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BIM Manager Role in the Integration and Coordination of Construction Projects

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Abstract: Building information modelling (BIM) methodology has been implemented in the construction industry, reaching all sectors: multidisciplinary design development; construction planning and monitoring; and building management and maintenance. A complete BIM project aggregates several disciplines and different professionals skillsets. In order to achieve a suitable control, contributing to improve the quality of the project, a BIM manager is required. The BIM manager has the responsibility to coordinate all tasks involved in a building design, as well as the associated activities usually that are normally worked-out, complementing the project. During the development of a project, a BIM manager can access various discipline models, located in a delayering shared platform, and request responsibilities and amendments if inconsistencies are detected. The relevance of the BIM manager function is illustrated with three building cases where distinct specific projects, disciplines, and tasks were elaborated: collaboration between disciplines (architecture, structures, and construction); structural analyses and reinforcement details; quantity take-off of materials and cost estimation; construction scheduling and simulation. Although there are limitations in the software interoperability capacity, within the elaboration of a multiple stage project, BIM implementation in the construction industry has been carried out. The present study shows that the BIM manager role in projects aggregates several disciplines and experts, bringing an important improvement in the quality of the final product. A suitable BIM implementation in the construction industry needs to be supported by the most current advanced technology and in adequate BIM manager coordination.

Keywords: building information modelling (BIM); BIM implementation; BIM manager; responsibility; coordination; integration; multidiscipline

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1. Introduction

Building information modeling (BIM) is a methodology demanded to support the design process and all building phases. Currently, it has been implemented in a wide range of infrastructures, making a positive difference in the global construction industry. A BIM platform can be considered as a useful resource for multidisciplinary coordination, extending the BIM three-dimensional (3D) modelling scope into the construction planning and after, and in the operation and maintenance stages. The BIM practice is applied as a part of the hand-over of the construction buildings, from the contractors to the owners. The main boost concerns mainly the capacity of improving the integration and collaboration among all professionals involved in the project, construction, and occupation of a building. During the interdisciplinary integration, in order to archive all design data and to support the elaboration of a large set of tasks, several complementary data must be created, manipulated, and collected in a centralized BIM model [1].

A BIM model is a 3D digital representation of a building and it is generated and updated along the entire life cycle of the infrastructure. In it, a BIM manager is required to guarantee the confidence, accuracy, and completeness of the data of the final project solution. Focused on the integration and collaboration of several experts in a building design, the role of a BIM manager has emerged as a necessary adjunct professional, in the coordination of BIM-enabled projects [2].

The most advanced technology is required to define efficient BIM models. However, the software used in integration between steps and experts still presents interoperability limitations [3]. In a collaboration-based BIM model, this type of limitation introduces several important problems, namely, reworks and errors regarding the BIM model development. As the BIM manager and the engineer team are normally located in different departments and offices, a centralized platform is needed to share the latest real-time BIM model contributions. In it, an effective collaboration-based BIM model progress management is required [4].

Approaches for data exchanges in BIM collaborative environments have been analyzed in recent researches, namely, oriented to the scope of incrementing the control of the BIM work. These investigations are related to the identification of parametric objects and to the production of complete and partial models. Capturing and representing buildings requires a highly interconnected design information of built facilities. This aspect has been subject to extensive investigations over the past decade [5,6]. The application of affiliated techniques can range from routing problems in complex networks to data fusion problems, and dependency representations in load-bearing systems [7].

What does a BIM manager do? The professional is responsible for the BIM strategy and its execution, acting as the guardian of the model created, developed, consulted on, and delivered in a complete building context, including design, construction, and operation [8]. In the interdisciplinary coordination work, the manager is able to open all project model files, archived in native format or in industry foundation classes (IFC) format, to establish an updated and complete global consolidated BIM model [9]. IFC models can lead to potential solutions for effective management of collaboration operations with BIM. IFC format is usually available to represent and share material information between partners involved in the project. However, this format has its own constraints to enable efficient data sharing amongst stakeholders [10].

The role of a manager can be settled in project offices, building enterprises, and construction contractors. It can be seen currently as a challenging start-up activity that is focused on the offsite production of projects. The BIM environment practice needs to be supported in roles and responsibilities of BIM specialists that must be well-defined across BIM users, following best practice guidance, as frequently there is a lack of definition of client-side roles in the BIM process [11]. Collaboration on BIM models involves iterative and distributed processes meaning the reuse of the information is exchanged directly between models in a collaborative environment [12]. One of the commonly recurrent purposes established in BIM guides and standards concerns achieving a higher degree of project collaboration [13]. A BIM manager is required, in particular, in buildings of an important volume and complexity:

- To **incentivize** the collaboration at work and to control responsibility given to each involved professional;
- To **guarantee** the correction of the amount and quality of the information included in each BIM model phase and transferred between tasks, requiring the performance control of distinct steps of data exchange;
- To **coordinate** all designs and the distinct mandatory activities (conflict detection, cost estimation or energetic simulation);
- To **verify** the level of development (LoD) of the BIM model in a transfer operation, concerning the volume and type of data required in each step;
- To **analyze** and **control** all required data workflows.

The current LoD classification of BIM models concerns the overall state of type, quantity, and quality of the information inserted in the centralized model, at each particular stage along the development of a complete project. This concept includes not only graphical objects, but also the data associated with the objects. LoD was first introduced by the

American Institute of Architects (AIA) in 2008, when it defined five different levels of development to define the detailing levels in a BIM model [14]. The AIA organization defined all the parameters and details associated with a digital model accessible for the team members at various stages of the design process.

However, current reports describe the development of various project phases using BIM advanced technologies, but some lack of information was found concerning refurbishment and demolition, or the assessing of sustainability information about the interoperability among BIM software (https://en.wikipedia.org/wiki/Building_information_modeling), namely, between energy simulation tools [15]. BIM allows a continuous use of digital building models throughout the entire lifecycle of a building, starting from the early conceptual design and detailed design phases, to the construction phase, and the extensive phase of facility operation. Along the development of distinct integrated stage, BIM expressively recovers data and facilitates the required information flow between stakeholders involved at all stages. As such, BIM increases the quality of the final product, supported on an efficient coordination, by reducing the labor time consumed on the re-entering of information, because of some misunderstanding or omission of data [16]. Other topics focused on the green building aspect. The implication of an organized BIM model have improved the sector of energy consume safety, analyzed during the building design stage [17]. In it, BIM is useful in contributing to an effective design progression and information availability, contributing to improving the efficiency of the buildings [18].

Various standards and guidelines have been defined on national and international levels to structure the workflows of collaborative design projects in the construction industry. The available standards describe mostly the process-related aspects and promote BIM-based collaboration using a federate multidiscipline model, including several components and tasks. Each domain works predominantly in an independent way on their respective component of the centralized model. An interdisciplinary coordination can be performed by combining the available discipline models into an integrated model. The present study concerns the coordination and integration aspects in a BIM manager perspective:

- **Problem statement:** Across the complete BIM model, the manager should be able to verify the existence of conflicts and the detection of eventual inconsistencies, and then proceed to warn those responsible of the identified problem. The aspect related to the management of the global project and the applications and functionalities provided for support this work is not yet widely disseminated in the scope of the construction industry. Knowing BIM does not mean knowing engineering and vise-versa, and as such, a BIM manager is required to connect both knowledge, improving the quality of the final product;
- **Scope of the paper:** The main objective is to show that the BIM manager role in projects aggregates several disciplines and experts, bringing an important improvement in the quality of a building design, reflected in the quality of the final product. The report analyses distinct cases associated with activities that the manager must take care of. The identification of the of type of works and the respective reasonability were carried out along the presentation of concrete situations. The most relevant responsibilities were identified. The principal considerations about the necessity and functionality of a BIM manager were carried out. The data transfer and complementary tasks developed over each project case show clearly the necessity that the enterprises must support the elaboration of a project under a BIM manager;
- **Methodology and contribution:** A first research work was conducted, focused on the relevance and the current involvement of the BIM manager as a new job in a BIM project environment. The case studies pointed out distinct relevant aspects of interest to be disseminated among BIM professional and construction enterprises. The study and the principal final remarks contributes positively to a better knowledge of the BIM manager work. Supported by this dissemination, an empowered final product is achieved.

The present study presents building cases where distinct specific projects and several tasks were developed, namely, conflict detection, structural analyses, cost estimation, and construction scheduling. All activities were worked out from BIM models created in construction planning and structural analyses contexts. The study demonstrates the large domain of BIM applications and the relevance of the BIM manager professional to improve quality and agility in multidisciplinary projects.

2. BIM Manager Characteristics and Function

The BIM manager is a professional with a background in engineering construction or architecture design with experience in collaborative work development, concerning design or construction coordination, and with knowledge at the forefront of the digital technology field [19]. This activity is an innovative and dynamic business that operates in an industry sector that has grown substantially lately. The ascent of the BIM application has attracted a new perspective of various competencies and responsibilities required of the role. Currently the engineer and architectural companies have been accepting the relevance of the BIM manager function [20]. This professional is involved in the management and delivery of client's information and construction projects requirements, being an important protagonist of significant relevance to the business:

- **Coordinates** the BIM design procedure, the technical authoring, the data verification and validation, the clash detection analyses, and the delivery of asset data from project inception to completion;
- **Collaborates** with internal and external stakeholders, organizing and chairing all necessary meetings and information reviews, either remotely or at design team meetings, and defines the digital information requirements of all the BIM project [21];
- **Leads** the team involved in the project when working in a multi discipline environment [22];
- **Provides** the project models and data auditing between steps, verifies the quality control, and assesses adherence to standards of all received deliverables throughout the lifecycle of buildings [23];
- **Works closely** with the design manager to support successful delivery of the digital aspects of the project from conception to completion and supports the management of software packages, including advising on when to upgrade to new versions and the need for software customization [24];
- Demonstrates current **experience** with BIM platforms and a great understanding of project processes, data workflows, contractual obligations, and use of BIM software [25].

In a collaborative process, developed in the context of a company that admits multiple specialties and activities, the project is controlled and shared through Revit's project browser functionality. Each performed component or task is referred to as a view of the global model. The distinct design views must be properly organized, specifying whether the view refers to imported computer-aided design (CAD) drawings, or data supported by the model, namely, tables of materials or components, or drawing sheets properly composed with cuts, views, and captions, constituting updatable dynamic components. The manager should demonstrate an agile handling of these kind of functionalities available in BIM software.

The BIM manager works on the quality of the project base in the completeness of the model. To achieve the required design value, the professional must align communication between all agents with regard to the flow of information, dates, and delivery files. Previously, all accords had to be contracted between the parties and the priorities that were set out [26]. The expert, in general, does not model or design, but has an important role in the strategic definition and management of the BIM implementation plan, a document previously established and associated with each new project [27]. This plan presents guidelines and criteria for implementing information modeling in a given enterprise. It determines, for example, the model applications, the responsibilities in all parts of the project during its development, the milestones and deliveries, the coordination rules and BIM software, the LoD required in each transfer step, and the required plugins or extensions that will be adopted.

In the last decades, there has been a construction technological evolution and BIM managers are in high demand. The main skills necessary for the BIM manager involved in innovative and major schemes across the built environment can be listed as requirements and desired competencies:

- **Knowledge of BIM software**—the professional should know the systems available in the market for different disciplines and uses, but should not necessarily be an expert or a qualified programmer. This includes architectural and structural design procedure and software used (from Autodesk, Graphisoft and Bently houses), knowledge about hydraulic and electrical installations, software mostly applied in construction planning and simulation (MSProject and Navisworks), manage visualization and rendering capacities of the most used software, familiarity with conflict detection software (Solibry), and with collaborative platforms (OpenBIM) [28]. The manager must have knowledge about what extensions (Reinforcement) or plugins (Dynamo) are planned to be used in each project delivery step and how to manage the model to extract quantities of objects or distinct type of material, supporting decisions concerning deadlines, quality, and specific details discussion with the experts of each area. The manager must have also knowledge about the interoperability level between different developers' systems and know how to work with IFC formats [29];
- **Experience in building project** and **strategic vision**—relevant experience in projects and technical knowledge is required. A BIM manager must have adequate competence to actively participate in strategic definitions, and pay attention to identifying errors in the model that can gain greater proportions in a complex project, later in the construction phase [30]. In the traditional process, the warning of problems is often achieved through emails with details evidenced about the digital drawings and added comments to indicate the problem that requires resolution. The information that is archived in IFC format is the coordinates of the place where this problem was found, the user's display parameters, and the intended comments related to the error (the inconsistency description, the deadline for correction, the person responsible for changing it, or the type of priority). This is a type of warning procedure that can be used by the BIM manager when supervising the growing of a global model of a multidisciplinary project. The manager must be able to lead with BIM delivery of large complex projects, requiring an adequate experience across a number of sectors at all design stages and a good understanding of buildings design;
- **Modelling and attention to detail**—the BIM model is a virtual construction and the quality of the model must be approved by the manager, and for that he/she must know how a building must be designed and executed. All information contained in the model must be coherent and organized, avoiding posterior problems, errors, or omissions in the construction work place. The BIM model allows teams to see the project virtually before it is built, which can help to identify mistakes and inconsistences in an early design stage, and support the ability to create sustainable buildings. The BIM manager must learn about new software and the most recent technologic achievements that can help the companies to improve the way to doing better business [31];
- **Communication and integration capability**—the work of a BIM manager requires liaising across many disciplines and companies and, as a project coordinator, they must easily communicate with different interlocutors, such as the client and all members of the project team, respecting different views and expertise. Although some professionals have more experience in construction, BIM is still in a global process of maturity, and so many BIM concepts, practices, and patterns are still being implemented. Therefore, an understanding between traditional professionals and BIM handlers is required;
- **Responsibility in delivery and coordination**—the BIM manager must ensure a high-quality service and provide the best technical solution and digital deliverables for the client, through all stages of the project, construction, and operation. The primary responsibility is to manage and coordinate BIM standards implementation and enforce-

ment on all related BIM projects, file documents, and digital models. The manager, working alongside the project director, follows the production and the control of a BIM project, planning and deliveries, through all stages, fully supporting the BIM teams assigned to it;

- **Active BIM**—currently, a new approach named active BIM is emerging in the construction community, connecting optimization techniques and BIM [32]. Dynamic systems, which connect BIM with analytical functions or solution techniques such as optimization methods, represent the active BIM concept. It concerns the accomplishment, the challenge, and the potential of BIM implementation to facilitate the developing of the area of the BIM model. Such a concept brings efficiency to building alternatives that can be evaluated during the design or the construction phases [33]. Management during the construction process could be improved using real-time communication and collaboration with devices that integrate BIM.

3. Materials and Methods

As a methodology, the upper **preliminary text** introduces the recognition that the development of BIM projects and associated tasks requires the intervention of a professional with knowledge in BIM, with the function of delivering, with correctness and responsibility, the global model within the various stages in which the transfer of data is required. In the next items, the BIM manager action was worked out from three **case studies**, in order to illustrate the type of involvement and the relevance of this BIM expert, within the elaboration of multidisciplinary projects (Figure 1):

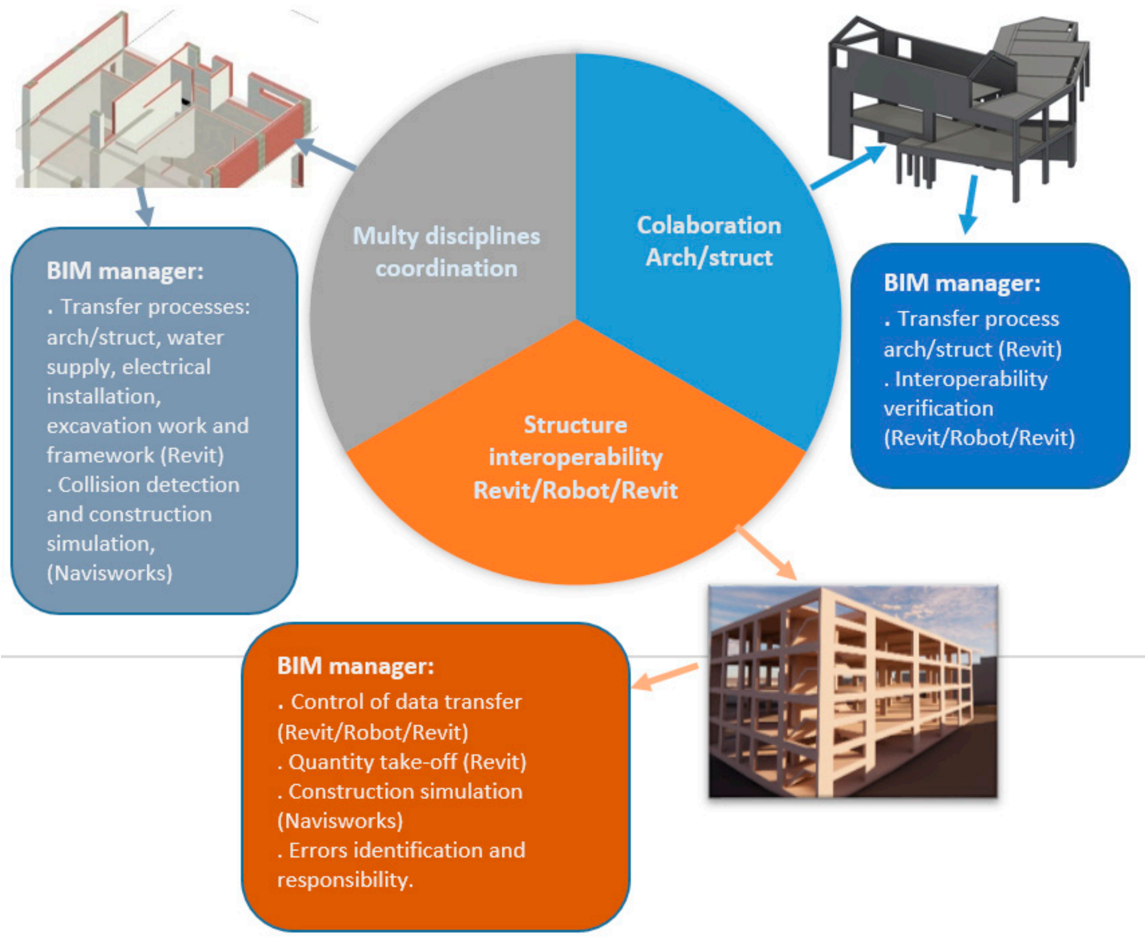


Figure 1. Case studies and type of BIM manager actions.

- **Design collaboration**: In the first case, an initial architectural project was defined, followed by the elaboration of a reinforced concrete structural solution. In collaboration with the architectural office, changes to the architectural design were studied, with direct implication in the structural solution. A BIM manager, established at the beginning of the process, supported the control of the two-way routing between the architecture and structures. Subsequently, during the structural analyses, which are processed in the structural software, and after the required transfer of the reinforcement detailing to the modelling software, the BIM manager carries out the quality control of the information that is transferred between both software, and evaluates the degree of interoperability;
- **Interoperability in structural design**: A preliminary structural solution was generated using Revit, and a first inconsistency verification was made. The transfer of the structural model between Revit (Autodesk) and Robot (Autodesk) and after, a more complete model was transferred again to Revit (Autodesk), in order to centralize all data, which was supported under the work of the BIM manager. Supervised by the BIM manager, the conflict detection, construction planning simulation, and the take-off of materials were performed over the complete structural model. An exercise concerning the detection of inconsistency and emission of warnings was also considered, as well a reference to the virtual reality (VR) technology that has been improving BIM performance in construction design;
- **Multidisciplinary project**: Beginning with the generation in a 3D BIM model of the architect and structure projects, other disciplines were developed and overlapped. The BIM manager controlled the transfer of the first model (architecture) to experts of water supply and electrical installation. After, a conflict detection analyses was realized, forcing some adjustments to the initial solutions of those disciplines. In addition, other necessary discipline projects were also performed, related to the excavation and frameworks.

The parametric BIM model supports a great level of **integration**, **communication**, and **collaboration**. The BIM manager must establish, at the beginning of all processes, a BIM execution plan (BEP), a document that defines how a BIM project must be developed and delivered among all experts involved [34]. The manager uses the Google Drive platform to store the files and to aggregate the team of experts. The platform allows for supporting the type of access permitted by each discipline responsible [35]. To obtain optimal schedules, engineers often need to develop separate optimization models with special tools, which, however, demands further processing and editing of optimization results into forms expected for project management. In this regard, separation of optimization requires considerable additional work for complete and harmonized updating of schedules during construction execution [36]. All of the mentioned aspects are reported in the text, after the description of each case. In summary, the main contributions presented in this text are:

- Pointing out the main **requirements**, **functions**, and **activities** related to the performance of a BIM manager in multidisciplinary projects;
- Evidencing the type of **collaboration** and **coordination** required in several mandatory steps identified alongside the elaboration of academic cases projects;
- Selecting of three specific cases allowing for the illustration of **distinct aspects**: the communication architecture/structure; the transfer Revit/Robot/Revit and the interoperability degree analyses; a building project including several disciplines requiring overlapping and integration;
- The **importance** of the manager is identified in each model transfer and combination of disciplines, revealing important remarks useful for a global BIM community.

Referring to the consulted literature, the present study, supported by the selected works developed and described in detail, brings a positive contribution in positioning the BIM manager among the project development process. There are several situations where the professional is required, namely, in delivering responsibilities and models within the team, in verifying the LoD of each model in the transfer processes, in validating the consistencies of the models, and in controlling the data extract from the models. All these aspects were carried out in the selected project cases. As such, the present text is useful to the BIM community, in the context of the project of structures and of the multidisciplinary integration.

4. Case Studies

The selection of the project cases considers a wide range of actions that the BIM manager must work across. As such, the strategy of the study considers the description of projects involving multiple disciplines, showing in detail the limitation found in the main transfer processes and in the development of all tasks supported across the BIM model database, where the supervision of a BIM manager is required. This study highlights the overall contribution of the BIM manager in the iteration and data transfer involved in controlling the collaboration transactions in a BIM data repository in a multi-model collaboration environment.

The selected illustrative examples of building cases demonstrate clearly the complexity in organizing and coordinating multidisciplinary projects. Several situations of collaboration between disciplines were made, the interoperability capacity was evaluated, some corrective solutions were performed, the clash detection analyses were verified followed by adequate adjustments and, after, drawings and tables of quantities were obtained over the centralized BIM model. The BIM manager controls all the processes where data transfer is necessary, contributing to the correctness of the model that is created, handled and increased with new disciplines or phases, resulting in a better final project. The BIM manager action is pointed out in each case.

4.1. Collaboration between Architecture and Structures

Following the progress of the dynamic process established between architectural and structural offices, a single-family house, located in the archipelago of Azores, Portugal, was selected [37,38]. The level of development of the building project was in a very early stage, allowing us to follow the architecture process together with the structural solution elaboration. The process of creating the architecture design admitted several alternative options, providing an interesting illustration of how BIM model constitutes an adequate work-base and an understanding of coordination between the activities of the architect and the structural engineer. The BIM manager coordinates all delivery processes, made in both transfer directions, following all steps of the model growing and admitting several changes along its progression. The experts involved, using BIM software, and controlled by the manager, easily follow the adaptation studies applied over both disciplines.

An architectural initial BIM model was first created, after a first suited structural component was defined confined to the architectural constrains. To initialize the architectural model, a set of technical drawing were inserted in the modeling software Revit (Autodesk), serving as the base of working (Figure 2).

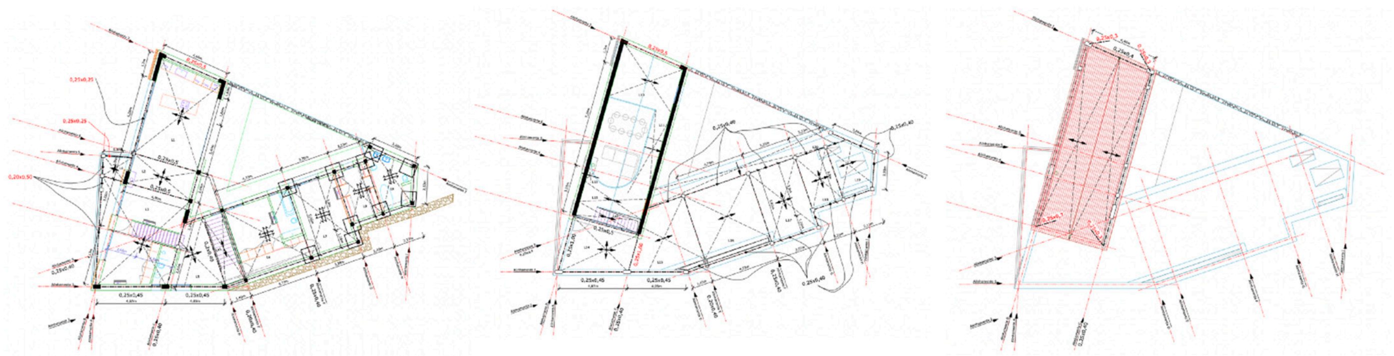


Figure 2. Architectural technical drawings.

Then, using the same software, a first structural solution was modeled (Figure 3). Both models were defined one over the other, helping the structural engineered to choose an adequate solution.

Figure 3. The initial BIM structural model.

Along the process, distinct adjustments to the architecture was made followed by a new suited structural model (Figure 4). In all adjustments, the BIM manager coordinated the delivery of the architectural and structural models between the respective professionals. The collaboration establish between the experts in architecture and structure was greatly improved when compared to a paper-based design, as the communication was supported in a BIM model.

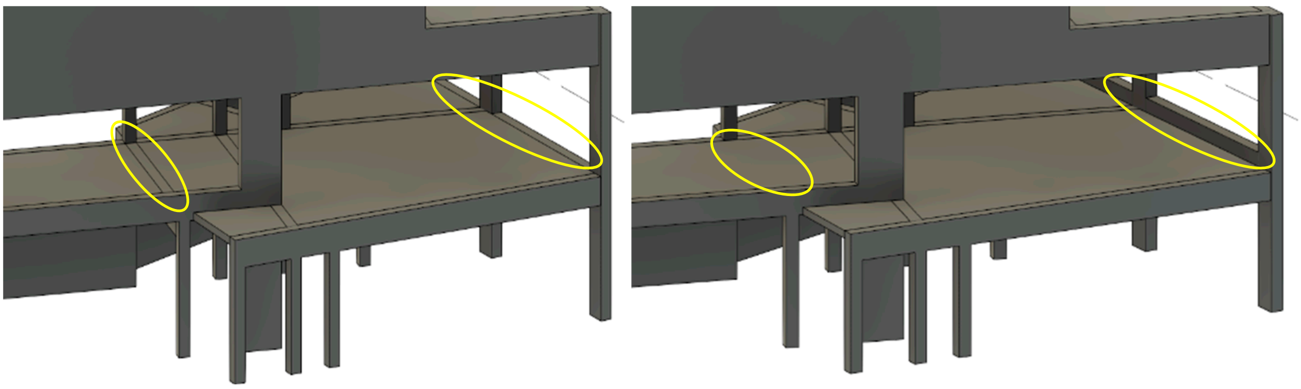


Figure 4. BIM structural model with changes applied.

4.1.1. Structural Analyses

To performed the structural analyses, the geometry consistence of the analytical connections was first verified in Revit and after in Robot (Autodesk). The BIM manager control the options for transferring the correct material and proprieties and updating elements such as foundations. The first selected options were *send model* and *update model*, and later to transfer the results obtained in the structural analysis to Revit, the option *update model and results*, was selected. In Robot, the loads and combination of loads were applied and the structural analyses was realized (Figure 5). For the determination of the seismic action, using the analysis mode parameter, the modal value was first changed to seismic, allowing the selection of the most relevant vibration modes for the seismic analysis, which are associated with a higher percentage of mass participation.

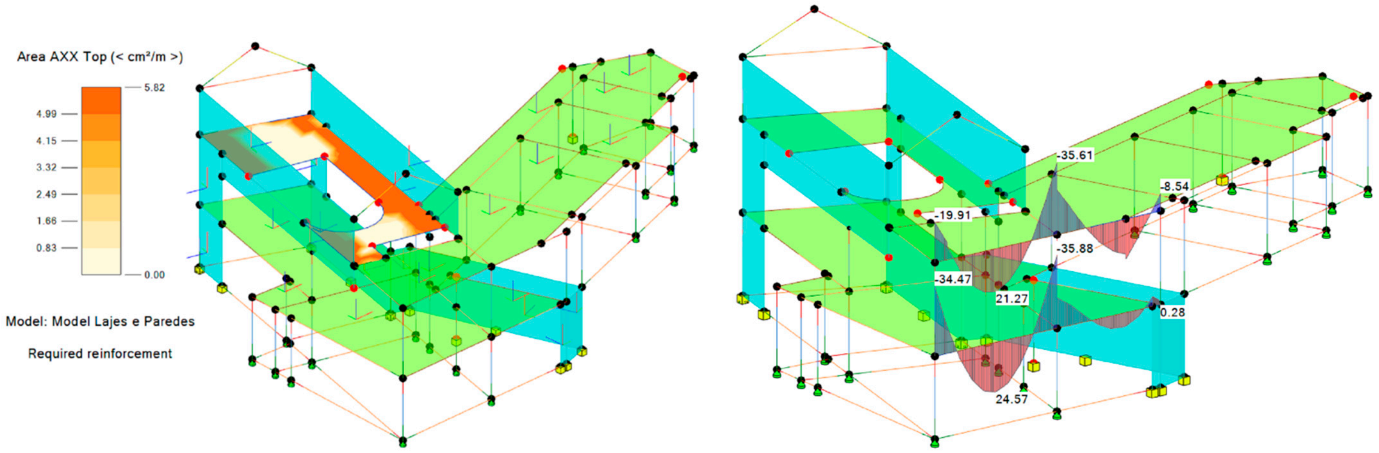
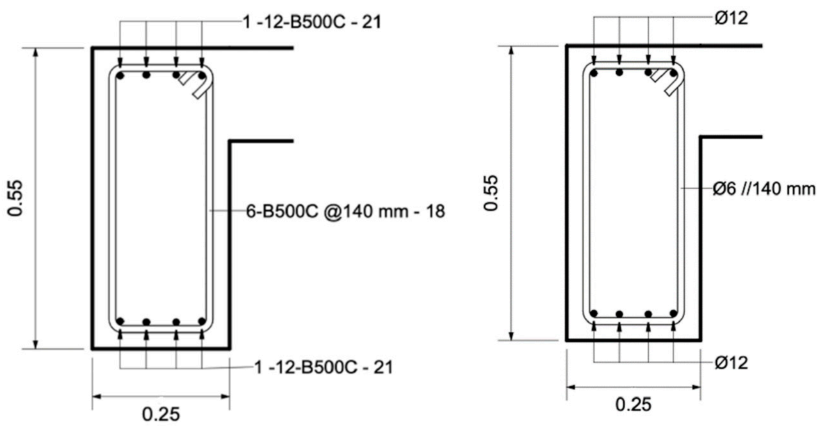


Figure 5. Results of the structural analyses worked out in Robot.

Also supervised by the BIM manager, other transfer process was realized. The calculated reinforcements for each structural component were transferred to the initial software, the Revit, in order to complete the initial structural model. In this step, the interoperability capacity in the way Robot/Revit was evaluated. The interoperability capacity between both software was analyzed. Several inconsistencies were detected and the required adjustments were performed [38]. The interoperability level in a structural design is currently still a limitation. It was found that the information transferred in Robot/Revit direction still presented several flaws. All the problems were corrected in order to obtain an accurate and complete structural model. In it, the BIM manager coordinates all processes. For that, knowledge about the structural software available and the interoperability level capacity of the systems used is required as part of the BIM manager skills.

4.1.2. Technical Drawings

After, and conducted by the BIM manager, distinct complementary tasks were extracted from the final structural BIM model. The required drawings and the tables of quantities of concrete and reinforcements bars were obtained automatically. The technical drawings were generated as cuts applied over the 3D model, presenting an elementary aspect. Then, some annotative adjustments were made (Figure 6).



(**a**) (**b**)

Figure 6. Technical drawing before (**a**) and after (**b**) the application of annotative changes.

Although the modeling process was relatively simple, the generation of structural drawings, which effectively correspond to cuts applied over the 3D model, is more complex and time-consuming, in order to achieve an aspect similar to that is normally required in a paper-based project. However, the great advantage in relation to the paper drawings is that they can are dynamic, and as so when the 3D model admits design adjustments, all drawings became automatically updated.

The development of traditional drawings requires some work and mastery of handling the distinct functionalities of the systems. Revit allows the recourse to advanced functionalities, which can be developed as Dynamo script, concerning the insertion of annotation associated with drawings. Creating specific features, using the Revit plugin Dynamo, requires a long experience in graphical programming.

4.2. Structural Interoperability

The second study case is a building with several elevated levels, situated in Lisbon, Portugal [39,40]. Initially, a first Revit model of the established structural solution was created (Figure 7). The level of development of the structural project was almost at the end, but the aim of the academic study was to conceive a complete structural design recurring to BIM methodology and associated software. The transfer data processes and the analyses of the interoperability between the software (Revit/Robot) used was analyzed in detail. The role of the BIM manager in collaboration with the engineer were highlighted in the present study.

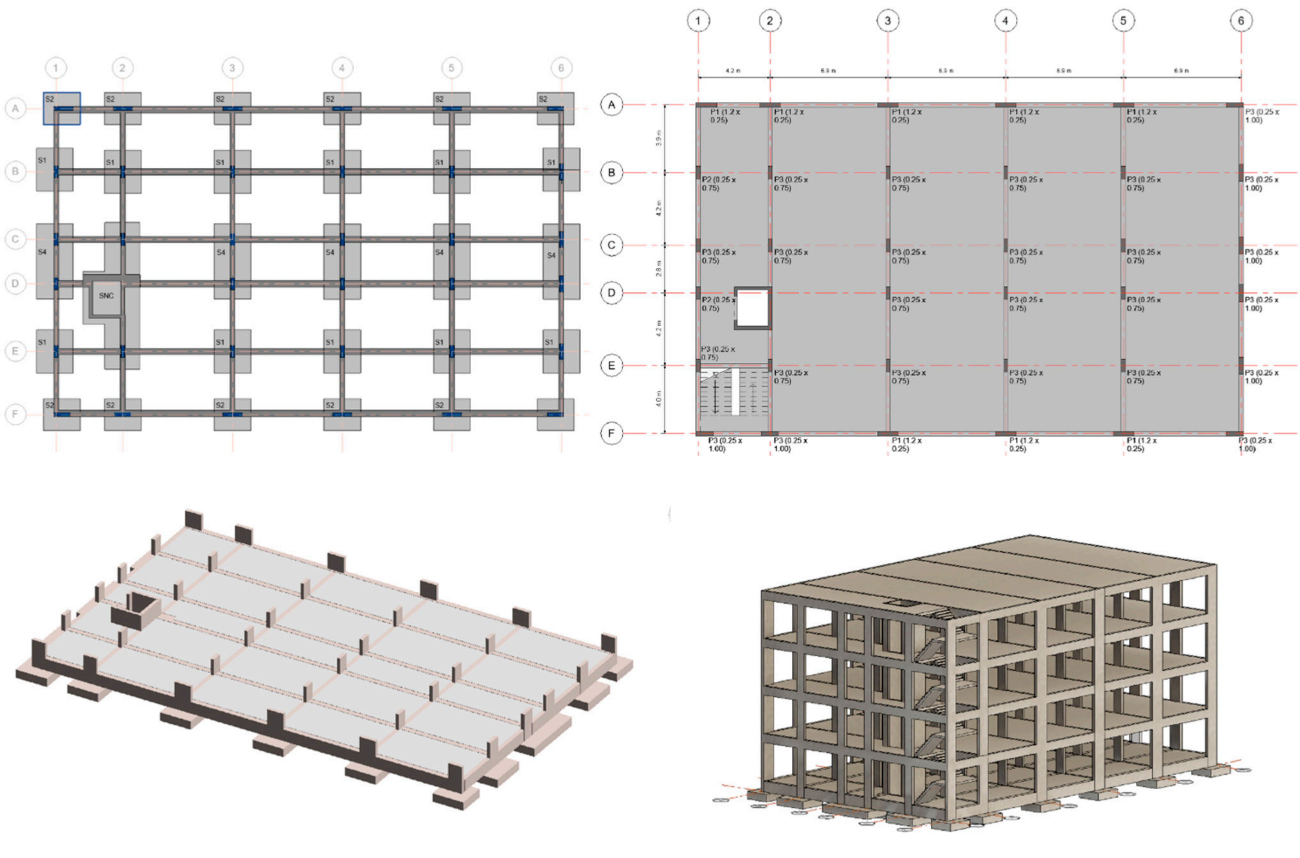
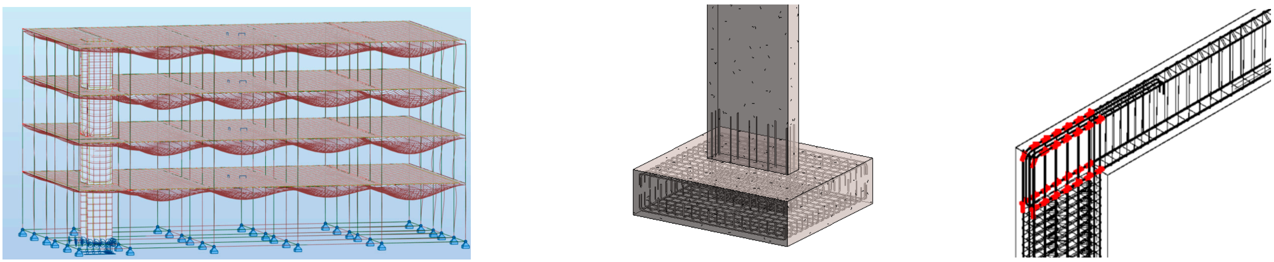


Figure 7. Sequence of the modelling process of the structural model made in Revit.

4.2.1. Structural Analyses

In Revit, the analytical structural model is checked, in order to guarantee the correct consistencies of the finite elements nodes connection. After this, it was transferred to Robot and the structural analyses was performed (Figure 8). Again, a BIM manager was responsible for controlling the efficiency of the BIM model transfer. After, the complete structural model, which includes the reinforcements of each structural element (slabs, columns, beams, and walls), was transferred to Revit.



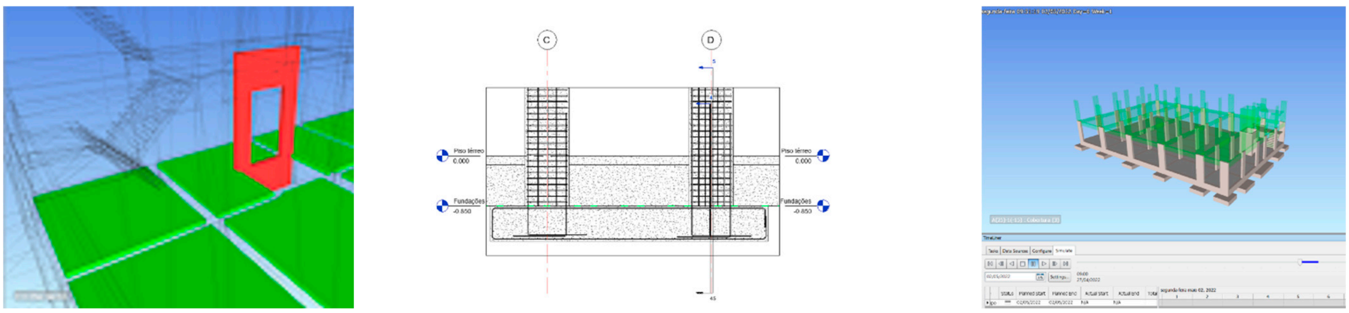
(**a**) (**b**) (**c**)

Figure 8. Structural analyses (slabs deflection (**a**)), performed in Robot, and the reinforcement (foundation (**b**), and beam (**c**)), detailed in Revit.

The BIM model is composed of a set of parametric objects, the most important concept of the methodology. This fact allows the user to extract several type of information from the model. In addition, it allows the professionals to enhance a high level of communication and collaboration within the project team, including the BIM manager.

4.2.2. Construction Planning and Budget Estimation

The generated complete structural BIM model presents an organized and centralized database covering all concrete components and the reinforcements bars calculated for each structural element. From the structural model, some task were carried out (Figure 9): conflict detection (Navisworks); preparation of technical drawings (Revit); definition of construction planning (Microsoft Project); generation of animated simulation (Navisworks); and obtaining take-off of several materials (Revit) from the budget estimation.



(**a**) (**b**) (**c**)

A	B	C	D	E
Category	Family and Type	Material: Volume	Material: Cost	Cost total
Structural Framing	Concrete-Rectangular	1.01 m³	120.00	121.254€
Structural Framing	Concrete-Rectangular	1.01 m³	120.00	121.254€
Structural Framing	Concrete-Rectangular	1.01 m³	120.00	121.254€
Structural Framing	Concrete-Rectangular	2.60 m³	120.00	312.480€
Structural Framing: 223		187.49 m³		22 498.474€

(**d**)

Figure 9. Conflict detection results (**a**), technical drawing (**b**), construction simulation (**c**), and table of concrete volume and costs (**d**).

4.3. Multidisciplinary Project

The third selected building case is composed of two elevated floors and two semi-basements. The house is located in a tourist bathing area near a lake, in Santarem district, Portugal [41,42]. In the present case, the academic intention on the development of the study was mainly to define a complete design including several disciplines, supported in BIM strategies. The relevance of the present study is to highlight the work of the BIM manager during all data transfer and the BIM data extraction.

In this case, the final model is formed by several disciplines (Figure 10): architecture, structures, water net supply, and electrical installation. All components of the centralized BIM model were defined using Revit software (https://en.wikipedia.org/wiki/Autodesk_Revit) and the parametric objects available in the libraries concerning each discipline.

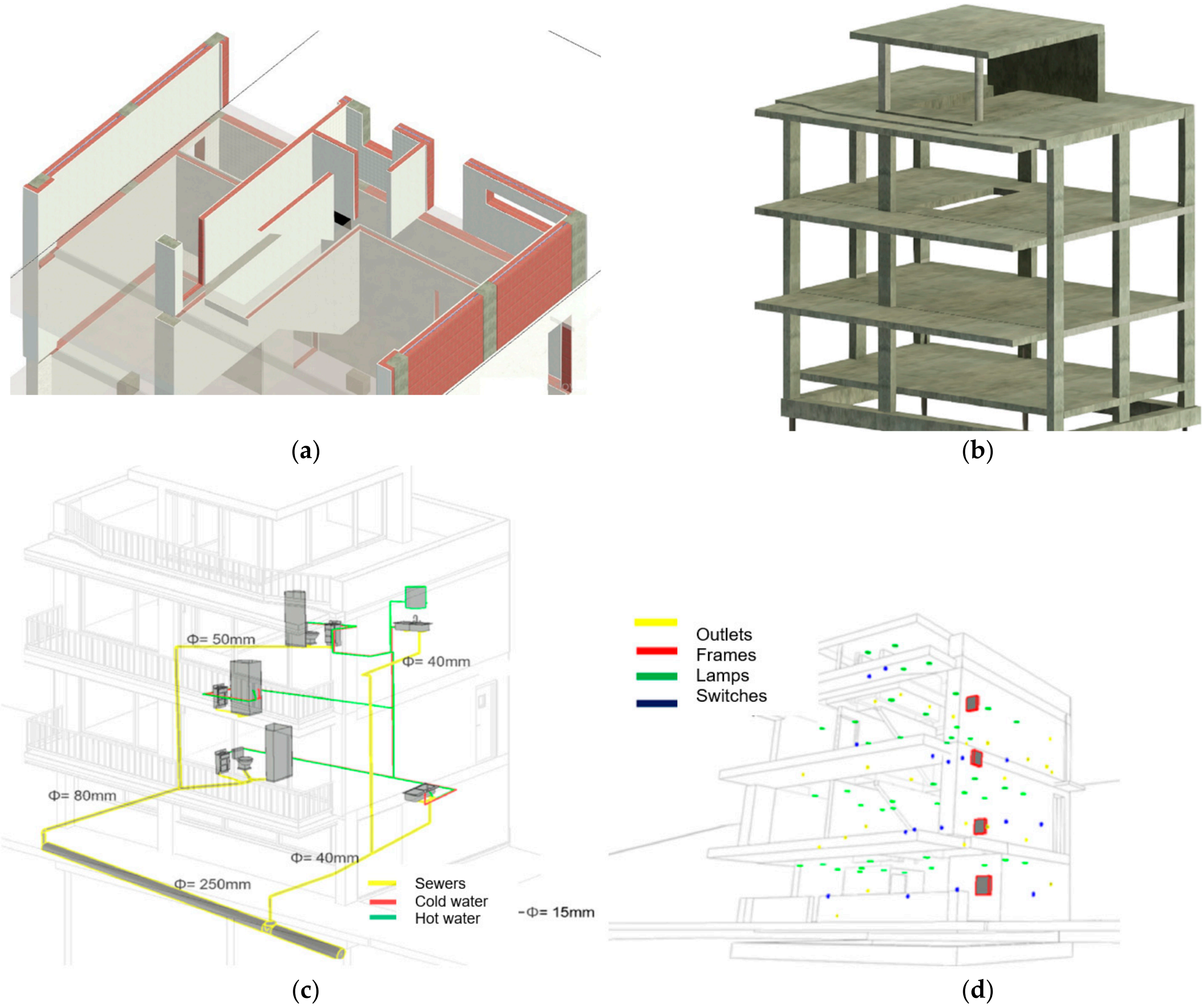
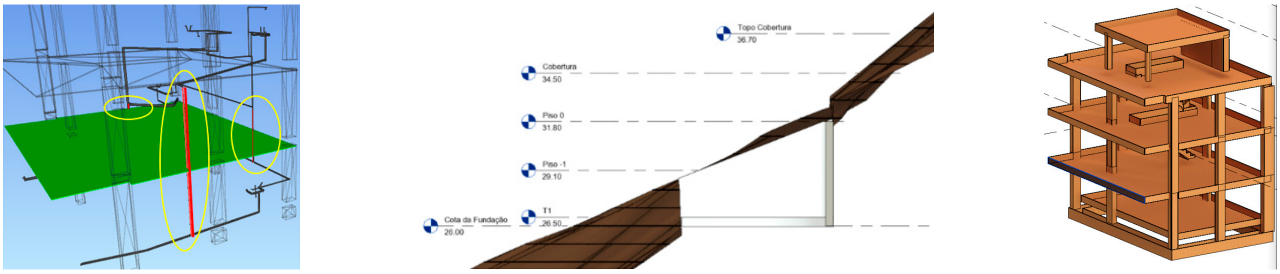


Figure 10. Components of the 3D BIM model: architecture (**a**), structures (**b**), water supply net (**c**), and electrical installation (**d**).

4.3.1. Overlapping Disciplines

All disciplines were created using an overlapped strategy where the architectural and structural components of the model can be visualized, along with conception of the water and electrical projects. A conflict analyses detection was performed, using the Navisworks (Autodesk) system, looking for errors or inconsistencies not previously identified.

The Revit model was transferred to the Navisworks software (https://en.wikipedia.org/wiki/Navisworks), using the native Revit format. In the detection analysis, some inconsistencies were found. Namely, between the water supply net and the architecture and the structural components of the BIM model (Figure 11a, red pipe colid with the slab). This type of analysis, made in an early stage of the BIM model generation, constitutes a positive improvement in the quality of the final product. In this case, the excavation work was also modelled (Figure 11b), as well the framework component used to form the structural elements (Figure 11c).



(**a**) (**b**) (**c**)

Figure 11. Collision detection (**a**), excavation work (**b**), and framework made in wood (**c**).

4.3.2. Construction Simulation

The construction planning of the structural component was defined using the Microsoft Project software (2020). After, the BIM model and the planning file were transferred to the Navisworks system. In it the construction activity schedule was linked, in a time liner, to the construction sets of elements (Figure 12). This system also allows programming a virtual presentation in an animated simulation presentation (Figure 13).

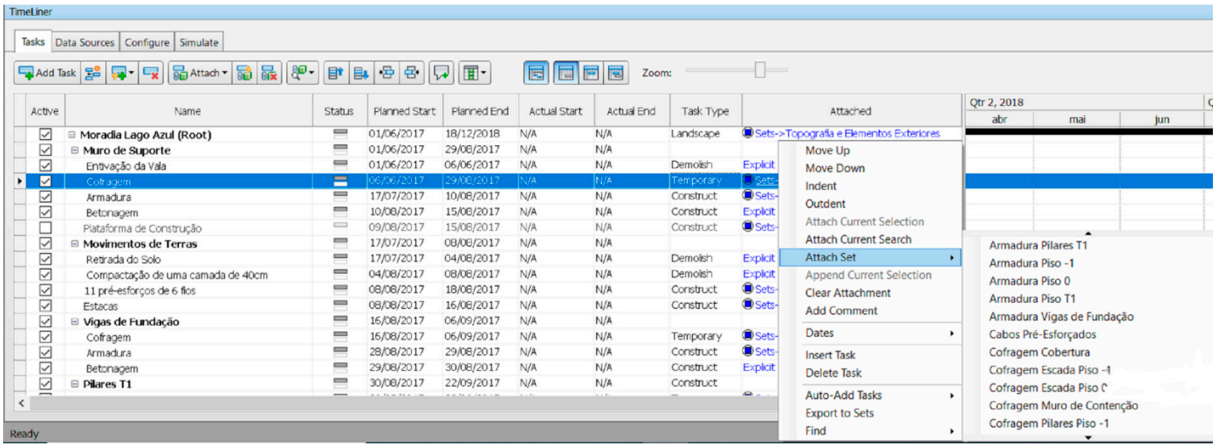


Figure 12. Schedule of the construction activity linked to component sets in a time liner.

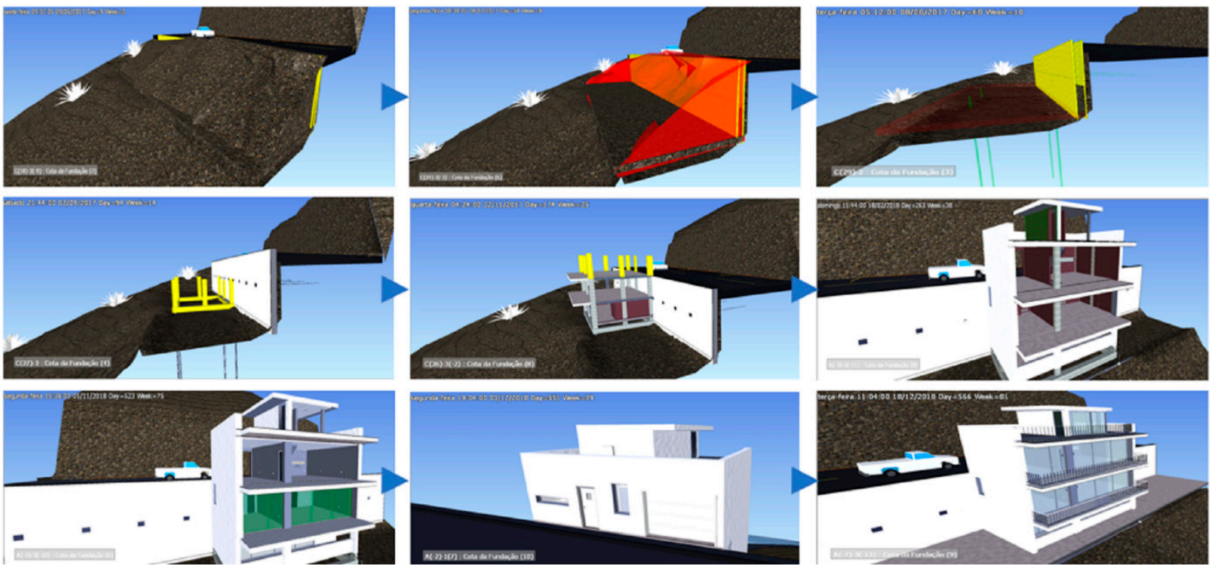


Figure 13. Sequence of the construction process elaborated using the Navisworks software.

The literature review present case studies focused on approaches for data transfer in BIM environments: on an efficient control of the BIM work, on the identification of parametric objects, and on the production of complexes individual partial models concerning distinct disciplines. Capturing and representing structures requires a highly interconnected design information. In the present study, the main output remarks of each project case reveals important achievements:

- In the first case, the **collaboration** between inter-disciplines, **interoperability** evaluation identifying limitations and benefits, and the automatic generation of technical **drawings**;
- In the second case, the structural solution development as well the alternative proposals to overcame the identified **interoperability** limits were described in detail;
- The last case shows the **modelling** process related to several **disciplines** and the potentiality of BIM to overlap all models, in order to detect physical **conflicts** and to simulate all the **construction** process.

5. Coordination and Collaboration

The BIM model enhances a high level of communication and collaboration, as it can support the overlapping of distinct disciplines and provide easy access to the database of each component. A BIM model that encompasses all the required disciplines (architecture, structures, and service networks), presents an organized and centralized database. The model database represents an adequate working base support to the BIM manager work. In the early stages of the project, coordination and collaboration between the different involved parties is essential, while in the execution phase, the focus is on cost, schedule, and quality and safety control.

The created structural BIM model, required in each building case, is composed of the physical and analytical structural solution and of all the 3D reinforcements inserted in each structural element. In addition, Revit enables the attachment of labels, images, and tables obtained from the model, or transferred from the Robot. These project elements were aggregated, as independent directories, to the BIM project, in order to allow it to be consulted when required in a later stage [37]. The different structural analysis diagrams, performed in the Robot, were placed in a view named "Analysis". This organization should be first included in the project BEP guidelines. Therefore, the experts know where to place each view and what kind of data consultation to perform. In the process, the role of the manager is, again, essential.

The ability to centralize information is very useful in a project revision process, as the model database can be easily consulted, giving a sustained knowledge for an eventual optimization decision concerning architectural, structural, or construction requirements.

5.1. BIM Execution Plan

A BIM execution plan (BEP) is a document that outlines how a BIM project should be executed, managed, and delivered, conducted partially by the project manager. It is an essential tool for ensuring that all stakeholders are heading in the same direction from the start of the project, and that every expert understands their roles and responsibilities. The BIM manager must coordinate the responsibilities and type of contribution [39].

If the information archived in a Revit model is outdated, the system issues a warning stating after each transfer, identifying the errors or omissions. After the overlapping of all disciplines and the elaboration of the required tasks, the global centralized model is composed of all components and all specific views that were considered. The manager must ask each partner for a responsible verification of its component. The final model should not present any kind of inconsistency, errors, inaccuracies, or omissions.

5.2. Dynamic Extension Files

A collaborative platform, organized by folders, allocates the results of each expert work to specific places or views of the global model, which can be achieved using common shared documents. The CADKEY Dynamic Extension file (CDE) is a common shared document. In it, the online Google Drive platform can store the CDE files, allowing the operator to add the team member responsible for each discipline or task [40]. The folders in the BIM model should be organized as shown in Figure 14:

- In the place **working on it** (WIP) folder, each team member stores the files concerning the project in a progress stage. The files archived in WIP folder have not yet been verified and authorized to be moved to the next stage;
- As soon as the model is approved by the expert in charge, it is transferred to the **shared folder**, which has all the shared files of the various disciplines to be coordinated;
- The **published folder** is used to support the review and coordination stages that must be first carried out, before it is ready to be worked in a final step;
- The **archive folder** follows the history of the various editable models created along the project development, ensuring that no information is lost.

Figure 14. Organization of a CDE file.

5.3. BIM Collaboration Format

The BIM collaboration format (BCF) file stores the model in progress in a virtual platform, and allows for the interaction between several stakeholders. When a problem is detected by the BIM manager, and after it is fixed by the discipline responsible, the communication between experts can be based on the generation and delivering of a BCF file [37].

When the file is opened in a BIM software, it is possible to read the text information about the inconsistency found, and display the parameters and the position where the problem was detected. This functionality allows for better understanding the issue situation, and the possibility to immediately make the necessary change in the model. As an example, an error caused by the transfer of reinforcement bars was detected in the second study case. Figure 15 presents the type of communication established between the manager and the structural engineer. The detected problem can be automatically synchronized with the virtual platform in use.

5.4. VR Technology and QR Code

In BIM, virtual reality (VR) technology has been enhancing the benefits of the methodology, with a great applicability in architecture, construction planning, and maintenance. The VR software (https://en.wikipedia.org/wiki/Virtual_reality_applications) allows immersive experiences when the user navigates through the interior and the exterior of the models. The main advantage in linking BIM/VR is being inside a realistic environment. This functionally transmits an adequate understanding of the project, making a virtual inspection possible, and observing the eventual inconsistencies on a real scale. Inside the structural model, BIM/VR allows the engineer to better communicate with other collaborators and to the owner (Figure 16a). The EnscapeTM is VR Revit extension that can be used to perform VR experiences [39]. It easily supports the detection of eventual physical collisions between elements, and allows direct adjustments made in Revit.

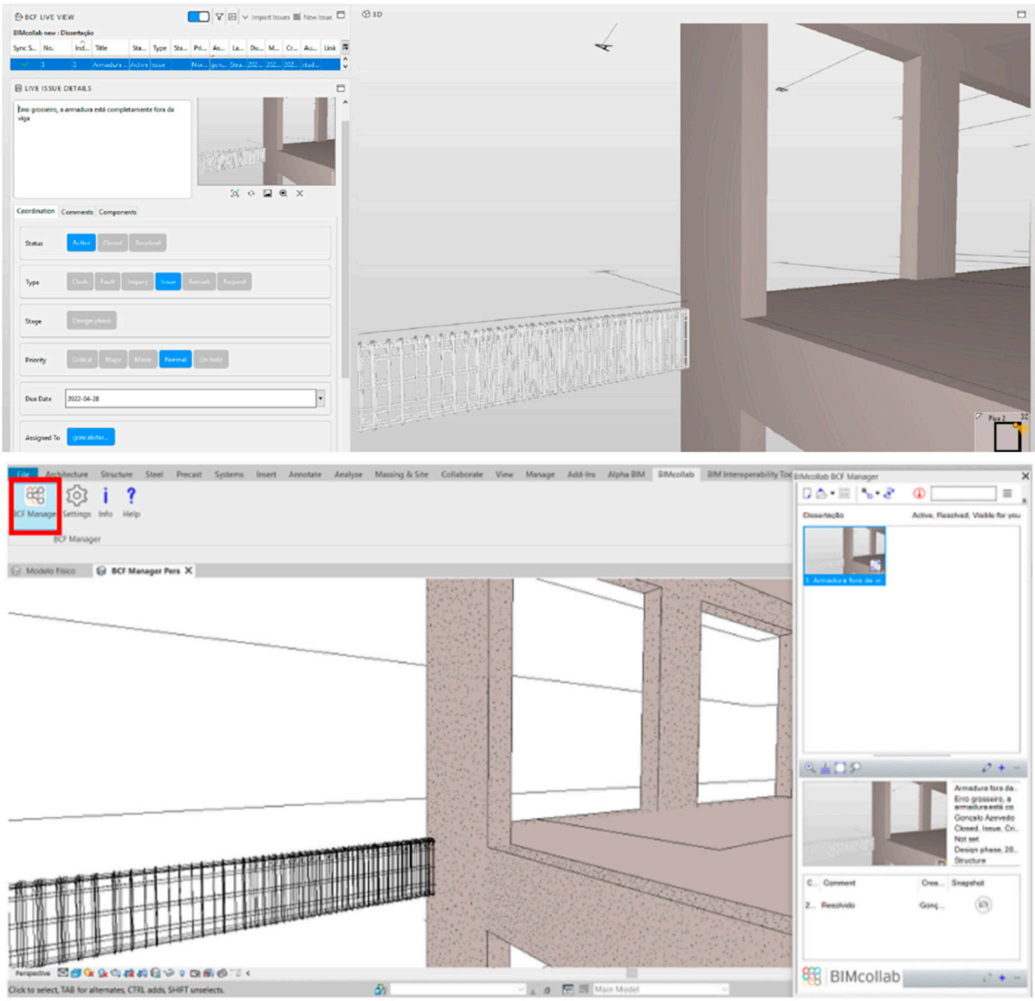


Figure 15. Generation of a BCF file and communication to the expert responsible.

(**a**) (**b**)

Figure 16. Immersive route inside the BIM model (**a**) and the created QR code (**b**).

A quick response (QR) code is a type of two-dimensional (2D) bar code that is used to provide easy access to online information, through the digital camera on a smartphone or tablet. In this case, it was attached to the global model, allowing users access to selected information concerning the project (Figure 16b).

6. Discussion

Productivity in the construction industry is currently a hotly debated topic. Companies in this sector are constantly adapting their workflow in order to reduce time and costs in the development of their activity. The technological advances associated with the BIM methodology have been presenting benefits in the productivity and quality of the construction. The present study aimed to analyze the action of the BIM manager along the development of each stage in a project as well the benefits and limitations of applying the BIM methodology in the execution of structural designs and construction plans.

6.1. BIM Manager Intervention

A reflection about the BIM manager function is presented and its important need is illustrated over real cases:

- The **multidisciplinary** design developed around a building requires following, controlling, and supervising by a professional with knowledge in BIM strategy and in complex projects;
- The **structural** design requires collaboration between the architect and the engineer and the transfer of BIM model in both ways, via Revit/Robot/Revit. Across the structural model, several tasks can be elaborated: inserting of all reinforcements inside the structural elements, obtaining tables of the materials quantities (volume of concrete and length of bars by diameter type), and the simulation of the construction process;
- In the **construction** context, the selected case involved the generation of four disciplines, the clash detection analyses, the materials quantity take-off elaborated over the final model, and the definition of the construction simulation. In all cases, the relevance of the BIM manager was evident.

The data transfer and all type of tasks developed over each selected project case show clearly the necessity that the enterprises must support the project elaboration under a BIM manager, as all designs are multidisciplinary, requiring an elevated level of integration and, naturally, adequate coordination. The study remarks the points where a BIM manager is more needed.

6.2. Main Benefits

In addition, the benefits of the implementation of BIM are essentially focused on aspects related to the correct operation, speed, and simplicity in the execution of some processes:

- The ability to effectuate a bidirectional **transfer of** information between software, finding that the model transfer from Revit to Robot is quite reliable and that in the inverse direction, the efficiency is reduced;
- In Robot, the **structural analyses** and reinforcements detailing have shown very satisfactory results, and after transposing the model in the direction Robot/Revit the completeness of the final structural model is easily achieved using the Revit extension Reinforcement;
- The 3D BIM **modeling** process, when compared to the traditional paper-based method, allows operators to easily perform eventual changes to the distinct components, supporting an adequate collaboration among the team involved.

6.3. Model Generation, Coordination, and Management

A separation between model preparation, coordination and management was identified:

- Concerning the first case, several data transfers were performed between platforms and controlled by the manager. In it, the **modelling** process was mentioned and evaluated from the perspective of an easy adaptation of both models. In the second case a structural project was performed, and the modelling process presented some inconsistencies that needed to be amended. Several projects (architecture, structure, and water supply) were modelled, and after overlapping, allowed a conflict detection, supervised by the manager;

- The **coordination** aspect was observed in all projects. In the architecture/structure case, an important coordination took place between the two offices. The second project required transfer between software, Revit/Robot/Revit, and an important task concerning the verification of geometric inconsistencies and control of the quality of the data transferred was performed. A higher degree of coordination was considered in the third case, as in involved several disciplines;
- The **management** and extracting of information concerning the automatic definition of technical drawings, tables of material quantities, and carbon emission on the fabrication of the concrete used in the structural elements. Across each case, it was possible to extract information and use it for several distinct objectives.

7. Conclusions

The present study shows that the BIM manager role in projects integrates several disciplines and experts, bringing an important improvement in the quality of a building design, reflected in the quality of the final product. To highlight some important aspects, the present study described three distinct projects involving the coordination of multiple disciplines. All cases were described in detail, showing the limitations found in the main transfer processes and in the development of all tasks supported across the BIM model database, where the supervision of a BIM manager was required.

The described study cases present the complexity of the projects composed of several disciplines and requiring the development of several tasks, using distinct software. The role of the BIM manager is mainly the coordination of steps and the control of the authorization of the collaboration of each expert:

- The distinct cases illustrated the **relevance** and the **necessity** of a BIM manager professional;
- Its **function** is associated with the coordinator of the project, but some knowledge inherent to BIM concepts and software use should be attended to by the manager in all BIM processes;
- It is a **new job** that should be incorporated within the technical team of the construction enterprises, in an interdisciplinary BIM users context;
- Currently, the projects are developed in a **global way**, with connections between distinct companies, and several countries, and the BIM manager professional is highly recommended;
- The BIM **manager** can work online using the Google Drive platform and several sharing files and places, supporting the coordination of a global project.

When following-up each case study, it was demonstrated that a BIM manager was useful to coordinate each task and to give responsibility to distinct experts. However, there is a strong consumption of time in coordinating the various models. The centralized model has a high capacity for integration, supporting collaboration and communication between experts and, therefore, projects with a higher quality can be achieved.

Some limitations of the study can be pointed out: the LoD definition of the partial models that are transferred between steps, software, and experts and the attribution, by the BIM manager, of responsibilities and control. As such, future work guides, directives and rules must be well-defined, and after, be disseminated through similar works such as the one presented here. As stated, the BIM integration activity must be supported by responsibilities of BIM specialists that must be attributed by the BIM manager, following available guidance, but this aspect lacks research, and must be studied.

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