Building Information Modelling (BIM) Issue Introduced in Master Academic Level

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Abstract: Building Information Modelling (BIM) is a methodology supported on the generation of a virtual three-dimensional (3D) model of building projects, providing engineers the visualization and the necessary data to support planning, construction and managing. The data base of the BIM model allows professionals to develop all activities that are normally worked out over the project data. In the last decades, BIM has been adopted in all sectors of the construction industry. As so, learning the BIM topic within the construction education, regarding its concept, the range of its applicability and the most used BIM tools, is currently required. Civil engineering schools have the mission of training future engineers by offering curricular subjects, master courses and workshops concerning the current advanced computer technology. As so, the upcoming engineers should acquire the ability to use the available BIM tools in the distinct sectors of the construction industry and to recognize the advantages in developing collaborative BIM projects. The text presents a master curriculum, for students of the last academic level, offered by the Civil Engineer Department of the University of Lisbon. The master course presents the concept of BIM and the large range of its applicability. The programmatic schedule begins with the generation of a building digital BIM model, composed of parametric objects, followed by the development of different design steps. The main activities are related with the collision analyses between disciplines, the construction planning, the cost estimation and the sustainability study. The course transmits in an evolutionary and sequential way the learning issues necessary to improve the BIM skills of the students, required in their future activity as civil engineers.

Keywords: BIM, Engineering Education, Student's Skills, Master Course, Contents, Evaluation

1. Introduction

The Building Information Modelling (BIM) methodology concept focuses on the development of a single digital model. The database of the BIM model includes, in an organized way, all the information generated, manipulated and actualized concerning the building design, construction and management (Khattra and Jain, 2024). The BIM processes include the creation and the management of digital representations of physical and functional characteristics of the buildings or infrastructures. Understanding the BIM concept and is range of applicability, involves the recognizing of its benefits and limitations on the elaboration of the entire set of tasks required in the construction process (Chen *et al.*, 2023). BIM has spread worldwide as a digital construction tool, an innovative method essential in the development of building projects and an important integration capability in the management of projects, throughout the building project lifecycle (Wang and Chen, 2023). The database of the BIM model supports the development of each design phase required in the building lifecycle context. The processes of transferring, manipulating and generating new data, are managed using the BIM tools resources, based on advanced technologies. The development of BIM projects is supported on an effective teamwork coordination and the correct management of the database of the model (Jung and Joo, 2011).

The master course, considered in the present text, was designed for students to learn the essential concepts of BIM, and the basic skills to create and manipulate a BIM model. Those skills must include how to use common BIM modelling tools, how to retrieve information from a BIM model and how to develop subsequent tasks (Salmi *et al.*, 2025). The virtual 3D model generation is the first stage in a BIM collaborative project (Yilmaz *et al.*, 2019). This step is based on the use of parametric objects generated, selected and adapted for each building project. Civil engineering students should take advantage of the new job opportunities that are emerging around the process of the global adoption of BIM, complementing there training with BIM knowledge. As so, education, that goes normally more slowly and lags easily behind the industry, must follow the BIM skills requirement (Raad *et al.*, 2023). The new civil engineers should acquire competencies in BIM allowing them to be able to participate in the process of the digital transformation of the construction sector. (Wang *et al.*, 2023). BIM education must address the challenges faced by educators in adapting to the digitalization demands of the architecture, engineering, construction, and operation sectors (Ozaer and Chen, 2021) (Sampaio, 2018)..

The present BIM master course was defined with the objective of integrating BIM knowledge and procedures into the current educational curricula. The new didactic programme issue explores a theoretical context for enhancing civil engineering and architectural education through the integration of BIM into the current curriculum and teaching methods. As BIM implementation covers various sectors of the construction industry,

the engineer should know what the available basic BIM tools in the market are, and how they can be manipulated to support the development of a huge range of activities in the building design and construction. BIM methodology interferes with all aspects involved in the project in construction:

- At the initial stage, concerning the generation of the shape of the building (architecture);
- At different phases of the structural analysis process (structural solution design and detailed reinforced drawings production);
- At the budget estimation (take-off materials and estimation of costs);
- At the construction planning stage (linking the Gantt map with construction components of the model);
- At the building occupation management (supporting the maintenance activity and the establishment of repair or rehabilitation projects).

In order to add the BIM topic to the current course offered to students, at the University of Lisbon, it was proposed the introduction of the BIM methodology subject in a master unit. This new curricular unit was inserted at the level of last year of the Civil Engineering course. The curricular program was established to encompass several primordial educational steps and presents a subject methodology involving distinct specialties:

- Introduction to the topic and to the parametric modeling process, pointing out the benefits and limitations of its adoption in the construction industry;
- Reference to the construction sectors in which the BIM has had greater visibility and success;
- Use of BIM tools, and explore their potentialities and specificities;
- Develop of a large set of specific tasks, supported in BIM platforms;
- Create and overlapped the model disciplines components, allowing users to analyse the eventual conflict between all design components;
- Verify the correctness of data transferred between components of the project using distinct software;
- Comparative analyse of the benefits and limitation identified in the project development, when confronted with the traditional way;
- Establishment of a methodology of collaborative work required in the process of its implementation.

With the introduction of the master course into the current curricula, the teachers intend to improve the student's skills. The BIM topic is inserted at the final stage of the student's education. The finalist students can more easily recognize the relevance of BIM's adoption in the sector and understand that the new competence will be useful for them in the future job market. These aspects justify and reinforce the introduction of the BIM course at the last academic year. However, the new BIM unit is elective and is offered to all branches of the Master curriculum. Besides the fields of building and structures, the sectors of architecture, management, and hydraulic systems can be latter also be involved. The training of collaborative working teams, involving this diversity of domains is, naturally, enrichment for students, for the Department of Civil Engineering teaching activity and for the school. The master's course is taught during one academic semester, with a relevant involvement of other teachers of fundamental civil engineering subjects. A pilot experiment was first experimented at the 2020/2021 academic year. The course structure has been adjusted since then until the current academic year.

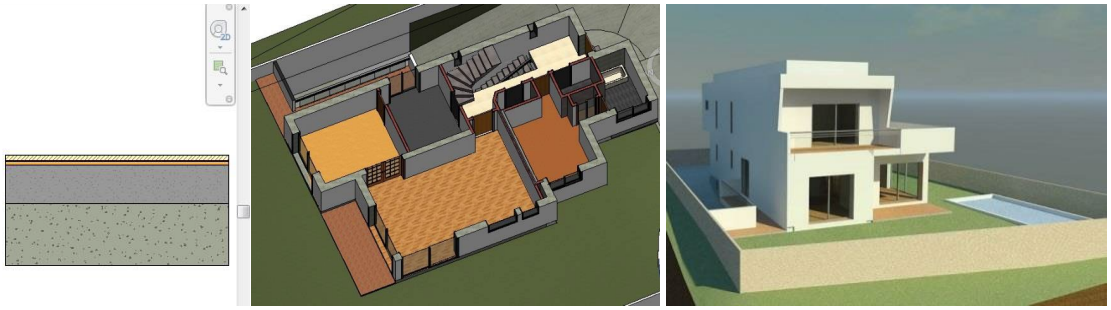
2. Teaching BIM Methodology

The BIM issue requires the enlightenment of concepts, its applicability and the level of implementation worldwide to students. However, the practical component is what makes the student able to act in different contexts and phases of the project. Therefore, the practical use of teaching basic BIM tools is essential in the course. The training provided should enable the student:

- To carry out the model generation of different disciplines and tasks, namely data transfer between phases, reuse and create new information;
- To be critical in every step regarding the correctness of the data transferred and know how to perform in accordance in order to obtain correct data;
- To add data concerning all disciplines components over the unique and centralized BIM model, meet its organization and learn how to establish effective management of information;
- To extract data from the model and to define the usual documents usually required in the construction project.

As an approach of training and learning how the BIM involves various aspects of the project, namely, the initial architectural component, it was proposed, in each new academic year, the implementation of a complete project over a distinct real case study. The student initializes the contact with the BIM methodology with the generation of the architectural model, and then proceed with the development of the other components that complete he multidisciplinary building project. Different stages of the learning process was established:

- Creation the architectural model using basic parametric objects associated to graphic patterns and to physical proprieties of the material (Figure 1);
- Generation of the structural models, physical and analytical, and the reinforcements detail (Figure 2);
- Definition of mechanical, electrical and plumbing (MEP) model concerning the service networks of water supply and waste and of the electrical installation (Figure 3)
- Realizing the clash detection analysis between the modelled disciplines of the project (Figure 4);
- Planning the construction process with the association of several model components to the Gantt map tasks, creating 4D BIM models (Figure 5);
- Extracting the required information from the model in order to obtain tables of take-off quantities of components and material (Figure 6).



a b c

Figure 1: Model of the architectural component: parametric object of a slab (a), perspective of the model submitted to a horizontal cut (b) and a complete model(c).

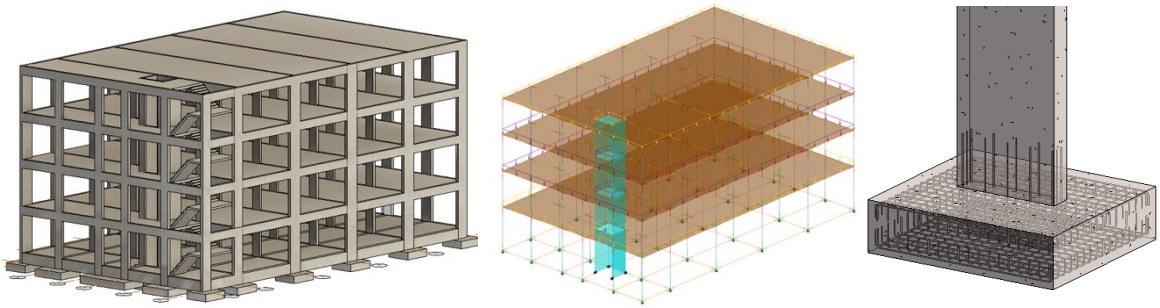


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Figure 2: Model of the structural component: physical (a), analytical (b) and reinforcements detail (c).

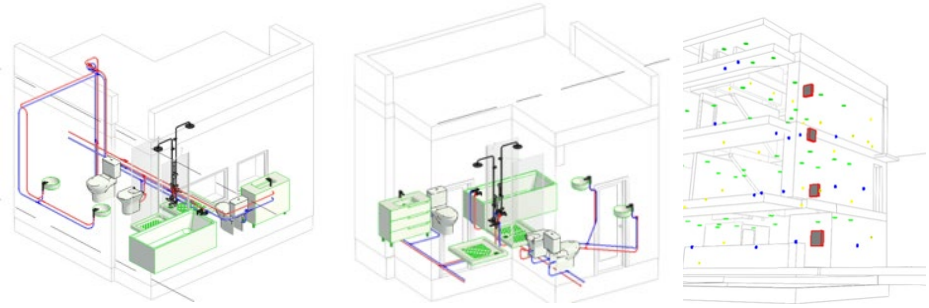

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Figure 3: MEP models of service networks: water supply (a), water waste (b) and electric system (c).

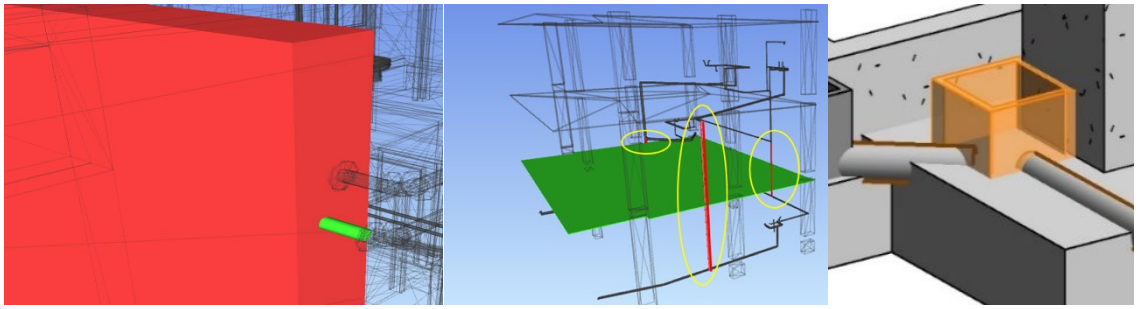

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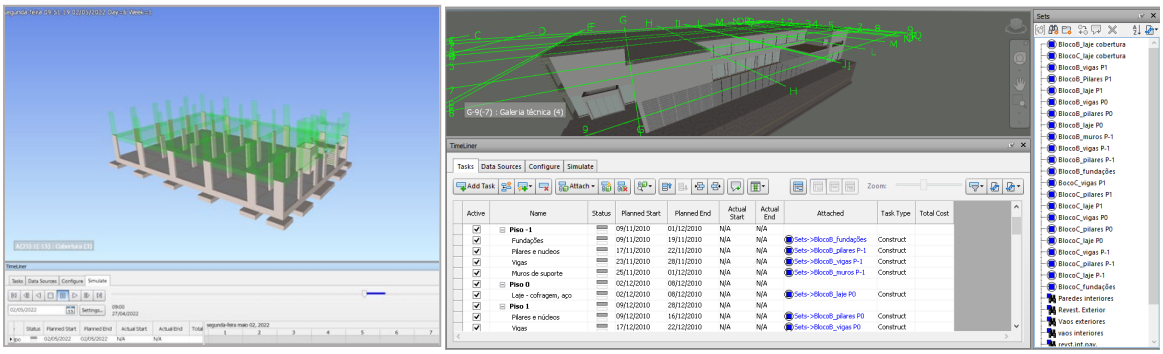
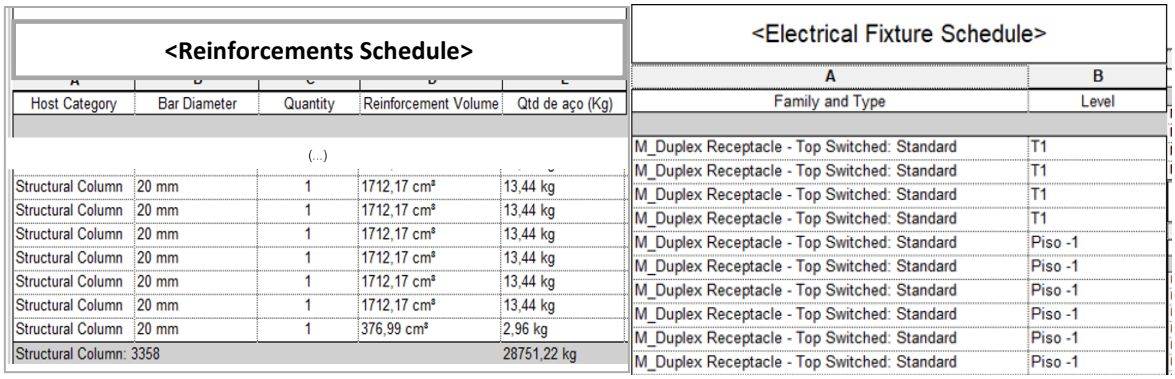
Figure 4: Clash detection analysis: between pipe and structure (a), water networks (b) and foundation (c).



a b

Figure 5: 4D BIM models creation: Foundation stage (a) and association of elements to Gant map tasks (b).



<Reinforcements Schedule>

Host Category	Bar Diameter	Quantity	Reinforcement Volume	Qtd de aço (Kg)
		(...)		
Structural Column	20 mm	1	1712,17 cm³	13,44 kg
Structural Column	20 mm	1	1712,17 cm³	13,44 kg
Structural Column	20 mm	1	1712,17 cm³	13,44 kg
Structural Column	20 mm	1	1712,17 cm³	13,44 kg
Structural Column	20 mm	1	1712,17 cm³	13,44 kg
Structural Column	20 mm	1	1712,17 cm³	13,44 kg
Structural Column	20 mm	1	376,99 cm³	2,96 kg
Structural Column: 3358				28751,22 kg

<Electrical Fixture Schedule>

A	B
Family and Type	Level
M_Duplex Receptacle - Top Switched: Standard	T1
M_Duplex Receptacle - Top Switched: Standard	T1
M_Duplex Receptacle - Top Switched: Standard	T1
M_Duplex Receptacle - Top Switched: Standard	T1
M_Duplex Receptacle - Top Switched: Standard	Piso -1
M_Duplex Receptacle - Top Switched: Standard	Piso -1
M_Duplex Receptacle - Top Switched: Standard	Piso -1
M_Duplex Receptacle - Top Switched: Standard	Piso -1
M_Duplex Receptacle - Top Switched: Standard	Piso -1
M_Duplex Receptacle - Top Switched: Standard	Piso -1

a b

Figure 6: Take-off of material´s quantity: structural columns (a) and electrical fixture (b).

2.1 Programmatic Content of the BIM Issue

The curricular program of the syllabus consists of different modules' trying in order to address all topics that will be useful for the future civil engineer. The sequence of items starts from the generic concepts reaching a comprehensive use of all the information added to the centralizer BIM model, throughout the all course. The BIM model is composed of the selected disciplines (architecture, structures and services) and must contains all the information that later is needed to define drawings and maps of quantities or to support construction planning and building maintenance. The list of the main topics and the respective items are as follow regarding the adequate numbered sequence:

1. Introduction to BIM concept:

- State-of-the-art, application, benefits and limitations;
- Parametric modeling process;

- Model detail levels and project phases;
- BIM implementation strategies in enterprises.

2. Interoperability capacity and standardization:

- Information transfer formats;
- Collaborative platforms and systems managers of BIM projects;
- Limitations of BIM interoperability in design management.

3. Model of the architectural solution:

- BIM base tools frequently used;
- General aspects of BIM base software (interface, parametric objects and unit definition);
- Initial settings of the modelling process (orthogonal grids and level of floors);
- Selection and edition of parametric objects (walls, windows, doors, floors, and roofs);
- Display views of the model (drawing plants, elevations, horizontal and vertical sections, axonometric perspective);
- Getting information query (type of objects or materials proprieties).

4. Model of the structural solution

- Re-use of information of the architectural model overlapping the new component;
- Selection and edition of structural parametric objects (columns, slabs, foundations);
- Association of material and physical properties to objects;
- Transposition of geometric model to analytical structural model.

5. Structural analyses:

- Transposition of structural model to a structural analysis software;
- Verification of the correctness of the transferred information;
- Structural analyses;
- Definition of reinforcement details;
- Transfer of structural results information to the initial BIM model;
- Elaboration of details drawings of the structural reinforcements.

6. MEP model:

- Networks and services equipment;
- MEP software-mechanical, electrical, and plumbing engineering;
- Modelling of water and sewerage networks;
- Analysis of conflicts between components.

7. Construction planning:

- Establishing milestones in Gantt map;
- Generation of the 4D BIM model;
- Use of BIM viewers;

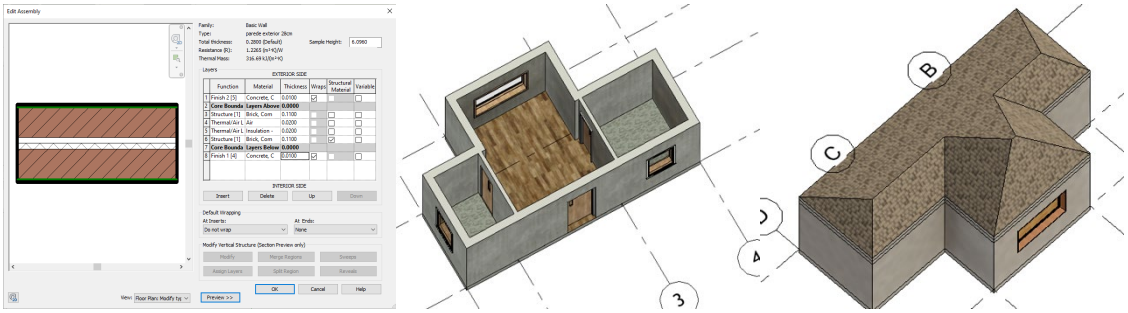
8. Extraction of information from the model:

- Maps of materials' quantity;
- Definition of technical drawings;
- Budgets estimation.

9. Coordination and management of information:

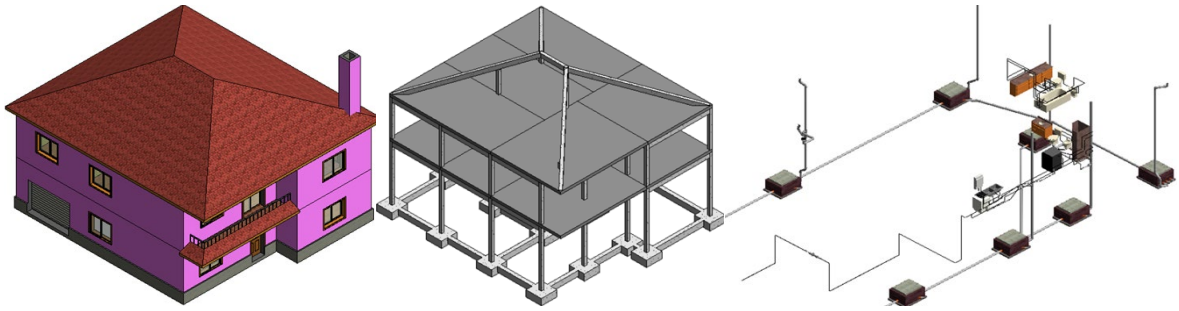
- Collaborative project (team and BIM work methodology);
- Analysis of advantages and limitations in BIM processes.

The students carry out the same exercises operated over a didactic example, a family house (Figure 6), and after they are invited to develop the same experience over a more complex and real case (figure 7).



a b c

Figure 7: Didactic example of a small house: parametric object (a), architectural walls (b) and roof (c).



a b c

Figure 7: Final project: architecture (a), structures (b) water waste system (c).

The workshops and the individual exercise were developed using the BIM software resources available in the computer lab of the Department of Civil engineering, equipped with the updated software required in the course.

2.2 Evaluation and Expected Results

The knowledge assessment is carried out on a final draft. A final and collaborative project is required to be developed by each student and it must include:

- Elaboration of architectural, structural and MEP models;
- Overlapping components and making the required analysis of conflict detection;
- Structural analyses including representation of detailed reinforcement drawings;
- Planning the construction process and defining the respective 4D model;
- Getting maps of quantities take-off and elaboration of budgets concerning several design stages.

For the preparation of individual BIM design concerning the application of BIM over real cases, a set of initial information is provided, composed of CAD drawings and the characteristics of the building components for a posterior comparison, between traditional way and BIM performance. This teaching methodology of BIM, makes students working in a collaborative way, more likely to work later in the context of the development of multidisciplinary projects in their future profession. The integration of all construction processes and the centralization of the created data in the unique BIM model, are the principal fundaments of BIM. The biggest drawback in this process is that each student does not develop in a balanced way its capabilities in relation to different specialties. However, the collaboration is needed and, bearing, transmission of knowledge is somehow made between the members of the working team. Performing a complex job and obtaining success is of course challenging and a cause for satisfaction for the student, making the students more confident in the individual achieved ability in using BIM in the development of future real projects. As a result, the students adds skills in the subject BIM:

- Along the course the student acquires knowledge concerning the applicability of BIM and its benefits in various areas of the project, as well as the working collaborative methodology inherent to BIM concept;

- The students are able to set important guidelines in the process of BIM implementation in an engineering office;
- The attendees are sufficiently capable to indicate which are the changes and the adjustments that must be made on the professional team and on the methodology practice, in order to establish collaborative platforms;
- The knowledge and training gained enables the students to perform with success the projects as may be requested by means of an innovative methodology, for which only a few engineers are currently trained.

In the national context, and in the current early stage of BIM implementation, the student, as a future professional, constitutes an important difference in a world of scarcity of job opportunities, motivated by the current enlarged activity of the construction industry.

2.3 Master Thesis and Professional Short Course in BIM

In the last academic years, the search for BIM theme in Master thesis context, has been great. The thesis' supervision has been one of the teachers' activity most involved in the BIM subject. All evaluated thesis were inserted in the digital platform of IST allowing its consult by the students of the Civil Engineering Department. Below are listed some of the most recent research works (Figure 8):

- Moreira, N.A, Application of BIM methodology in the maintenance of railways (Moreira, 2024);
- Figueiras, J.P. Contribution to the implementation of BIM methodology in structural design: case of box-section viaduct (Figueiras, 2023);
- Sarmento, R.S. BIM implementation in multidisciplinary project development: 4D and 5D models and VR integration (Sarmento, 2023);
- Gomes, N.E., Analysis of BIM technology capabilities in the generating of 4D models (Gomes, 2022);
- Sequeira, P.M., Structural design in a BIM environment: technological advances in information transfer (Sequeira, 2022);
- Azevedo, G.F., Implementation of BIM methodology in structural design: adaptation of procedures and information management (Azevedo, 2022).

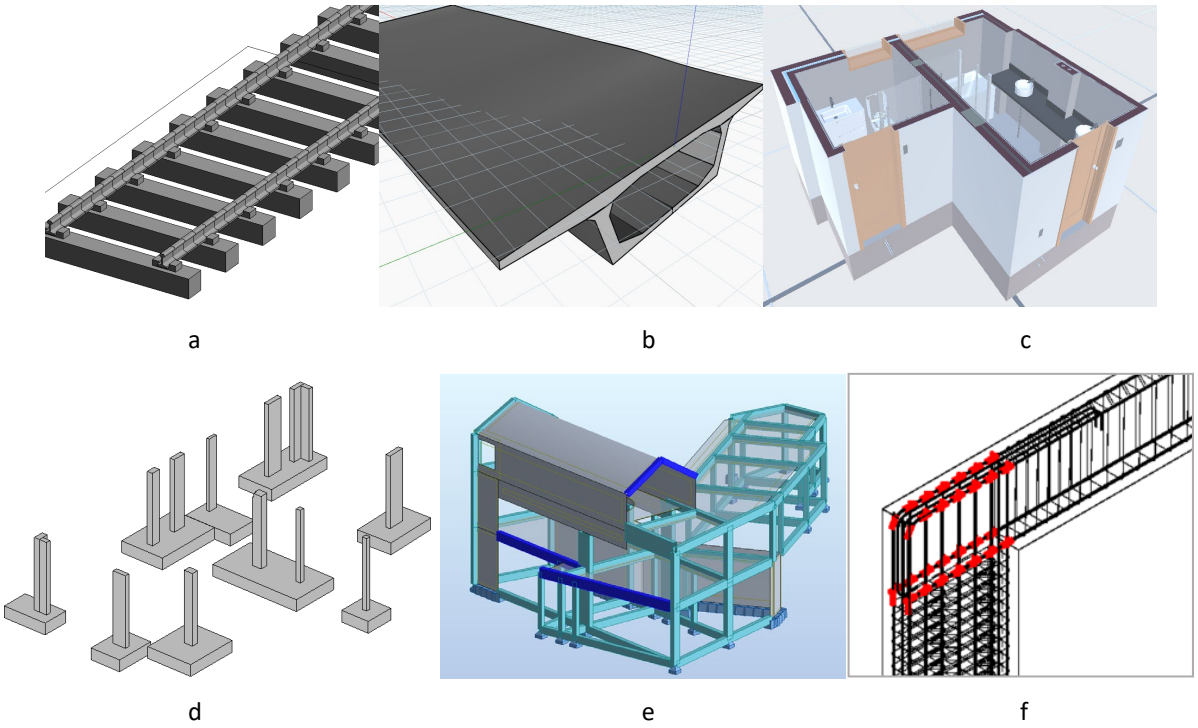


Figure 8: Master thesis: railway (a), viaduct (b) VR/AR technology (c), 4D model (d), structure (e) and reinforcement (f).

Additionally, within the Department of Civil Engineering of the University of Lisbon, BIM professional workshops have been organized. The last short course that was offered in November 2024, includes the basic notion of BIM, its implementation degree worldwide, and the large range of BIM applicability required distinct in a complete project (Figure 9).

a b c

Figure 9: Images presented in a BIM professional short course: architecture (a), structures (b) and sanitary room (c).

3. Conclusions

The Department of Civil Engineering of the University of Lisbon follows the newest advances in technology that can be applied in the Construction activity. The BIM methodology, its concept and the available based tools are important issues to be taught to civil engineering students. The present report describes the curricular program approach of an academic unit proposed and applied in order to introduce this emergent topic in the scholar activity.

The motivation and contextualization are referred in detail as well as the teaching methodology. Some examples that were worked out in classes by students follow the detailed programmatic content; some images, presented along the text, illustrate the positive result achieved with the course. Other activities supporting the course are also described, namely, master thesis and short professional courses.

As referred, BIM implementation is a new process that requires study, practice, research and dissemination. The described teaching work is a positive contribution that goes in the right way in the digital transformation of the construction industry.

Ethics Declaration

No ethical clearance is needed

AI Declaration

No AI tool was applied.

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