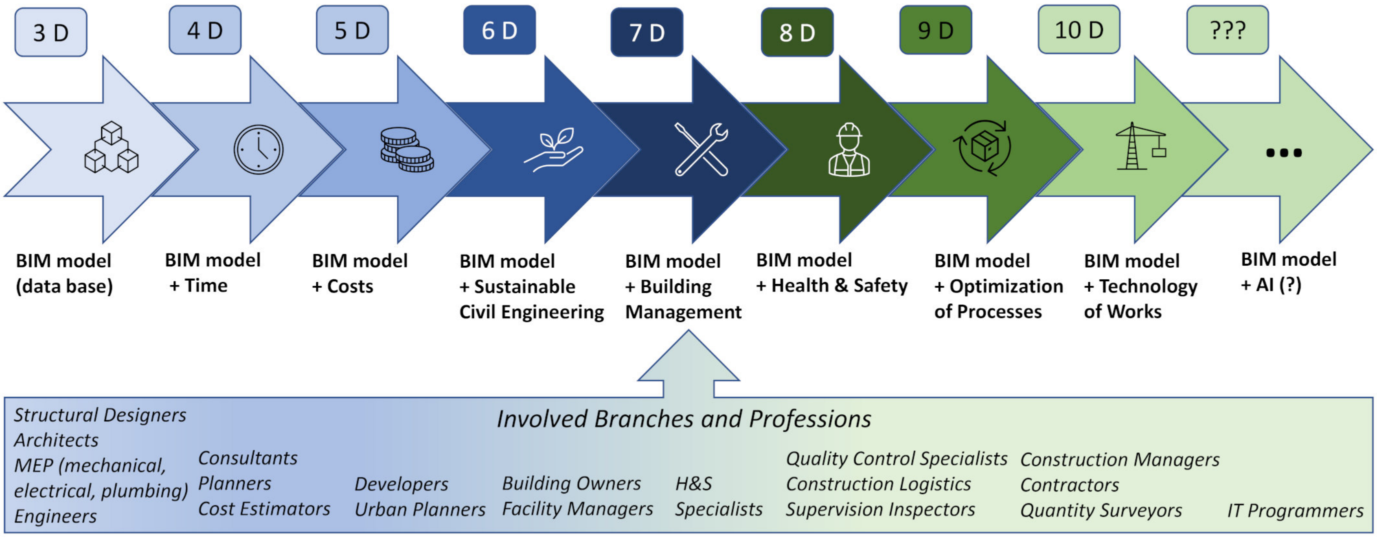


Fig. 1. Scheme of BIM development and branches involved in the architecture, engineering and construction (AEC) sector

ways of working together and cooperation in organizing joint workshops [7]. The results of such international cooperation at the bachelor and master education level, concerning the design of buildings in urban areas, are presented in Section 2 as part of the Erasmus+ project. This program contributed to the development of BIM education methods in the HEIs involved. Particularly it concerns changes in curricula at the master level of the Bridge Engineering at the Wrocław University of Science and Technology (WUST, Poland) and the bachelor/master level of Civil Engineering at the Instituto Superior de Engenharia do Porto (ISEP, Portugal), both described in Section 3.1. The effects of the modifications applied to the teaching methods in bridge design at WUST are presented in Section 3.2. Furthermore, the partnership between HEIs provides an opportunity to carry out scientific research, including at the PhD level of education, which contributes to further advances in BIM application. One of the research subjects currently being studied at ISEP/FEUP (Faculty of Engineering of University of Porto, Portugal) and the challenges it presents are all discussed in Section 3.3.

2. DIGITAL TRANSFORMATION IN DESIGN OF MODERN AND SUSTAINABLE BUILDINGS

In recent years, the integration of digital technologies into the design and construction of buildings is revolutionizing the architectural, engineering and construction (AEC) industry, allowing for the reduction of environmental impact, enhancing efficiency and improving project management. The BIM-based and parametric design are key enablers of this transformation, allowing for data-driven decision-making and optimized resource utilization. To keep up with these advancements, academic initiatives/trainings (such as summer schools, hackathons and short courses) promoted by HEIs play a significant role in up-skilling future professionals with the necessary competencies. By integrating BIM, computational design and simulation tools into dedicated initiatives, HEIs provide hands-on experience that fosters innovation, problem-solving and sustainability-focused design [8, 9].

Since 2022, WUST has been involved in the Trivarsity project [10] as a result of international cooperation with ISEP. One year earlier, ISEP joined the program being run before by three HEIs: South East Technical University (SETU, Ireland), Copenhagen School of Design and Technology (KEA, Denmark) and Sheffield Hallam University (SHU, Great Britain). The Erasmus+ Trivarsity project is focused on BIM in building structures. The BIM original tools and workflow methodologies in the AEC programs are constantly being improved and the project is being developed [10]. The general idea of this international project is the integration of students at bachelor and master levels in architecture and civil engineering. They are representatives from different HEIs and countries. The frames of the Erasmus+ Blended Intensive Programme (BIP) are the following: the online part, which contains introduction, software trainings, using CDE and preparing the design concept; the intensive one-week workshop organized at one of the universities, where all teams meet and continue their work under the tutors' supervision. Notable technical outcomes are discussed and evaluated at the end of the project and the best of them are rewarded. The students have to creatively solve a task which involves designing a multi-story building in a real location and taking into consideration topography, urban planning and cultural aspects.

In Trivarsity 2022, hosted by ISEP, the students were challenged to perform a large-scale urban intervention in a non-occupied area located in Quebrantões, city of Vila Nova de Gaia (Portugal). This area is located on the bank of Douro River right in front of the east part of the city of Porto (see red marked area in Fig. 2a). The total intervention area is approximately 124 acres and has an external perimeter of 2.88 km. The concept of the intervention consisted in the design of several high-rise buildings considering a demanding urban insertion due to the

(a)

(b)

(c)

Fig. 2. Urban intervention in Quebrantões area in Vila Nova de Gaia (Portugal): (a) view of the area of intervention (source: Googlemaps); (b) skyline of BIM models of the designed high-rise buildings; (c) examples of BIM models of specific buildings (KEA, SETU, SHU, ISEP & WUST Trivarsity 2022)

presence of the river and the famous bridges of Porto. Some relevant information was provided to the students, particularly: i) municipal master plan of Quebrantões area; ii) digital mapping and geotechnical information; iii) information about the future accessibility bridge and road infrastructure to be built in the area (the new planned bridge is marked with a blue line in Fig. 2a); iv) Douro River flood bed protection area. Additionally, some constraints were imposed for each individual building, namely: max. high 70 m, max. gross floor area (GFA) of 9000 m^2 with a mixed usage of 50% residential, 30% office and 20% public space. Moreover, a 20 m offset from the river line was imposed to the first line of buildings in relation to the riverbanks, due to the river flood protection area. Figure 2b presents an overview of the skyline of the BIM models of the designed high-rise buildings. Figure 2c shows three examples of BIM models of the designed buildings.

Selected project proposals of buildings are presented in more detail in Fig. 3–5. The projects include *inter alia*: a BIM model of the building (Fig. 3, 4), exported architectural drawings of cross-sections, floor plans and elevation views (Fig. 4), a MEP (mechanical, electrical, plumbing) model, finite element (FE) structural model for basic calculations of the structure members (Fig. 3), selection of appropriate materials and technical solutions in terms of sustainable urban development, results of solar analysis (Fig. 5), calculation of investment costs, interior designing of the building (e.g. rooms, furniture, equipment, etc.).

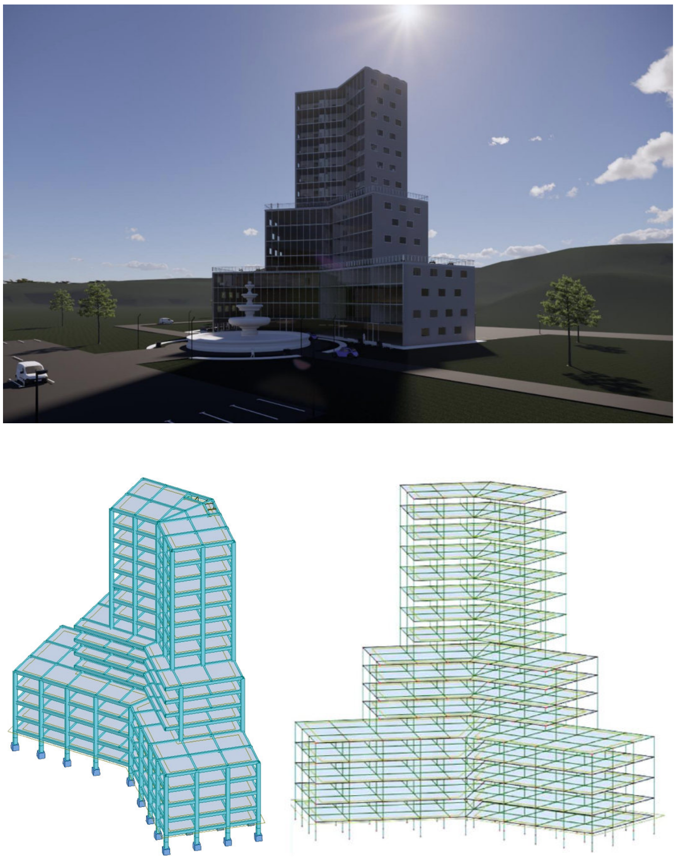


Fig. 3. BIM and FE models of the G5 Tower (KEA, SETU, SHU, ISEP & WUST Trivarsity 2022)

The edition of Trivarsity in 2024 titled "Upcoming Digital Technologies for Sustainable Construction" was hosted by University Institute of Lisbon (ISCTE, Portugal) and gathered students and teachers from 6 European HEIs (SETU, KEA, SHU, WUST, ISCTE and Frederic University (FU, Cyprus)). The main task was to design a complex of mixed residential-office buildings with a combination of green areas in the city center of Lisbon (Portugal), Entrecampos district (Fig. 6a), under real conditions – considering the most important aspects of urban designing and using state-of-the-art technology. The final

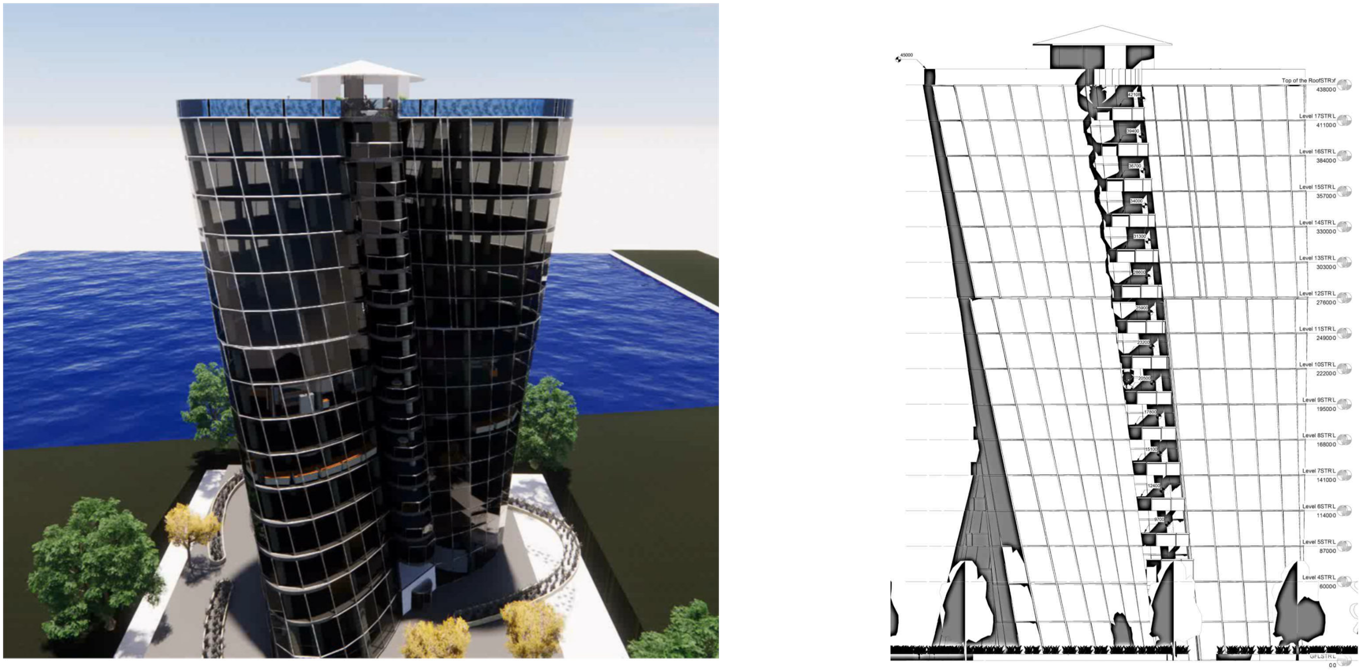
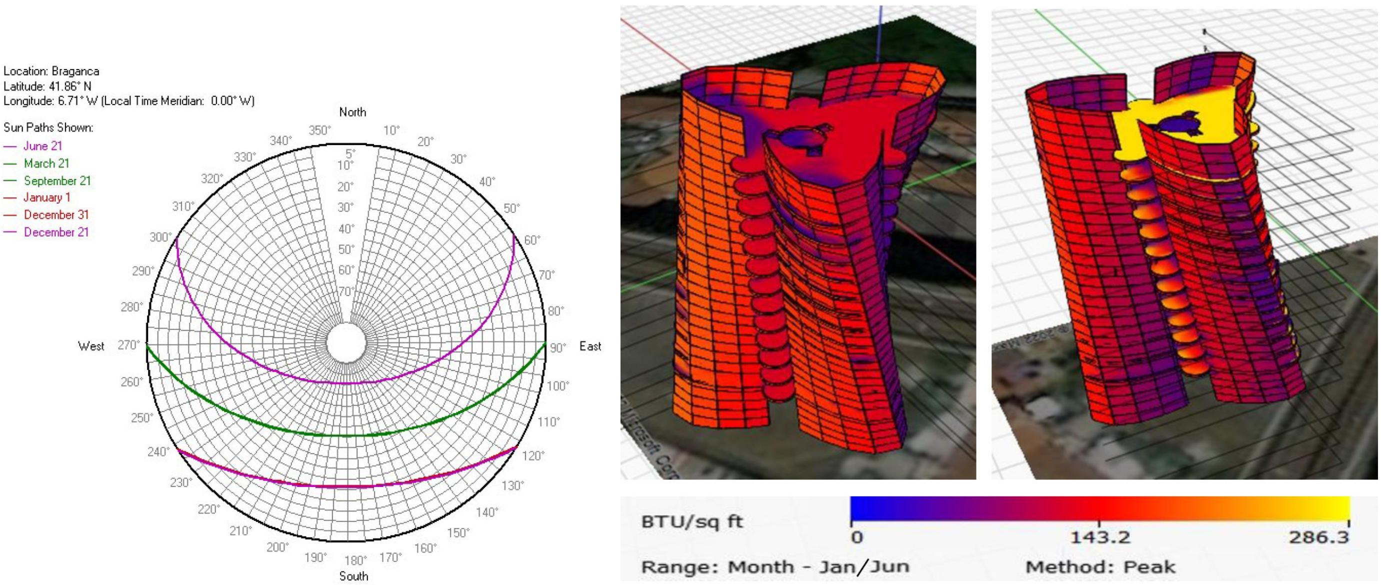


Fig. 4. BIM model and exported architectural drawing of elevation view of the Iris Blue building (KEA, SETU, SHU, ISEP & WUST Trivarsity 2022)

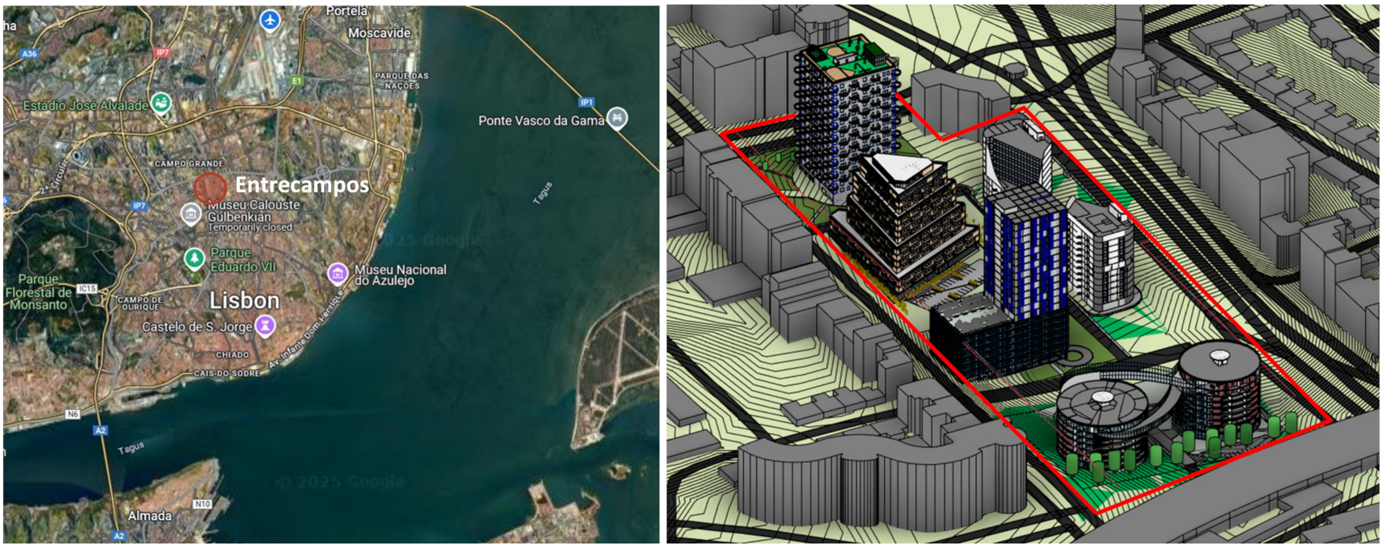


(a) (b) (c)

Fig. 5. Solar analysis of the building: (a) sun paths during the year; (b) in winter; (c) in summer (KEA, SETU, SHU, ISEP & WUST Trivarsity 2022)

effect of working in teams was the master plan, which illustrates an integrated project of several buildings designed in the considered location, marked with a red line in Fig. 6b. Figure 7 presents one of these buildings in more detail, including location, the structural FE model and BIM model for carrying out solar and wind analyses.

The experience of international collaboration during the Trivarsity project, which is focused on building designing, influenced the development of BIM education methods and curricula in Bridge Engineering and Civil Engineering at WUST and at ISEP. The most important effects and achievements are indicated in Section 3.



(a) (b)

Fig. 6. Urban intervention on Entrecampos district in Lisbon (Portugal): (a) view of the area of intervention (source: Googlemaps); (b) visualization of the designed urban area marked with a red line (KEA, SETU, SHU, ISCTE, WUST & FU Trivarsity 2024)

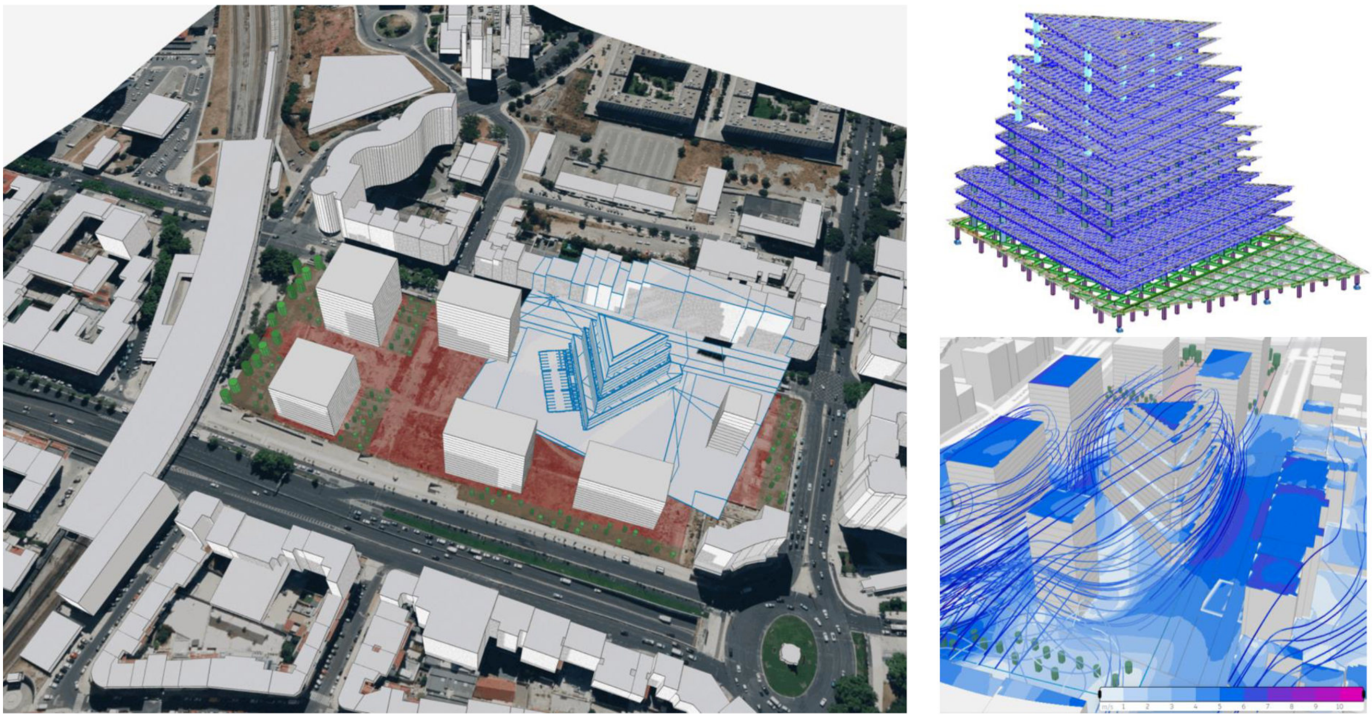


Fig. 7. Example of the designed buildings: (a) location on the 3D map of Entrecampos in Lisbon; (b) FE model; (c) BIM model for solar and wind analyses (KEA, SETU, SHU, ISCTE, WUST & FU Trivarsity 2024)

3. DIGITAL METHODS IN CREATING SUSTAINABLE AND DURABLE SOLUTIONS FOR BRIDGES

Urban systems are very often divided by obstacles such as rivers, canals, roads or railways crossings. To connect divided areas in agglomerations, bridge structures are among the most essential solutions. The approach to designing these types of structures has changed recently due to BIM implementation, which is becoming the current standard, more often and intensively practiced in the design offices that follow the innovative trends and take advantage of the latest digitalization achievements [11–13]. It has similarly affected the methods of teaching Bridge Engineering, where the BIM standard has been implemented into the education offer.

3.1. Innovative BrIM technology start-up and development trends

Trainings in BIM for bridges (BrIM) technology and a process of BIM implementation in Bridge Engineering at WUST started in 2016. At the beginning it was focused on non-structured, external education beyond the study program. A new subject was formally added to the educational offer in 2019 with the first courses organized online in 2021. Preparation for start-up of BrIM included participation in branch conferences and practical training in the use of software dedicated to BIM technology: Autodesk Revit and Dynamo. Two training courses were organized at the basic level and then at the intermediate level. Participation in the Erasmus+ project (Section 2) changed the approach to the BIM course in Bridge Engineering on the master level at WUST. The modifications introduced into the educational program and development of new methods resulted in the improvement of students' collaboration (group work), their skills in leading projects and in increased quality of students' work. The main revision in the course was related to conducting the structural design process within CDE, according to the general idea presented in Fig. 8. In this case the Autodesk software environment, i.e. Revit and Robot Structural Analysis Professional (RSA), showed the relevant integration and high workflow potential. The interoperability of this software allows to transfer BIM models (developed in Revit) directly to analytical FE models (RSA), making structural numerical analysis more convenient. The graphical representation of the workflow between BIM and FE models in the selected CDE and brief guidelines for generating a consistent analytical model for calculations is shown in Fig. 9.

An additional change in the course concerned the presentation of results by recording realistic movies based on virtual, 3D BIM models of bridge structures.

The first edition of the student classes took place in 2023 and their exemplary learning achievements are presented in this paper (Section 3.2). The contents of the new subject are outlined below. During the lecture titled "BIM in Bridge Engineering", the following topics are discussed:

- benefits of using BIM technology,
- new technology standards,
- BIM software,
- application of BIM in the designing and building process,
- 3D laser scanning,
- maintenance and inspection of bridge structures using BIM technology.

The computer laboratory classes include:

- introduction to using the software and exploring its potential,
- creating basic models and "families" in Autodesk Revit,
- preparation of a 3D model of a concrete bridge and a steel or composite bridge in Revit,
- creating 2D drawings in Revit,
- preparation of an analytical model of a selected structure element, exporting the model to a computer program based on the finite element method (FEM) and carrying out further numerical calculations.

A similar process of the curricula revision of the Civil Engineering bachelor and master courses has been recently conducted at ISEP – based on the Trivarsity outcomes as well. This revision involved the inclusion of new topics on digital construction, namely: *i*) introduction of concepts of digital models

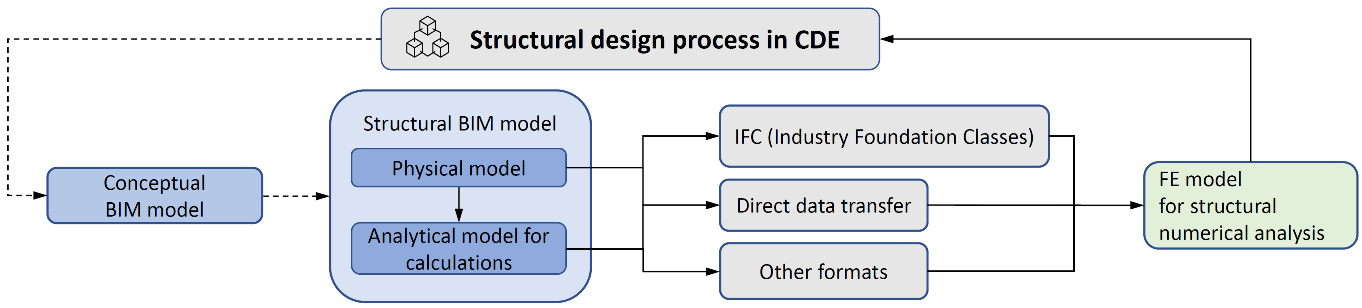


Fig. 8. General scheme of BIM model to FE model workflow

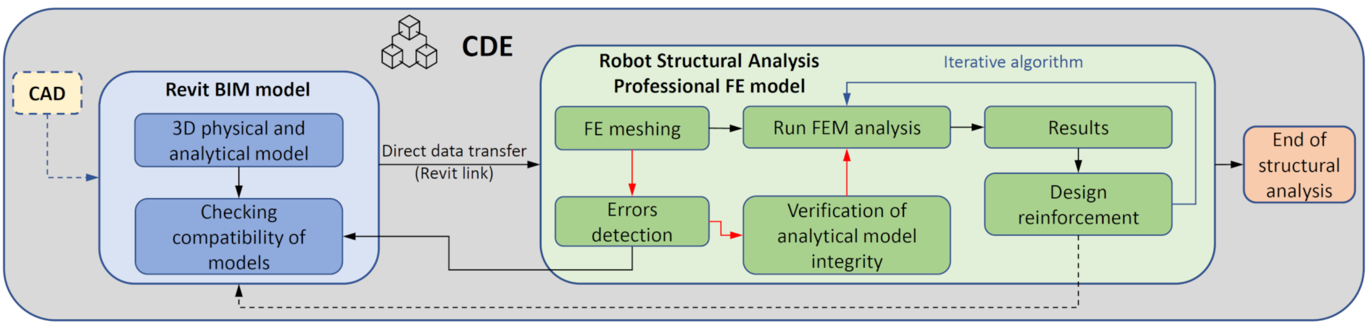


Fig. 9. Scheme of Revit to Robot Structural Analysis Professional workflow

using Revit platform in Year 1 of the Civil Engineering bachelor course, particularly in the curricular unit on Construction Drawing; ii) inclusion of a new curricular unit in Year 2 of the Civil Engineering bachelor course, denominated as Digital Technologies in Construction. The curriculum includes:

- an introduction to BIM fundamentals (introduction to parametric modeling, use of BIM platforms and introduction to OpenBIM);
- digital survey technologies (Lidar technology, satellite and drone images and geographic information systems);
- applications of virtual and augmented reality (VR/AR) in construction.

At the same time, a new curricular unit in Year 4 of the Civil Engineering master course, denominated as Digital Methodologies in Construction, has been introduced. The curriculum includes:

- BIM processes (BIM uses, coordination of multi-disciplinary projects, OpenBIM-specification and validation of information requirements in open formats);
- BIM policies (adoption of BIM at national and international level, policies, standards and guides);
- automation and robotics in construction (collaborative robotics, additive manufacturing, Artificial Intelligence);
- digital twins, data analysis (types of sensors, predictive analysis, Big Data) and digitalization in sustainability analysis (life-cycle analysis and CO_2 footprint).

3.2. Modern technical solutions in modelling bridges

The effects of BIM modelling of bridges crossing the city infrastructure are discussed in this section. In all presented case studies, which are the results of the learning process, modern techniques of designing and visualization are used. The first structure is a two-span, composite bridge situated over the railway line and artificial canal (Fig. 10, 11). The model of the structure is prepared in the BIM Autodesk Revit software. The structural analyses have been conducted in the FEM Autodesk Robot Professional computing program. Figure 10 shows a complex, 3D BIM model of the terrain and the bridge structure. In the model, the characteristics of construction materials are defined and the function of texturing the material surface is implemented.

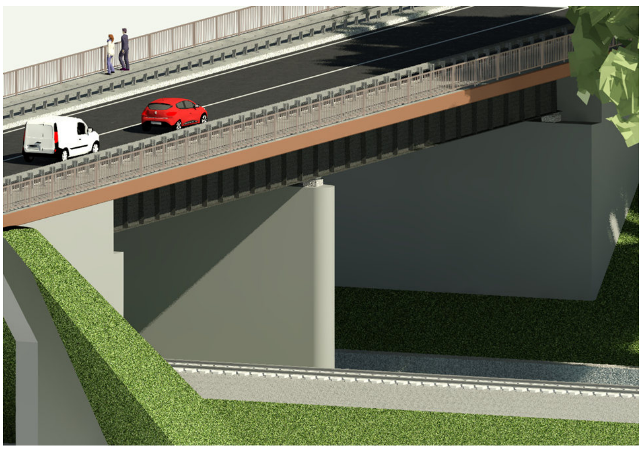


Fig. 10. View of the bridge BIM model together with traffic on the structure and surrounded terrain [11]

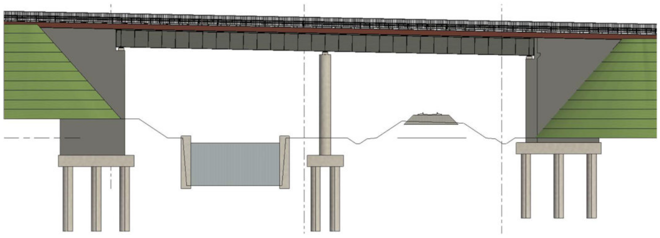


Fig. 11. Side view of the BIM bridge model [11]

A qualitative change is visible and the advantage of the BIM methodology over the classic Computer Aided Design (CAD) technique is noticeable. The software allows to easily present any two-dimensional sections of a structure, as it is shown in Fig. 11. The content of 2D drawings can be refined further on, e.g. by adding dimension lines or necessary descriptions. The main simplification is that each selected 2D cross-section can be automatically generated basing on the cross-sectional plane indicated in the spatial model. Solid modelling is particularly helpful in the case of complicated structure joints, because it decreases the possibility of errors and omissions. It is equally useful for detecting unwanted clashes of structural elements.

Technical solutions of invisible structural parts (abutment, foundations and piles) of another concrete bridge are presented in Fig. 12. The abutment was the subject of detailed numerical analyses, firstly created in Autodesk Revit, then exported to Autodesk Robot Professional, where calculations using the finite element method (FEM) were carried out [14]. The software allows to import results of calculations back into the graphical environment – programs are systemically integrated.

Another bridge crossing a river and a flood terrain in a town is presented in Fig. 13. It is designed as a two-span, prestressed concrete bridge, whose deck is equipped with pre-cast "T" beams [15]. The project included complex graphical and numerical modelling in the Autodesk environment. The scope of the project is similar to the structures discussed previously. The main difference concerned final visualizations of the model, which are prepared in Twinmotion software. This program allows to achieve photorealistic effects on rendered images and on generated recordings. The high quality of the final effects is illustrated in Fig. 13.

3.3. BrIM scientific perspectives and challenges

Current research activities performed at ISEP/FEUP, supported by PhD works and Research and Development (R&D) projects, are mainly focused on the integration of 3D scanning technologies into BrIM, as well as on the automation of the scan-to-BrIM process.

The evolution of BrIM has been significantly influenced by the advancement of 3D scanning technologies, such as laser scanning (LiDAR) and photogrammetry [16–20]. Terrestrial laser scanning (TLS) is widely used to produce dense point clouds for accurate as-built documentation, deformation monitoring and construction verification. Mobile laser scanning (MLS), which collects point clouds data while in motion, is mainly employed to rapidly scan bridge details, such as support bearing, expan-

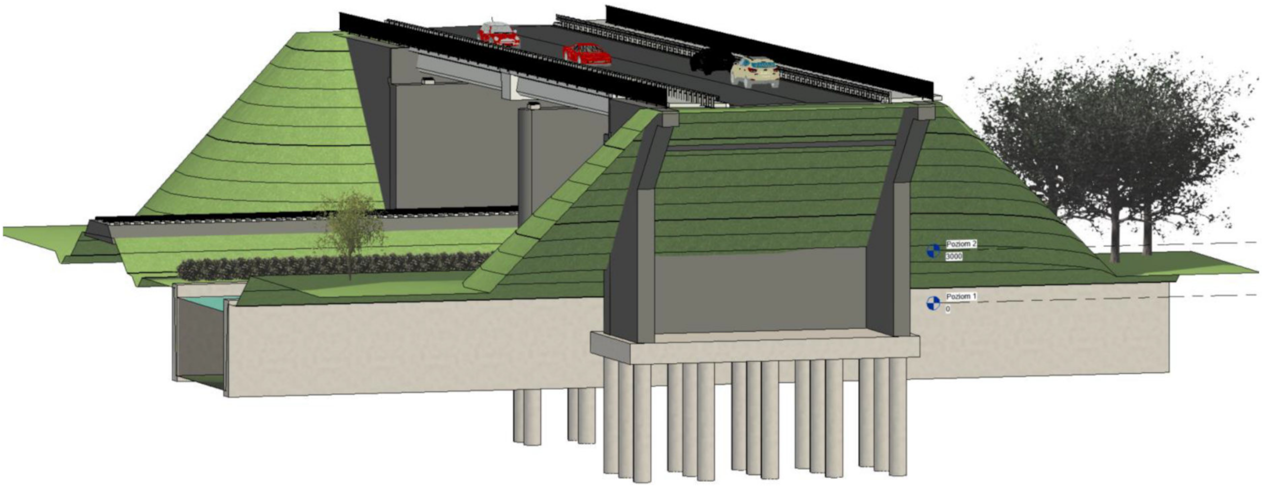


Fig. 12. View of the bridge abutment and foundation (WUST team work)

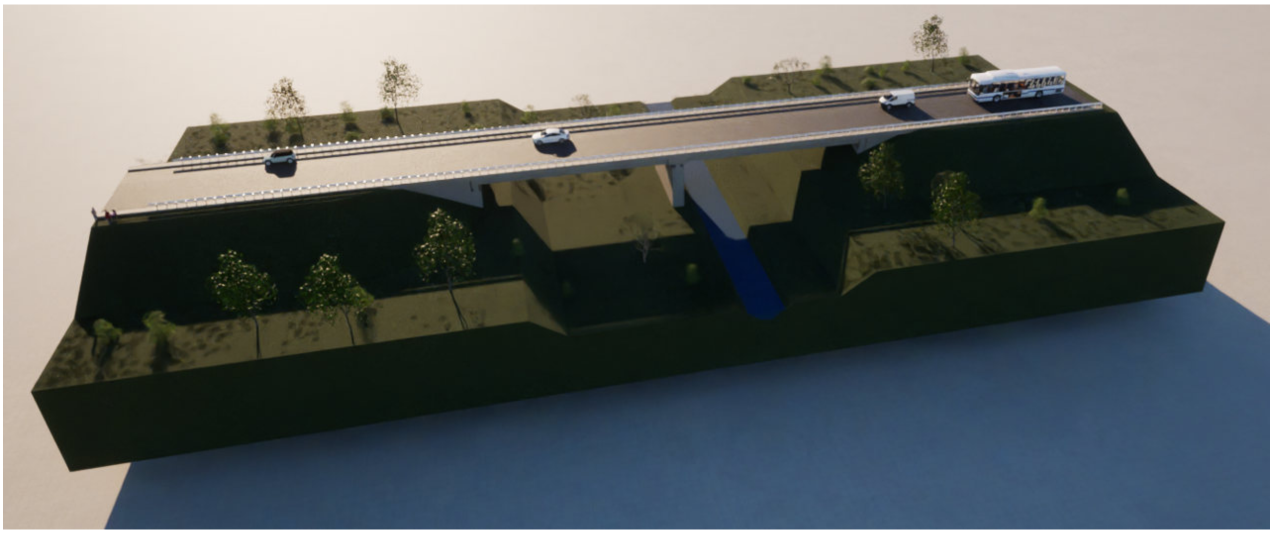


Fig. 13. Visualization of the BIM bridge model rendered in Twinmotion software [15]

sion joints, etc. Unmanned aerial vehicles (UAVs) equipped with photogrammetric cameras have enabled efficient data capture for large or hard-to-reach bridge areas, such as over water or at height. Moreover, data fusion from these technologies is relevant to obtain highly detailed 3D digital representations of bridges.

Cabral *et al*. [21] describe the development of an accurate 3D image-based model of the current condition of a railway bridge, which is performed by combining UAV-photogrammetry and TLS technologies. The case study focuses on a section of the west access viaduct that leads to the Pirâmides bridge in Aveiro, Portugal. This section comprises four 25-meter continuously supported spans, resulting in a total length of approximately 100 meters, as illustrated in Fig. 14.

The side and bottom sections of the deck surfaces were scanned using TLS, while the side and top sections of the deck and the track were captured via UAV. The fusion of data from both approaches resulted in a precise 3D representation of the entire railway bridge, as presented in Fig. 15.

Fig. 14. Extremity section of the west access viaduct of the Pirâmides bridge (Aveiro, Portugal) [21]

Additional detailed images from the 3D image-based model are presented in Fig. 16. It is important to note that the findings of this study have significant implications for the industry, as they provide a powerful tool for surveying and monitoring large-scale infrastructure projects, as well as for developing 3D BrIM models of bridges to support digital twins.

Also, a major research challenge is related to the development of efficient Scan-to-BrIM strategies to process and convert large-scale point cloud data into semantically enriched BrIM components. This involves segmenting the data and identifying bridge elements (piers, girders, deck, abutments, etc.) so that they can be properly labeled and integrated into a structured model. Machine learning (ML) techniques are increasingly used to automate this process, although current models often require human oversight to validate results.

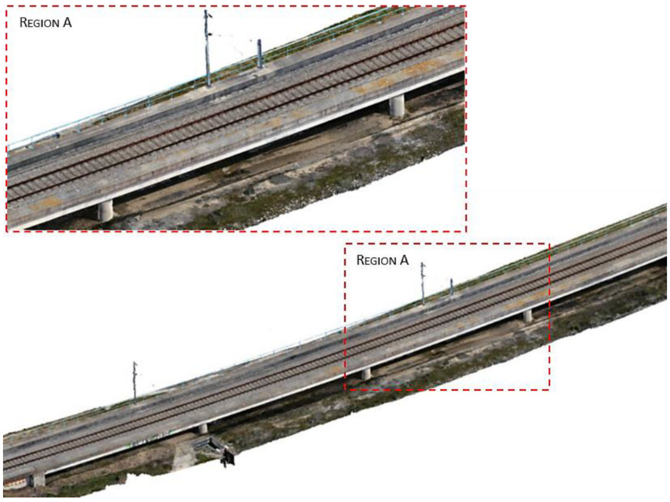


Fig. 15. 3D image-based model of the extremity module of the west access viaduct of the Pirâmides bridge [21]

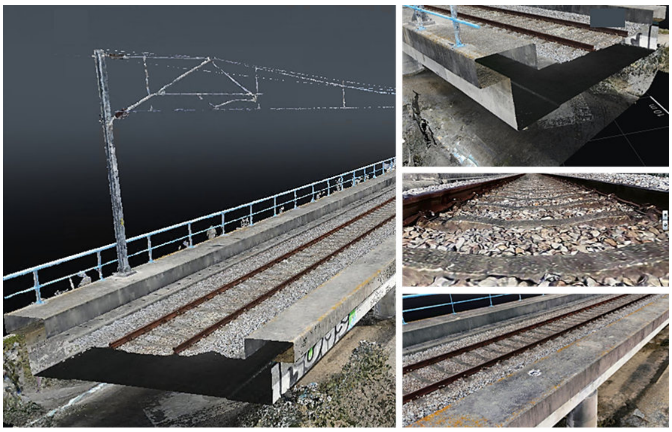


Fig. 16. Detailed images of the 3D image-based model [21]

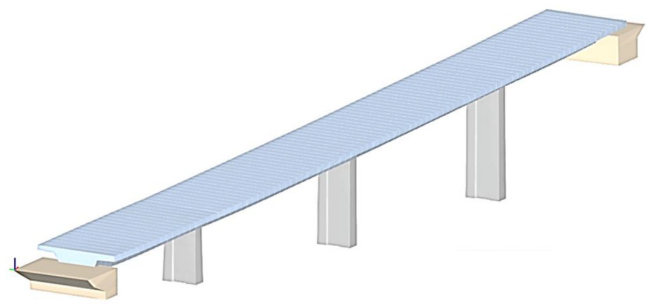
Cabral *et al*. [22] propose a methodology for automated geometric digital twin generation within BrIM at LOD 300 for existing railway bridges. The proposed AI-based methodology involved: i) automated background removal of the 3D image-based model based on a semantic segmentation using a SegNet Convolutional Neural Network, ii) scan-to-BrIM process of critical bridge components and automatic generation of BrIM components following the IFC-bridge standard and ensuring interoperability with custom BIM tools. Figure 17 presents the result of the scan-to-BrIM process applied to Grândola railway viaduct located in the Southern line of the Portuguese railways that connects Lisbon to Faro.

4. CONCLUSIONS

One has no doubt that BIM technology offers new possibilities for complex structures modelling and carrying out various numerical analyses during designing and scientific research. Due to its interoperability, accessible data base and real-time updating, it provides cross-branch cooperation. An additional advantage is its ability to program design problems in visual programming languages, which are user-friendly and create digital representations of a project. Most companies have recognized the innovative potential and use BIM software and its components to improve the efficiency and effectiveness of their activity. The BIM technology brings a lot of versatile benefits, and it is described by experts as a revolution in the AEC sector. It tends to be a standard in development of urban systems, accelerating industrial changes and supporting sustainability, as well as durability of structures in the eco-friendly trend, fulfilling the social needs of residents.

In this paper the authors emphasize the importance of BIM implementation at all levels of education of future architects and engineers, and demonstrate how BIM technology enhances the quality of common projects, improves communication between disciplines and opens up new opportunities for scientific

(a)



(b)

Fig. 17. Scan-to-BrIM process: (a) 3D image-based model, (b) 3D BrIM model [22]

research. Further direction of BIM technology development involves adopting it to facility lifecycle management or integration with other advanced technologies, such as AI or the Internet of Things (IoT), in order to increase efficiency and productivity [23].

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REFERENCES

[1] D.P. Pocobelli, J. Boehm, P. Bryan, J. Still, and J. Grau-Bové, "BIM for heritage science: a review", *Herit. Sci.*, vol. 6, no. 30, 2018, doi: 10.1186/s40494-018-0191-4.

[2] R. Sacks, Ch. Eastman, G. Lee, and P. Teicholz, *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers*, John Wiley & Sons Inc., 2018, doi: 10.1002/9781119287568.

[3] A. Tomana, *BIM. Innovative Technology in Civil Engineering. Fundamentals, Standards, Tools*, Cracow: PWB MEDIA, 2016 (in Polish).

[4] D. Kasznia, J. Magiera and P. Wierzowiecki, *BIM in Practice. Standards, Implementation, Case study*, Warsaw: PWN, 2017 (in Polish).

[5] Presidência do Conselho de Ministros, Habitação e Coesão Territorial, Portaria no. 71-A/2024, Portugal, 2024 (in Portuguese).

[6] D.R. Scheer, *The Death of Drawing: Architecture in the Age of Simulation*, New York: Routledge, 2014, doi: 10.4324/9781315813950.

[7] G. Chisholm, J. Pereira de Sá, G. Olner, F. Robertson, P. Hawryszków, and D. Ribeiro, "The collaborative evolution of digital tools and technologies in international higher education: the cyclical development of BIM authoring tools and workflow methodologies into the multi-varsity curricula of architectural, engineering and construction programmes", in Proc. *Eur. Conf. Comput. Construct. (EC3)*, 2024, pp. 618–625, doi: 10.35490/EC3.2024.223.

[8] V. Pereira, J. Santos, F. Leite, and P. Escórcio, "Using BIM to improve building energy efficiency – A scientometric and systematic review", *Energy Build.*, vol. 250, p. 111292, 2021, doi: 10.1016/j.enbuild.2021.111292.

[9] J. Santos and P. Escórcio, "Full integration of building information modelling education in civil engineering curricula: a proposal", *Eur. J. Eng. Educ.*, vol. 47, no. 6, pp. 1278–1295, 2022, doi: 10.1080/03043797.2022.2160307.

[10] P. Hawryszków and M. Knawa-Hawryszków, "Building information modelling of concrete bridges and residential building structures", *Adv. Sci. Technol.*, vol. 164, pp. 57–64, 2025, doi: 10.4028/p-06wQpu.

[11] P. Hawryszków and M. Janicki, "Building Information Modelling of bridge structures over the railways", in Proc. 18th *Wrocław Bridge Days Conf. (WDM)*, 2023, pp. 411–418 (in Polish).

[12] K. Korus, M. Salamak, and J. Winkler, "Digital twins of bridges: characteristics of a framework leading to practical implementations", in Proc. *ASCE Int. Conf. on Comput. in Civil Eng. (i3CE)*, 2023, pp. 605–612, doi: 10.1061/9780784485231.072.

[13] M. Fawad, M. Salamak, Q. Chen, and K. Koris, "Development of an immersive digital twin framework to support infrastructure management: a case study of bridge" in Proc. 41st *Int. Symp. on Autom. and Robot. in Construct. (ISARC)*, 2024, pp. 808–814, doi: 10.22260/ISARC2024/0105.

[14] A.Z. Sampaio, P. Sequeira, A.M. Gomes, and A. Sanchez-Lite, "BIM methodology in structural design: a practical case of collaboration, coordination, and integration", *Buildings*, vol. 13, p. 31, 2023, doi: 10.3390/buildings13010031.

[15] M. Borowski.,"BIM in bridge engineering. Concrete bridge case study", Report, Wrocław University of Science and Technology, Poland, 2023 (in Polish).

[16] Z. Ma and S. Liu, "A review of 3D reconstruction techniques in civil engineering and their applications", *Adv. Eng. Inform*, vol. 37, pp. 163–174, 2018, doi: 10.1016/j.aei.2018.05.005.

[17] M. Mohammadi, M. Rashidi, V. Mousavi, Y. Yu, and B. Samali, "Application of TLS method in digitization of bridge infrastructures: a path to BrIM development", *Remote Sens.*, vol. 14, no. 5, p. 1148, 2022, doi: 10.3390/rs14051148.

[18] F.N. Catbas, J.A. Cano, F. Luleci, L.C. Walters, and R. Michlowitz, "On the generation of digital data and models from point clouds: application to a pedestrian bridge structure", *Infrastructures*, vol. 9, no. 1, p. 6, 2023, doi: 10.3390/infrastructures9010006.

[19] V. Barrile, G. Candela, A. Fotia, and E. Bernardo, "UAV survey of bridges and viaduct: workflow and application", in Proc. 19th *Inter. Conf. on Comput. Sci. and Appl. (ICCSA) 2019*, pp. 269–284, doi: 10.1007/978-3-030-24305-0_21.

[20] M. Mohammadi, M. Rashidi, V. Mousavi, A. Karami, Y. Yu, and B. Samali, "Quality evaluation of digital twins generated based on UAV photogrammetry and TLS: bridge case study", *Remote Sens.*, vol. 13, no. 17, p. 3499, 2021, doi: 10.3390/rs13173499.

[21] R. Cabral *et al.*, "Railway bridge geometry assessment supported by cutting-edge reality capture technologies and 3D as-designed models", *Infrastructures*, vol. 8, no. 7, p. 114, 2023, doi: 10.3390/infrastructures8070114.

[22] R. Cabral, R. Santos, D. Ribeiro, and J. Correia, "Optimal reconstruction of railway bridges using a machine learning framework based on UAV photogrammetry and LiDAR", *Struct. Infrastruct. Eng.*, 2025, doi: 10.1080/15732479.2025.2531562.

[23] L. Yang, "Comprehensive review of Artificial Intelligence applications in Building Information Modeling (BIM) and future perspectives", *J. Comput. Tech. Appl. Math.*, vol. 2, no. 2, pp. 1–10, 2025, doi: 10.70393/6a6374616d.32363.