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THE BENEFITS OF USING BUILDING INFORMATION MODELLING (BIM) IN STRUCTURAL ENGINEERING

By

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ملـــخـص

هذا المشروع النهائي للتخرج الجامعي عبارة عن بحث حول مفهوم بناء نماذج المعلومات (بيم) في الهندسة المدنية والهندسة المعمارية ومجال الإنشاءات.

يتناول هذا البحث عدة مفاهيم تترأسها الدراسة الببليوغرافية التي تركز أساسا على التعريف بمفهوم البيم ونشأته وتاريخه وتطوره بالإضافة إلى فوائده وأهم التحديات التي تواجه تنفيذه كما تطرقت الدراسة لأهميته في تكوين المدن الذكية والمباني الخضراء.

كما تحدثنا عن بيم في الهندسة المدنية والهيكلية بصفة خاصة بالإضافة إلى تنفيذه في البنية التحتية مع ذكر سير عمله بالتفصيل.

وأخيرا قمنا بالتعريف ببعض أدوات البيم واستعمالها للقيام بعملية النمذجة والحساب مع الشرح عن التكامل بين هذه الأدوات وكيفية قيامها بعملية متكاملة.

RÉSUMÉ

Ce projet de fin d'étude est une recherche sur le concept de modélisation de l'information du bâtiment (Building information modeling « BIM ») dans l'industrie de l'architecture, de l'ingénierie et de la construction (AEC).

Cette recherche prend de nombreuses conceptions à partir de l'étude bibliographique qui se concentre principalement sur la définition, l'histoire et le développement de BIM en plus des principaux défis et avantages de mise en œuvre ainsi que la BIM dans les bâtiments verts et les villes intelligentes.

Puis la BIM pour le génie civil et structurel et son flux de travail interne avec sa mise en œuvre dans l'infrastructure.

Enfin, l'étape la plus importante de cette recherche est la modélisation et l'analyse structurale à l'aide d'outils BIM et la compréhension de l'intégration entre ces outils et de la façon dont elle rend un processus complet.

ABSTRACT

This graduation project is a research about the concept of building information modeling (BIM) in Architecture, Engineering and Construction industry (AEC).

This research takes in many conceptions starting with the bibliographic study that mainly focuses on the definition, history and development of BIM besides that the major implementation challenges and benefits as well as BIM in green buildings and smart cities. Then BIM for civil and structural engineering and its internal workflow along with its implementation in infrastructure.

Finally, the most important step of this research which is the structural modeling and analysis using BIM tools and understanding the integration between these tools and how it makes a complete process.

ACKNOWLEDGEMENT

First of all am grateful to ALLAH for giving me the power and courage to bring this work to life.

I dedicate this work to my parents, my sisters and everyone who believed in me.

My gratitude to all my teachers and professors specially MR ISMAIL DERBAL for trusting us in the process.

It was a long road but not a dark one thank to thus ho bring light to my world…

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In the first place I would like to thank Almighty God for giving me the courage, the will and the patience to carry out this work.

I would like to express my deep gratitude to MR DERBAL ISMAIL, for supervising and trusting us in the process.

I dedicate this work for

My dear father AMAR for supporting me morally and materially to this day, for his love, and his encouragement. May ALLAH the Almighty preserve you, grant you Health, happiness and protect you from all harm.

My dear mother RAZIKA who filled me with tenderness and affection throughout my journey. For supporting and encouraging me during all the years of my studies. May ALLAH protect you and give you health, happiness and long life.

To my whole family

Special thanks to all my supportive friends: Samia, Meriem, khawla, Nabila

To all my friends without exception

To all my teachers

To a very special person on my heart

Finally yet importantly, I would like to thank myself for believing in me

NEMRI FATMA ZAHRA

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LIST OF ABBREVIATIONS

BIM: Building information modeling.

2D: Two dimensional.

3D: Three dimensional.

4D: Four dimensional.

5D: Five dimensional.

7D: Seven dimensional.

AEC: Architecture Engineering and Construction.

CAD: Computer aided design.

NBIMS: National building information modeling standers.

MEP: Mechanical engineering and plumbing.

EPC: Engineering process control.

IPD: Infrastructure planning and design.

IFC: Industry foundation classes.

IT: Information technology.

ICT: Information communication technology.

ROI: Return on investment.

LCA: Life cycle assessment.

CIFE: Centre for integrated facility engineering.

A/Es: Architects/engineers.

SaaS: Software as a service.

GIS: Geographic information system.

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GENERAL

INTRODUCTION

Construction projects involve complex sets of relationships between parties under different professional background in order to achieve a complex goal. The complexities of construction projects are resulting from thousands of documents and drawings that being used manually.

In conventional practice, construction parties still use 2-Dimensional (2D) information that is sometimes resulting in miscommunication among them and not appropriate for complex projects. Miscommunication in construction could lead to mistakes in construction process such as fumble of design, drawings are not updated; delay, cost overrun, poor quality of work, as well as design clashes. Therefore, Information Communication Technology is required for managing a bundle of information and documents, decision-making tasks and to deliver the level of consistency and reliability of information in construction. Currently, the process remains fragmented in the current AEC System and it depends on paper-based modes of communication. Alternative organizational structures such as the design build method the use of real time technology, such as project Web sites for sharing plans and documents and the implementation of 3D CADtools.

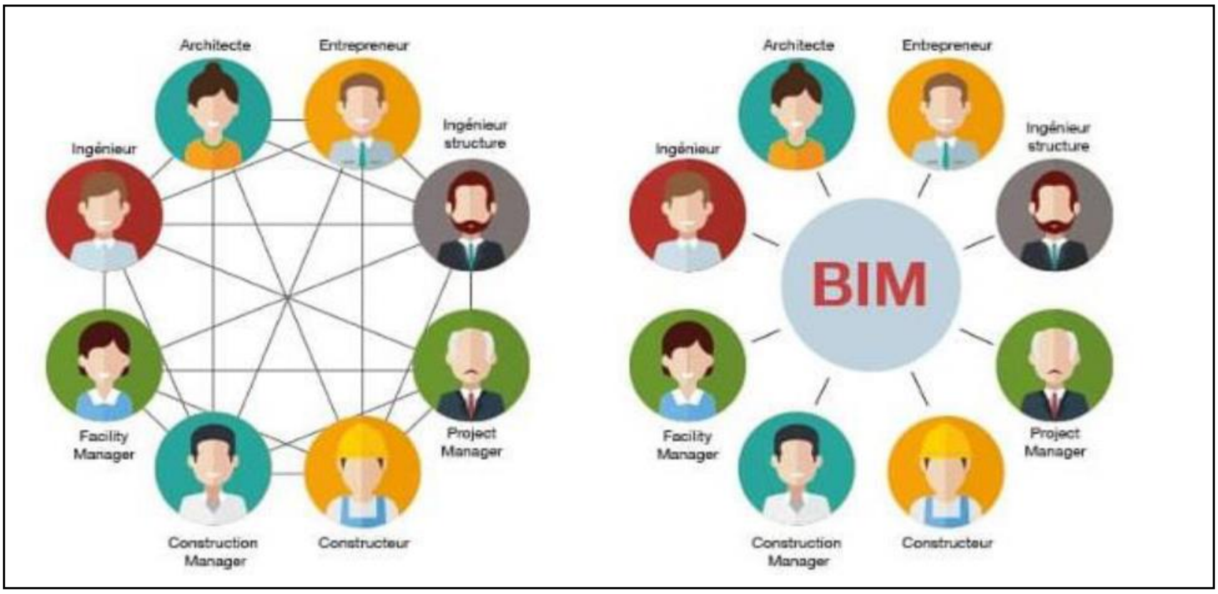


Figure I: BIM interoperability concepts.

Though these methods have improved the timely exchange of information, they have done little to reduce the severity and frequency of conflicts caused by paper documents or their electronic equivalents. One of the most common problems associated with 2D-based communication during the design phase is the considerable time and expense required to generate critical assessment information about a proposed design, including cost estimates, energy-use analysis, structural details, and so forth. These analyses are normally done last, when it is already too late to make important changes. Because these iterative improvements do not happen during the design phase, value engineering must then be under taken to address inconsistencies, which often results in compromises to the original design.

As a result, Building Information Modeling (BIM) has been introduced in construction projects in effective and efficient way by computerized and integrated information management systems.

CHAPTER I:

BIBLIOGRAPHIC STUDY

I. BIBLIOGRAPHIC STUDY

I.1.Introduction

Building Information Modeling (BIM) is a new method that presents a number of opportunities and challenges for the architectural, engineering and construction (AEC) industry.

It is an evolution of the computer-aided design (CAD) system, which provides more intelligence and interoperable information and is named as project modeling, virtual building, virtual design, construction and finally nD-modeling. BIM is unequivocally a tool of collaboration.

I.2.Building information modeling

Is a process of creating, developing, and sharing a digital information model of a building project to improve it design, construction and performances is supported by various tools and technologies.

The modeling includes different design items as elements, these elements is assigned geometric and technical properties and given parameters and conditions describing their relationship with each other. Then there is the viewing stage of these elements then their documentation using various design tools that use BIM technique.

One can generate different plans and views of the building for further documentations. These elements are only defined once, and through the BIM application, their views are generated and collaborated automatically with each other [1].

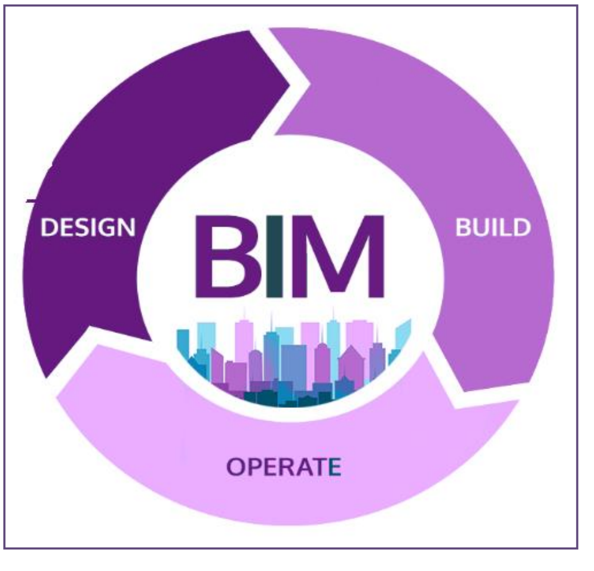


Figure I. 1: BIM process.

In addition, you can see the process of BIM in the figure I.2 and figure I.2.

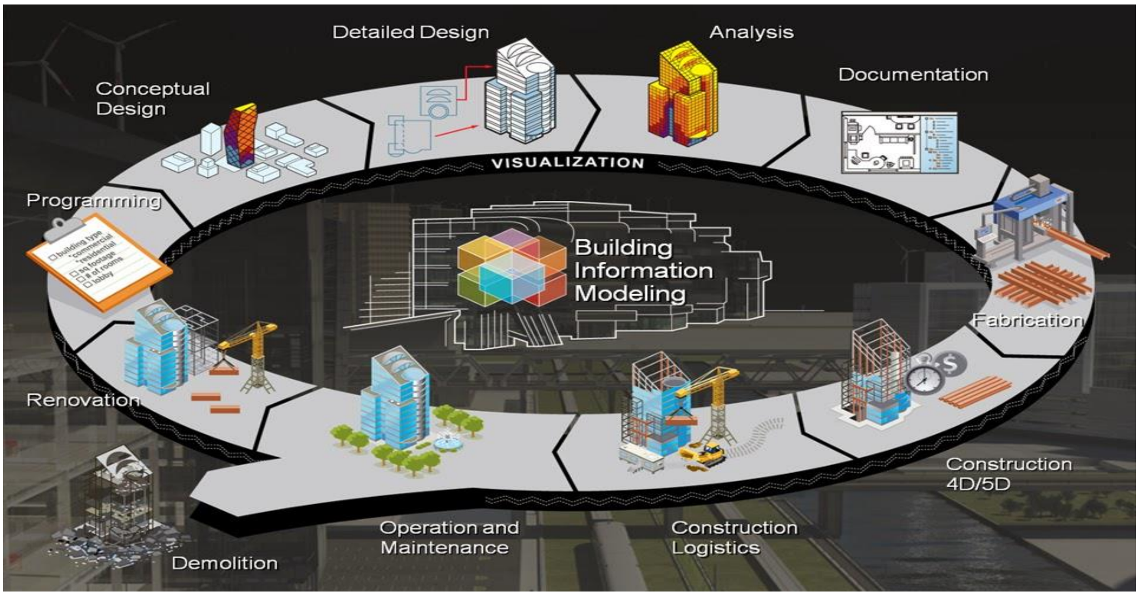


Figure I. 3: BIM detailed process.

I.3. Building information model

The National Building Information Modeling Standards (NBIMS) Committee defines BIM (model) as:

"... A digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder" [2].

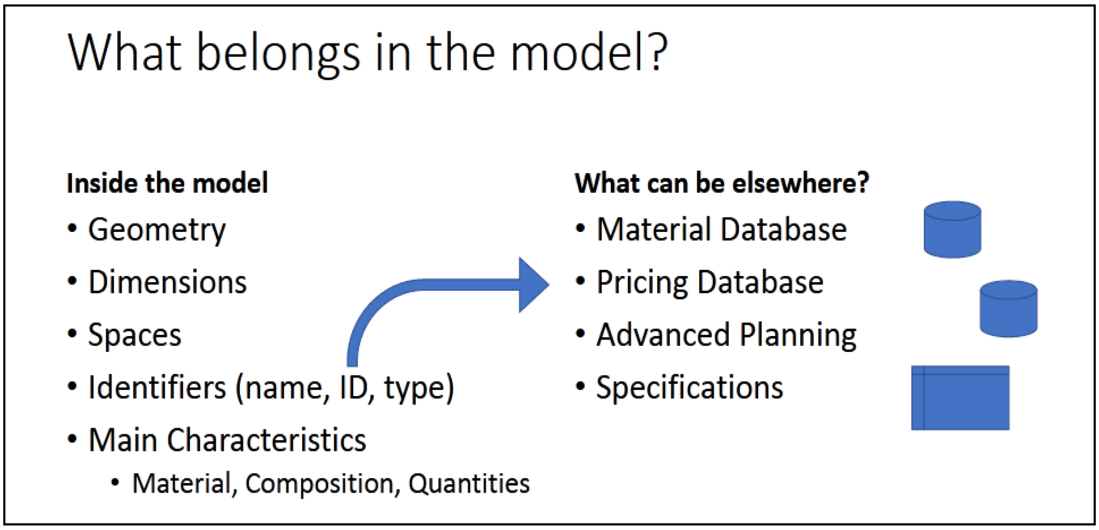


Figure I. 4: Components of a BIM model.

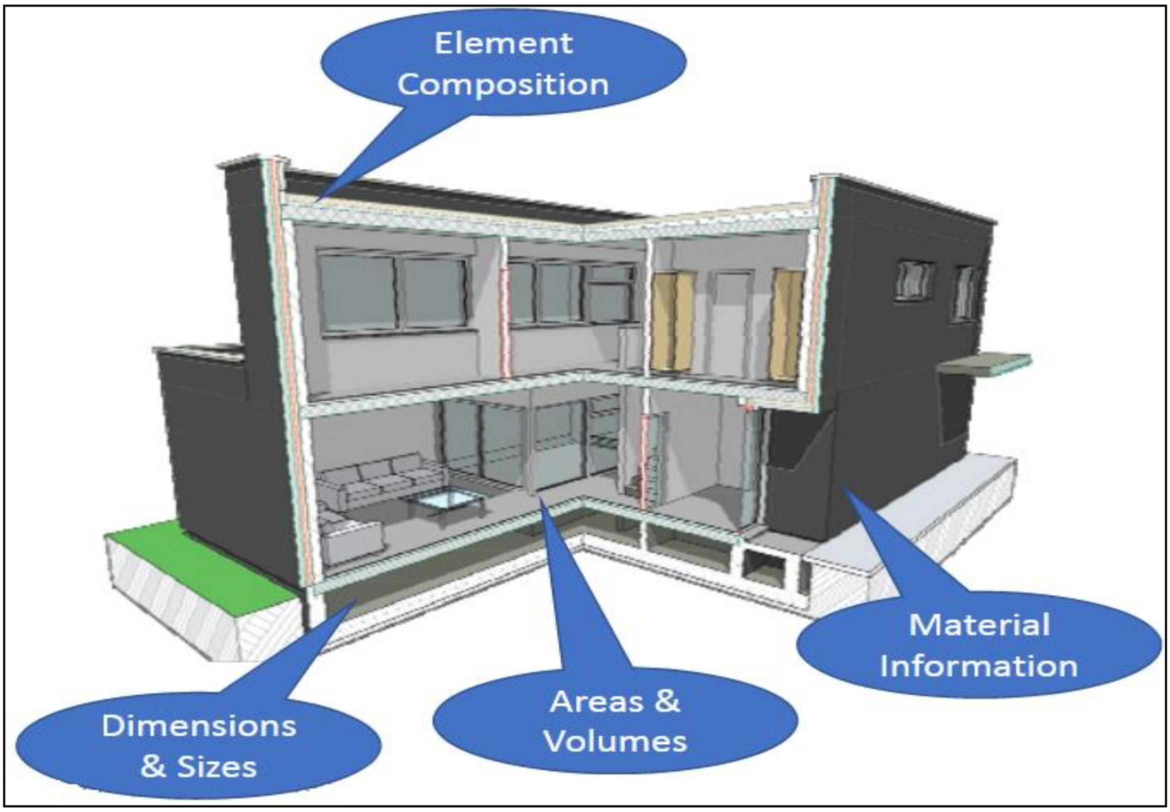


Figure I.5: 3D BIM model.

The figure I. 4 represents the 3d BIM model, which contains the dimensions and sizes, area and volumes, material information and element composition.

I.4.Building information management

The Primary use for BIM models in preservation is for the management of data. A Finnish study presented at the 2007 Education and Research in Computer Aided Architectural Design in Europe, found that renovation projects benefit from using BIM models for inventory of existing data and not just for representing geometry within a building. Emphasis on quality over quantity of information was a key observation of the study, and the researchers found that BIM should be started early in the renovation process to allow time for data collection and verification. The major difference between BIM and traditional project structure is the shared database used by all project participants. Everyone works in the same model. Users see changes reflected in real time, which improves coordination. Consultants such as the MEP and structural engineers often work in separate models that are linked to form the final complete model. BIM does not only mean 3-D representation of a building. It includes all facts about the project such as cost estimates, technical specifications, quantities of building components, as well as a 3-D model of the building geometry itself. Unlike new buildings that begin with a blank sheet of paper, recording for preservation purposes works in reverse order. Existing building information is reconstructed in a BIM model Not only is data collected and recorded, but it can also be manipulated to generate reports that account for spaces, objects within those spaces, or particular building components. Multiple views of a building are quickly generated to understand a buildings scale and complexity or how an addition fits with the original design. In addition to its use as a database of information, a model reflects the phasing of work from the original built conditions, to subsequent additions and renovations, to a buildings present state [3].

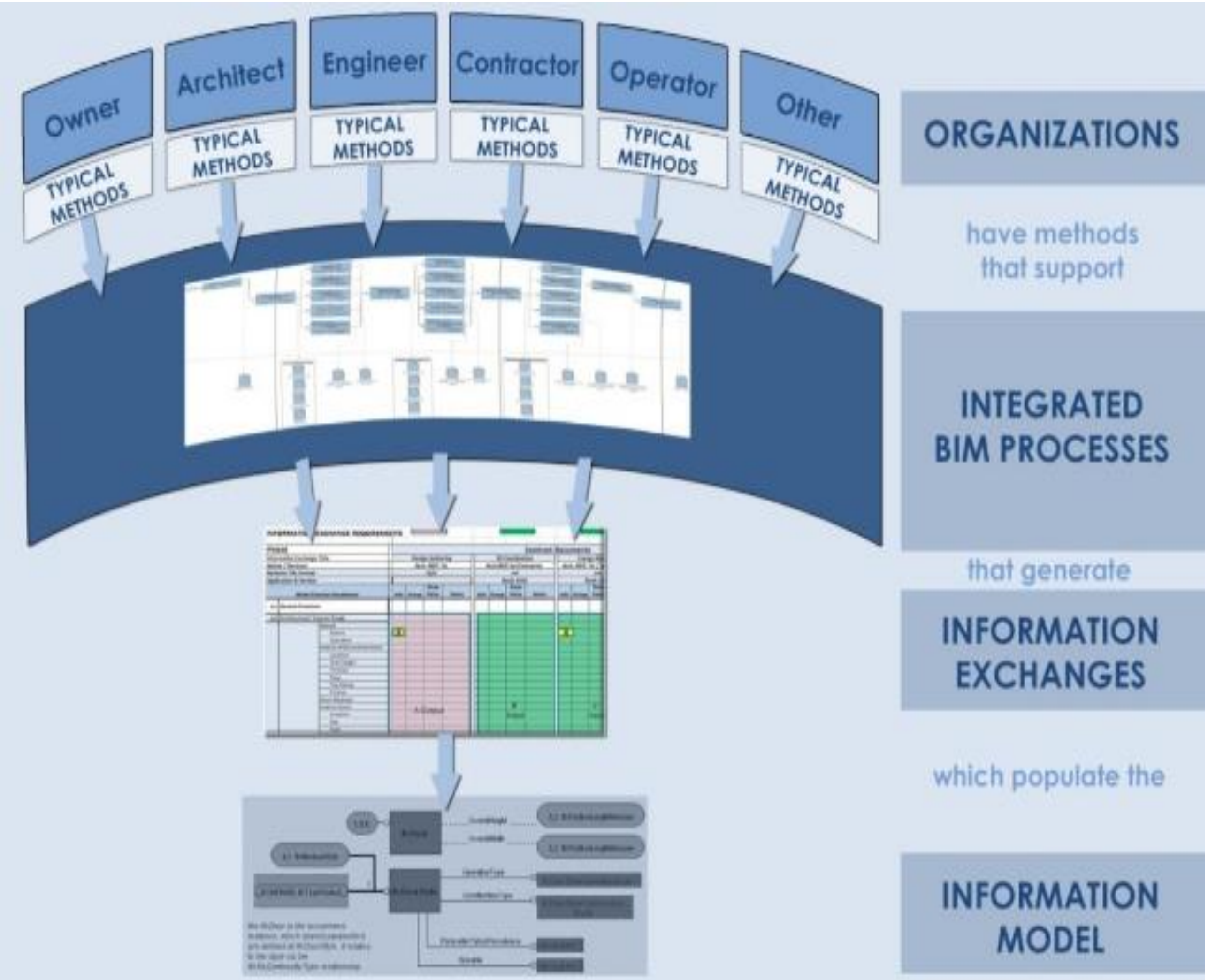


Figure I. 6: Participants in the project in all phases.

I.5.History and development of the building information modeling

The concept of BIM has existed since the 1970s. The first software tools developed for modeling buildings emerged in the late 1970s and early 1980s.

Charles (Chuck) M. Eastman

(May 5, 1940 – November 9, 2020) was a professor and a pioneer in the areas of design cognition, building information modeling (BIM), solid and parametric modeling, engineering databases, product models, and interoperability. He is best known for his work on building description system, which later gave him a title as the 'father of BIM.'

Figure I. 7: Charles (Chuck) M. Eastman.

The term 'building model' was first used in papers in the mid-1980s in a 1985 paper by Simon Ruffle eventually published in 1986, and later in a 1986 paper by Robert Aish , then at GMW Computers Ltd, developer of RUCAPS software - referring to the software's use at London's Heathrow Airport. The term 'Building Information Model' first appeared in a 1992 paper by G.A. van Nederveen and F. P. Tolman.

However, the terms 'Building Information Model' and 'Building Information Modeling' did not become popularly used until some years later. In 2002, Autodesk released a white paper entitled "Building Information Modeling", and other software vendors also started to assert their involvement in the field. By hosting contributions from Autodesk, Bentley Systems and Graphisoft, plus other industry observers, in 2003, Jerry Laiserin helped popularize and standardize the term as a common name for the digital representation of the building process. Facilitating exchangeand interoperability of information in digital format had previously been offered under differing terminology by Graphisoft as "Virtual Building", Bentley Systems as "Integrated Project Models", and by Autodesk or Vectorworks as "Building Information Modeling" [4].

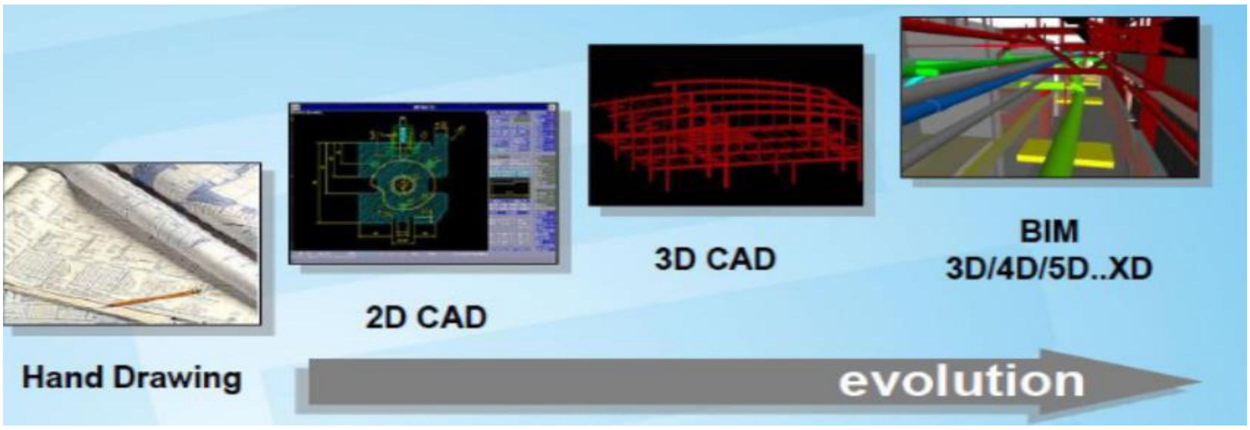


Figure I. 8: The evolution of BIM.

Laiserinas have recognized the pioneering role of applications such as RUCAPS, Sonata and Reflex well as the UK's Royal Academy of Engineering. Due to the complexity of gathering all the relevant information when working with BIM, some companies have developed software designed specifically to work in a BIM framework. These applications differ from architectural drafting tools such as AutoCAD by allowing the addition of further information (time, cost, manufacturers' details, sustainability, and maintenance information, etc.) to the building model.

As Graphisoft had been developing such solutions for longer than its competitors had, Laiserin regarded its ArchiCAD application as then "one of the most mature BIM solutions on the market." Following its launch in 1987, some as the first implementation of BIM regarded ArchiCAD; it was the first CAD product on a personal computer able to create 2D and 3D geometry, as well as the first commercial BIM product for personal computers [5].

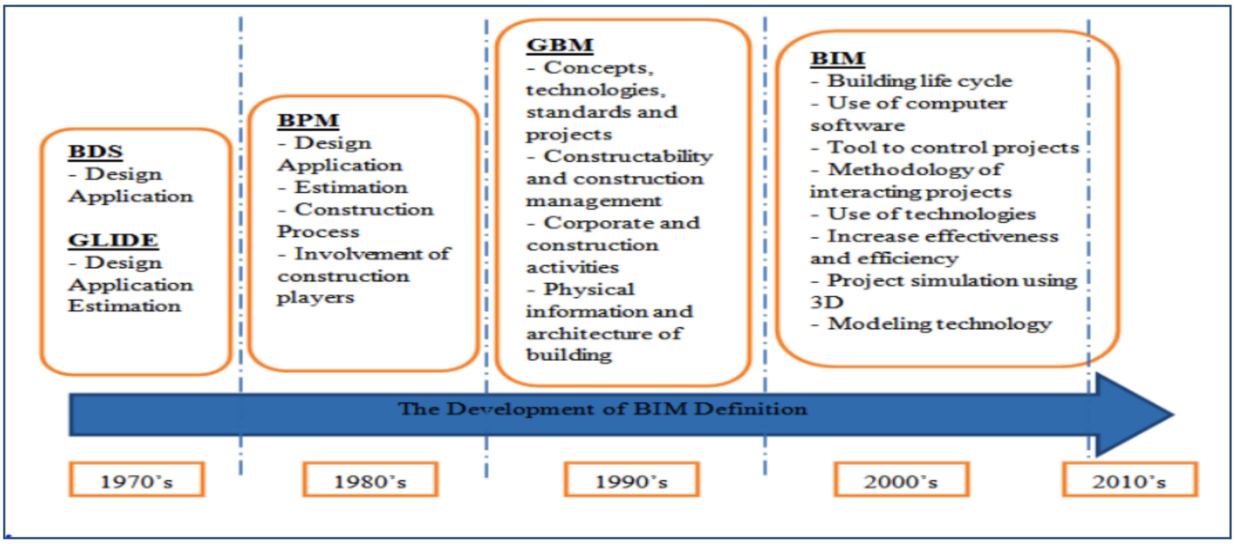


Figure I. 9: The development of BIM definition.

Table I.1 presents the analysis of BIM development from the year 1975 to 2021 the technology had helped the construction players in improving collaboration and communication among them. It had also improved the management of documentation in order to achieve more effective and efficient performance in construction projects [6].

Table I. 1: The analysis of BIM development from the year 1975 to 2021.

Development	Construction Phases			Category
	Pre-Construction	Construction	Post-Construction	
BDS	√			Design
GLIDE	√	√		Design and Estimation
BPM	√	√		Design , Estimation and Construction Process
GBM	√	√		Design , Estimation and Construction Process
BIM	√	√	√	Design , Estimation, Construction Process, Building Life Cycle, Performance and Technology

I.6. Why is BIM important

Building Information Modeling (BIM) is a challenge to fully grasp for a surprisingly simple reason: At its core, it is a form of systems thinking. A full system designed to facilitate interactions between architects, engineers, customers, and construction firms; BIM uses a set of common standards and shared information.

Ask anyone who has worked on a construction site or manufacturing process; they'll tell you how difficult it is to imagine a complex system as a whole. Managing the system of a company or process presents its own challenges, often leading to huge inefficiencies. Managers need more perspective to be able to see these issues. What makes BIM such a game-changer for the construction industry is that, if implemented well, it's an integrated and open system.

And here's why we should consider BIM as an important part of the construction industry.

1. BIM improves team collaboration and workflow efficiency

Architecture and design are iterative processes that have traditionally been manually intensive. Architects, structural engineers and builders all need to view different pieces of information and use different design templates [7].

As noted, BIM allows all of these specialists to access information in the format that they need without the requirement to duplicate the data. The collective utilization of a single dataset means that edits made in one format are automatically propagated throughout the system, removing the need to update different drafts as plans progress. Approaching design through database storage further removes the need to manually produce most other end-product design documents such as schedules, color filled diagrams, drawings and 3D models. These can all be rendered automatically from the BIM database [7].

BIM means that :

- Greater iteration can be embraced during the design phase.
- Teams are allowed to work more collaboratively and are no longer required to waste time crosschecking documentation and files.
- Specialists are more easily able to provide input across all areas of a project.
- The amount of time it takes to develop a plan is reduced.
- Workflows will produce fewer errors and require less oversight.

2. BIM provides a stable platform for computer simulations and 3D models

A BIM database not only improves collaboration, it provides a store of architectural and design data that can be used for 3D modeling and software simulations. These programs can be used for design and structural purposes, allowing for the creative deployment of new materials and design concepts [7].

Options include:

- Adding paint to walls.
- Adding interior features.
- Simulating sunlight at different times of day.
- Investigating the impact of an earthquake.
- Testing the structural viability of an experimental plan.

3. BIM enables clients to engage with projects prior to construction

The 3D models you can use for design purposes also make it easier to share ideas with clients. 3D modeling makes it easy for individuals without specialist architectural training to view plans and visualize the result. Even people in the construction industry struggle to accurately interpret architectural drafts.

Having a 3D model has become part for the course in construction. It is possible to invest time in 3D modeling without BIM data. However, BIM creates 3D models as an automatic part of the design process. It is simply one of the ways in which your data can be presented.

BIM enables you to design plans and then present them for review by clients or others without specialized architectural training and without extra planning. The 3D model created allows open accessibility, enabling anyone to explore or even edit, if they have the correct permission. This helps design teams, modelers and architects become more proactive in their workflow with clients on construction projects [7].

4. BIM follows buildings throughout their lives

BIM schematics aren't only useful to construction teams; they create the foundations for a true digital handover. A database of all the relevant information about a building or facility is passed on to the building manager at the end of a construction process. This allows building managers to easily acquaint themselves with a building and learn critical information about the facility they have been tasked with operating. It will include much more information than is included in a traditional architectural draft; more importantly, that information can be more flexibly accessed [7].

I.7. Benefits of BIM:

There is a wide range of clear and current benefits associated with the use of BIM. These range from its technical superiority, interoperability capabilities, early building information capture, use throughout the building lifecycle, integrated procurement, improved cost control mechanisms, reduced conflict and project team benefits.

I .7.1. Technical benefits

BIM has been proffered as a substantial technical advance on traditional CAD, offering more intelligence and interoperability capabilities [8, 9]. Digital representation of physical and functional characteristics of a facility enables users to transfer design data and specifications between different software applications, both within an organization and more widely in a multidisciplinary team. BIM has been described as “the technology of generating and managing a parametric model of a building” [9, 10]. BIM tools provide optimized platforms for parametric modeling, enabling new levels of spatial visualization, building behavior simulation, effective project management and operational collaboration of AEC team members. BIM refers to a set of technologies and solutions that can enhance inter-organizational collaboration and productivity in the construction industry, as well as improving design, construction and maintenance practices [8]. BIM technologies are continually expanding and evolving new functionality.

I .7.2. Standardization benefits

In order to fully enable collaboration among BIM tools users, data exchange standards have been developed. The establishment of these standards in the form of Industry Foundation Classes (IFC) for construction objects was led by building SMART [11]. The operative definition of an IFC is “a neutral and open specification that is not controlled by a single vendor or group of vendors” [12]. IFCs have been a major step forward in organizing the BIM development process [12, 13]. This has contributed to enabling and systematizing interoperability among AEC BIM users through the provision of standard models encompassing rich semantic and geometric information of building components.

I .7.3. Knowledge management benefits

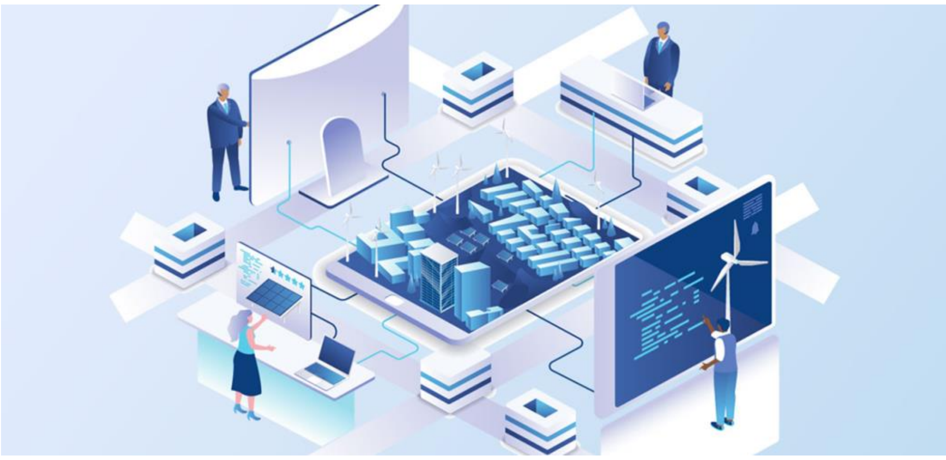


Figure I. 9: BIM and Facility management.

BIM tools have enabled comprehensive information about the building to be captured during the design process, ranging from individual building components and locations to relationships between those objects. BIM incorporates building information ranging from geometry, spatial relationships, light analysis, geographic information, quantities and properties of building components product's material, specification, fire rating, finishes, costs and carbon content. These features in turn allow designers and engineers to keep track of relationships between building components and their respective construction-maintenance details. In the event of design changes BIM tools can integrate and systematize changes with the design principles, intent and design ‘layers’ for the facility/project [14]. Moreover, BIM could be used essential for facility management integration. BIM tools provide interoperability opportunities plus the capability for proper integration, allowing inputs from various professionals to come together in the model [15].

I .7.4. Integration benefits

In order to cater for the rising complexity of diverse projects, Information Technology (IT) and Information Communication Technology (ICT) have been developing rapidly to facilitate innovative solutions [16, 17]. To reflect this BIM as an alternative method of design and construction has gained popularity amongst key players in construction industry [18]. BIM has developed to facilitate the increasing complexity of construction projects, able to facilitate design, construction and maintenance of projects through an integrated approach. It provides a collaborative platform for different stakeholders involved in a project lifecycle. Owners, designers, contractors and construction managers can use BIM to undertake construction projects more efficiently than ever before. BIM can be used as an interactive manual for safely managing and operating the building providing complete facility information [19], such as physical structure, mechanical and electrical systems, furniture and equipment. BIM models can simulate maintenance or the retrofit process [20]and therefore help reduce facility management costs [21, 22] and improve the maintenance process as well as provide an accurate cost estimate of renovation [23].

BIM is considered a key solution towards future enhancement of smart housing and intelligent buildings [24].

I .7.5. Economic benefits

BIM has also been identified as having significant economic benefits. A robust driver for technology adoption is monetary evidence. Return on investment (ROI) is a key value to consider in such practices. In the context of BIM, various analyses have reported high ROI results. The importance of BIM-assisted design validation is acknowledged. Research has confirmed that the impact of BIM on preventing schedule delays has the most influence on

Increasing ROI while rework preventions based on initial model validation/assessment is also a driver [25].

Figure I. 10: Building business infographic.

BIM users have outlined both short and long-term benefits of using BIM. The most important short-term impact of BIM was minimizing documentation errors. This was followed by using BIM as a marketing tool for the business. Less staff turnover was also seen as short-term benefit of using BIM. Fewer contractual claims and reduced construction costs are considered as long-term benefits. Maintaining recurrent business with past clients is also a major benefit of BIM [26].

I .7.6. Planning/scheduling benefits

Figure I. 11: BIM digital planning.

BIM 4D schedules are powerful tools for phasing, coordinating, and communicating planned work to a variety of audiences. Since all materials and components are predetermined and their quantities are automatically calculated, building materials and components can be ordered electronically and delivered on site just in time, therefore increasing workers' productivity [27].

The 3D model provides an acceptable visualization of working space while the 4D schedule offers simplified comprehension of various requirements throughout the project lifecycle. This is particularly useful for the stakeholders directly responsible for executing the construction-maintenance work.BIM tools are expected to provide smooth real-time updates and sufficient visualization performances to enable effective collaboration among team members [28].

I .7.7. Building LCA benefits

BIM provides project managers with the potential to re-engineer design-construction-maintenance progress for optimized collaboration amongst diverse team members. Stanford University Centre for Integrated Facility Engineering (CIFE) confirmed that application of BIM has a number of benefits. It eradicates unforeseen modifications by up to 40%, provides cost estimation with an error threshold of 3% and up to 80% reduced generation time [29].

Figure I. 12: BIM life cycle assessment.

it also provides clash detection capable of saving up to 10% of the contract value and reduces the project completion time by up to 7%. More recently the research focus has shifted from the early building lifecycle stages to the maintenance and refurbishment phases. This has emphasized the advantages of utilizing BIM not only for design but also for maintenance of buildings [29].

I .7.8. Decision support benefits

BIM offers all engineering stakeholders the opportunity to utilize a unified shared model to achieve the project goals at an optimum level. The data sharing provided by BIM among different team members allows for constant evaluation and information control [30]. Exchange of visual information among designers and clients mitigates the time needed for communicating complex ideas.BIM enables immediate and accurate comparison of different design options, which enables the development of more efficient, cost-effective and sustainable solutions. BIM also enables the project team to virtually rehearse complex procedures, such as planning, procurement, site equipment and work force allocation. Multidisciplinary integration of teams allows the identification and resolution of issues in advance of construction. By using BIM tools contractors can also minimize construction risks by reviewing complex details or procedures before going into site [30].

BIM technology brings many benefits, in the figure I.13 are some of them, check them out.

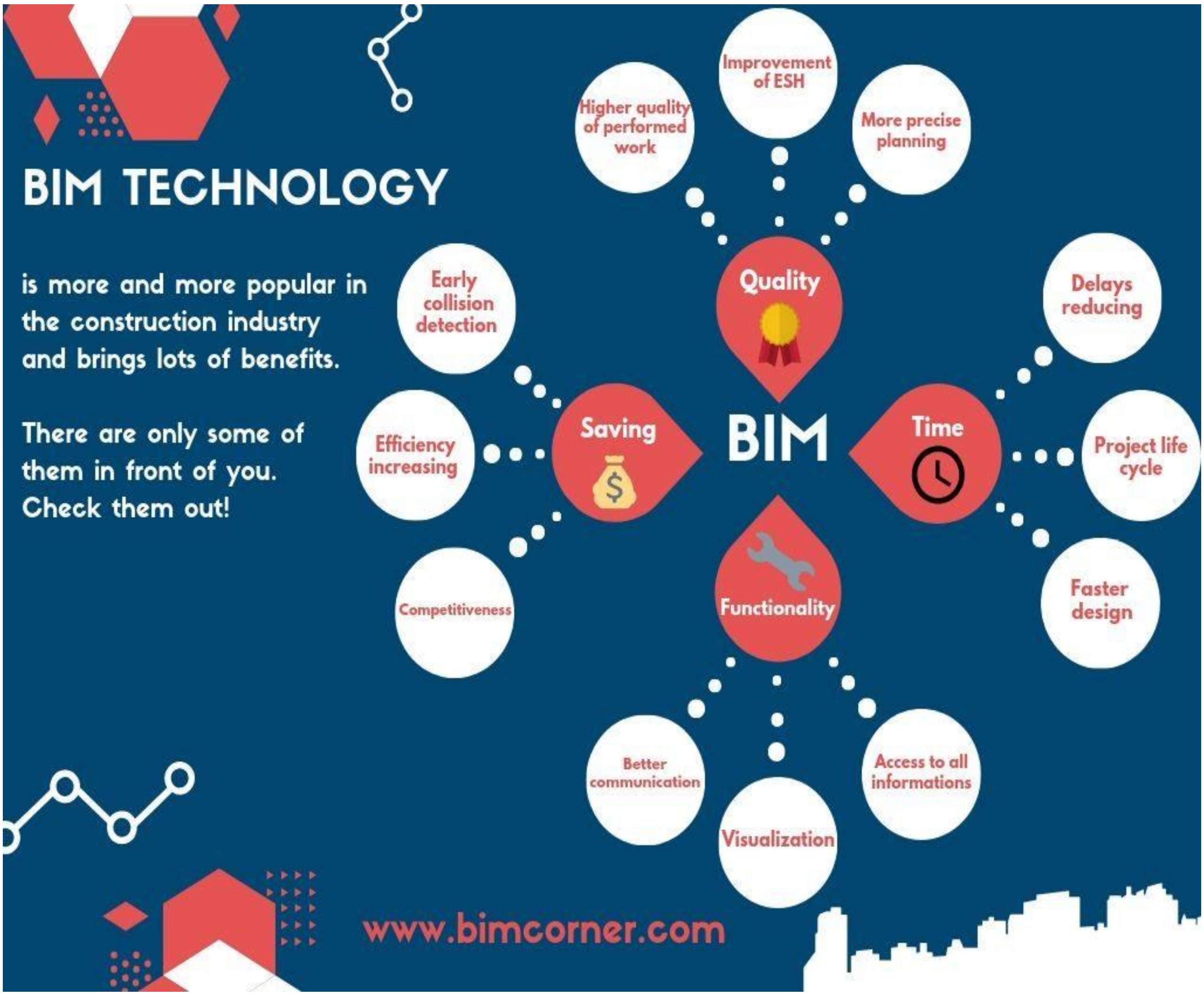


Figure I.13: The advantages of BIM in the construction sector.

I.8.Building information modeling implementation challenges

Despite the great benefits of BIM, there is still no clear strategy for its widespread use in the future. There exists vast variety of classifications in different studies with regard to barriers against implementing BIM. After reviewing over 100 studies and selecting 47 final papers that were more related to this subject, five major problems in BIM implementation are divided by location listed in Figure below [30].

Major issues according to the author's opinions and frequency of appearances on are management (30%), cultural (27%); legal (20%), financial (17%) and security issues (6%) [30].

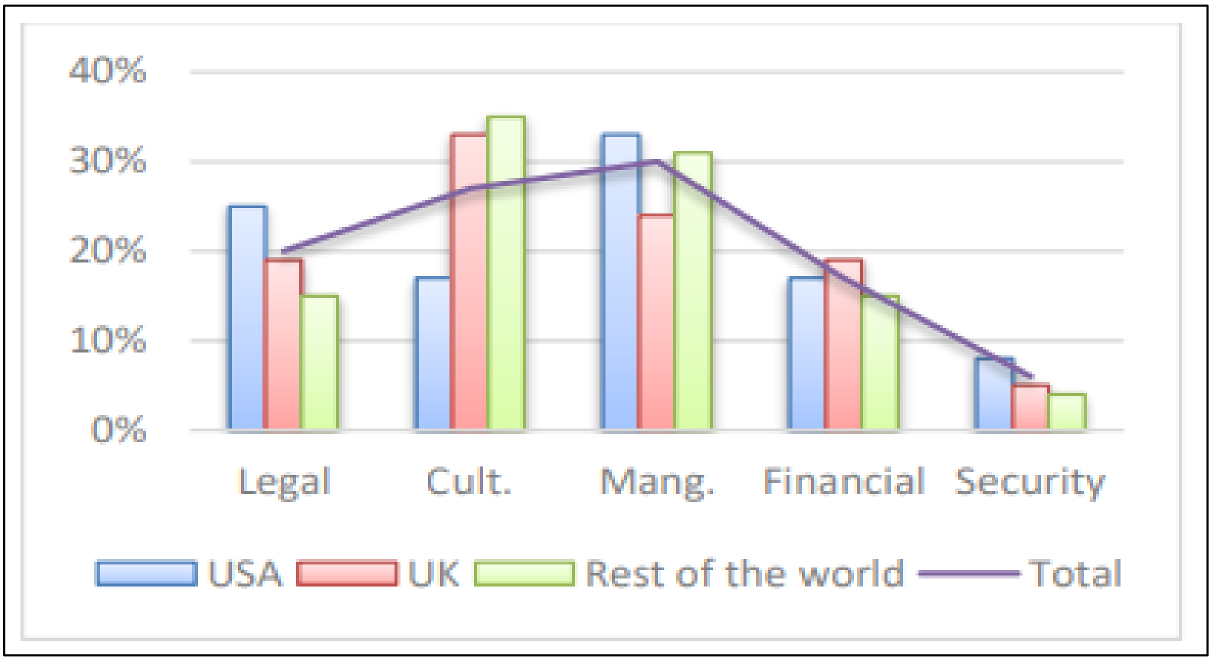


Figure I. 14: Distribution of BIM implementation Challenges.

I .8.1.Legal and contractual issues

The fact that BIM technical issues have been highly considered in recent years and considerable energy has been spent on these areas, “maturity of the legal body of BIM as well as its contractual configuration is more unsophisticated than its technical aspects” [31] This weakness has a special effect on contractual terms and there is a challenge that limits the responsibilities of legal issues related to BIM implementation. Therefore, an appropriate substrate for implementing BIM in contract clauses of projects should be created or added.

I.8.1.1. Legal issues

In addition to technical barriers, resistance to changes in employment patterns and the need for education and training on the path toward implementing BIM in the industry, legal issues are the most neglected challenges against BIM implementation. These legal problems are generally due to:

- **Liability issues:** Legal liabilities are due to the multiple numbers of stakeholders contributing to the model and/or dependent on the precision and quality of the data in the model [32]. Moreover, fraction of sufficient legal structure for managing owners' comment in design, construction and installation is one of them [33].
- **The need for regulations:** Executive regulations in this regard and their coordination at international level to create a common language, reduce conflicts and create a clear path to resolving the dispute are essential.
- **Intellectual property rights:** Because BIM models can be easily extracted and copied, intellectual property rights are determinative in BIM implementation [31]. For example, a BIM protocol may need a higher price intellectual property licensing than that procured under traditional contracts [30]for intellectual property rights in contracts, these provisions are important: model ownership, copyrights, authorized and unauthorized uses of models and e-documents, and the level of exposure of the special trade information.

I.8.1.2. Contractual issues

Poor contractual agreements in addition to failing to implement BIM may pose a significant risk to the success of the entire project. BIM contractual language must deal with two important risk categories, including:

- **BIM behavioral risks:** This may include collaboration issues, efficiency level of coordination, and collaborative information development,
- **Issues in BIM technological aspects:** Arise in forms of information reliability, model accuracy, model management and maintenance, and model ownership. BIM contractual provisions refer to levels of BIM maturity, which, in higher maturity level contract, should address more issues and more details

on BIM implementation. This is because responsibilities, relationships, interactions, and technologies are different at each maturity level [31].

I.8.2. Cultural issues

Cultural problems are the background of other problems and by solving them; a great step can be taken to solve the problems of implementing BIM. Cultural problems include many aspects and the most important ones are resistance to change, lack of cooperation between project stakeholders, and the absence of the real BIM-based sample.

- **Resistance to Change Actually**

Only small fractions of companies are aware of BIM and are using this technology to benefit their own projects. While other companies do not have experience in this field and carry out their own projects traditionally as they are unwilling to use BIM technology. These companies believe that BIM is an underdeveloped technology with limited capabilities; they also feel that using BIM is very complicated and thus it is best to do their own projects using non-BIM tools. The lack of knowledge and education is another factor; engineers and companies are doubtful about learning BIMs concept and they believe that it is costly to train their employees in this regard. In addition, the lack of knowledge and trained staff as well as inability to persuade other stakeholders to handle BIM implementation costs is among other issues that make it difficult for individuals to carry out their projects using non-traditional methods [34].

- **Lack of Cooperation between Projects**

The collaboration and reflection of the project team can help ensure the success of the project, rather than discussing the goals that contribute to the success of the project. Lack of cooperation from any of the stakeholders can cause serious damage to the entire project. In general, BIM implementation in construction projects requires more collaborative and integrated delivery of the project [34].

- **Absence of a Real-World BIM-Based Sample**

Another approach to persuading stakeholders to use BIM technology is the availability of run-time examples of projects implemented using BIM technology. If project stakeholders and companies visit a real sample of BIM-based project, they are more willing to do their projects using BIM technology. It is also possible to add a course to the university curriculum and invite BIM experts to train students in BIM area and related software.

Companies and organizations can also arrange classes for their employees to become familiar with BIM technology. Moreover, BIM experts could be asked to prepare educational videos for teaching BIM software. Because BIM-based projects require teamwork, before the start of the project, it is necessary for one of the specialties to be selected as the head of the group and clearly describes the responsibilities and duties of all the team members. It is also necessary to control the work of all the members to guarantee a collaborative work [34].

I.8.3. Management issues

There is much debate on the benefits of implementing BIM. This improvement surely will make the project managers more likely to be happy since BIM helps managers to reduce their concerns in the following areas [35, 36]:

- "Complexity of infrastructure development projects needs strong project management for a multidisciplinary management system to support decision making and to motivate many practitioners involved in the design process".
- The role of information in the management of the design phase workflow.
- Knowledge management for better risk management: One of the principles of risk management in the project is that all the team members must contribute to the risk database in different phases of the project. It is complicated to manage these databases with traditional methods.
- Based on the main failures identified, and compared to international standards, cost management is one of the main categories, arising as the recurrent issue.

In addition to the above, there are plenty of other things that cannot be considered here. With BIM, project management is better to be performed in these areas, and its quality becomes better through using less energy. However, to reach this point, the project manager should face the following challenge [34, 37]:

1. Need to upgrade the communication platform: Vital communication is more important than ever before; it puts new risks on the project.
2. The complexity of team building in this new environment: The performance of virtual teams requires their own techniques, which usually require managers to master their skills. It should be recalled that in the last 40 years, the productivity of human resource in the construction industry has been less than productivity in the nonfarm industry.

3. Challenges are caused by longer project engineering time, especially in EPC projects, where its nature is the integration of the stages of engineering and construction. Justifying the expectation of completing the model and engineering will be to some extent difficult.
4. Considering the production of the visual model: Stakeholders seem to be more willing to comment. Since prioritization is different from each stakeholder's point of view, their summing up in stakeholder management processes sometimes will be more challenging.

I.8.4. Financial issues

Financial and investment issues are the determining factors in any project. These issues become more important during emerging BIM technology. As mentioned in the "cultural" section, the lack of a real and complete implementation of the model creates many doubts for investors and stakeholders.

Most of the investment required to implement BIM is spent on purchasing software, hardware, personnel training, and recruiting specialized staff. The main challenge is to justify and explain these costs to project stakeholders. These costs are only seen as purchases of software and personnel training, or as part of a business change process [34].

I.8.5. Security issues

Cyber security of BIM tool outcomes as information sharing makes project data accessible to team members, cyber security is a concern due to the possibility of online unauthorized access and copyright infringement .Data security is essential to avoid snooping, theft, virus and worms, and hacking .One of the major challenges in BIM implementation at the AEC industry is security issues .Clearly, solving this issue is beyond BIM control., cyber security is a global challenge; however, it should be considered as one of the main challenges facing the implementation of BIM. Since there are fewer projects, not all stakeholders have the same sensitivity to the information leakage. Therefore, solving the cyber security problem is crucial for the development of BIM implementation [34].

I.8.6.BIM adoption challenges in the third world countries

BIM has been around for nearly two decades but has recently become more mainstream in the professional consciousness. The adoption of BIM technology has been slower than expected in the third world countries due to some inherent challenges. Here are some significant hurdles that BIM adoption construction industry faces:

- **Lack of Expertise**

The biggest challenge faced by the construction industry for BIM adoption is the lack of widespread expertise. It is fair to say that the majority of the third world countries' construction companies do not have many employees who are qualified or knowledgeable enough to integrate BIM and construction projects seamlessly. The lack of in-house expertise results in BIM experiments. Projects suffer from inefficiency and loss of profits due to increased operating costs. This creates the perception that the technology is hard to adopt.

- **Lack of Awareness**

The second most significant hurdle is the lack of awareness regarding BIM technology.

- **Cost-effectiveness for small projects**

BIM has more than proved its mettle in big projects by saving humungous amounts of money by reducing operating and inventory costs. However, this cannot always be said for smaller projects. These projects lend themselves easily to more intuitive and experience-driven decision making. The penalty for mistakes is also smaller as are the budgets. This makes it less attractive to implement BIM with its operating costs and effort commitments.

- **Resistance to change**

A growing fraction of construction companies has adopted BIM for their construction projects. However, implementing BIM also necessitates a change in the operations of the construction company. Better planning means greater responsibility for perfect execution. There is less room for error and hence greater pressure to perform.

- **Lack of cooperation between stakeholders**

The most significant advantage of BIM technology is the integration of the workflow of all the involved stakeholders. Now, this involves high levels of collaboration from the interested parties. This is a significant challenge that only becomes greater as the project becomes bigger. Large infrastructure projects have multiple teams associated with specific point responsibilities. Quite often, the involved parties lack the will to cooperate. Conflicts arising due to noncooperation between the stakeholders make it difficult to carry out work -BIM-led or not.

I.8.7. Challenges resolved over time

It seems that problems related to the software issues were largely resolved. In the early papers (early 2010), widespread mention was made of technical problems, especially software problems; Problems such as the lack of single software, lack of coordination between the software used in different sectors, and lack of a single standard for software output. However, today, with the advances in software, the standard definition of the unit and the acceptable coordination between different software have been largely resolved [34].

I.8.8. Future challenges

Problems that will emerge in the future on BIM implementation path will be mainly contractual and security issues. However, in short, the successful implementation of BIM requires new contractual types. IPD contracts may be a way out of this turbulent path. Making secure information in BIM also requires defining a new protocol security. Defining and limiting access to various levels of software and clouds is an interdisciplinary field that requires more research [34].

I.9. Digital transformation in construction

Figure I. 15 : Digital transformation in construction.

Within the AEC sector, the design and engineering areas are undoubtedly the most advanced in terms of the implementation of digital solutions. However, despite the appearance of multiple technologies, such as the use of drones, robots, intelligent tools, etc., physical construction has assimilated a few changes and remains mainly an analogue process.

Some of the main technologies that can help the transformation of the sector and increase its efficiency and productivity could be:

- The implementation of the BIM methodology, advancing in the implementation of all its dimensions, until reaching the BIM 7D, focused on the subsequent management of the buildings, or even higher levels focused on the efficiency of the operations to contribute added value to the maintenance of the buildings and facilities.
- Tools for digital collaboration and mobility that help to overcome problems in the relationship between the different actors in the projects, both internal and external.
- Quality control systems and management of safety and regulatory processes.
- Applications to improve real-time information flows and interoperability with other systems.
- Advanced data analysis.

The implementation of these technologies is intended to improve aspects such as efficiency, sustainability or costs, which are vital to ensure a return on investment and a significant improvement in the results of the organizations [38].

I .9.1. Importance of digitalization for the construction sector and its benefits

Digitalization is essential for the development of the construction sector with the opportunities it offers to change and optimize the construction business. Digitization affects every stage of it, its processes, and the whole value chain. As for many other industries, as well as in the construction sector, it has many advantages [35].

- increased productivity and efficiency;
- increased speed of construction activities;
- saving time in the implementation of construction projects and improved opportunities for adhering to construction schedules;
- Significantly higher quality and safety of construction, incl. and the quality of the accompanying construction documentation;

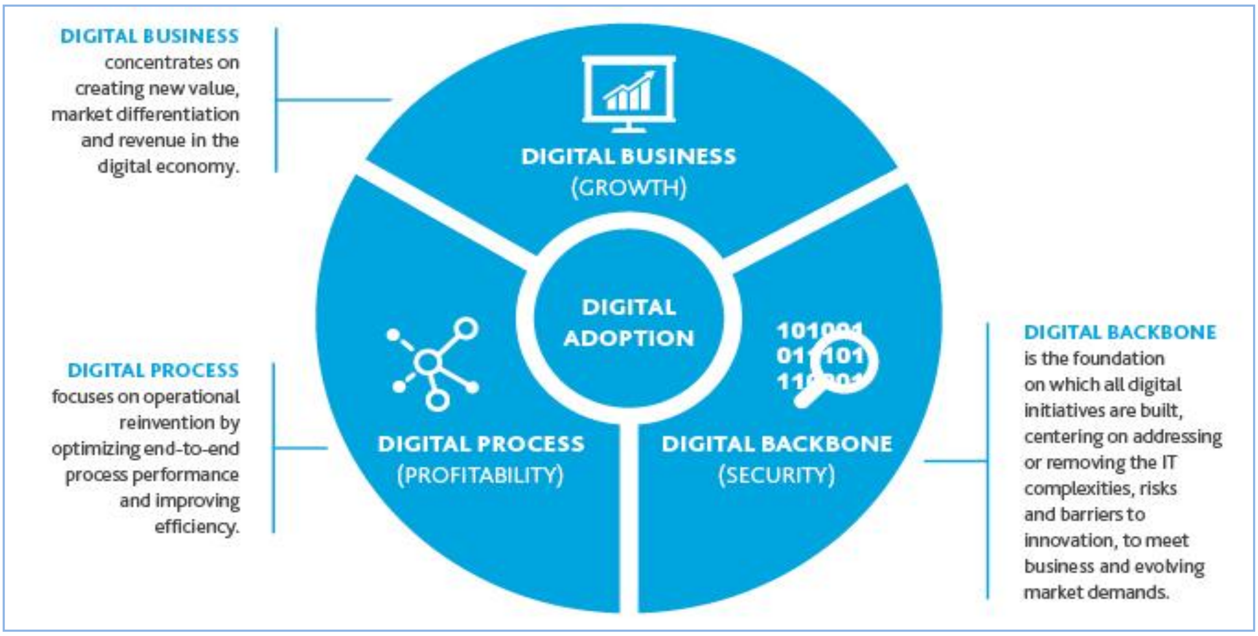


Figure I. 16: The future of construction and the digital transformation.

I .9.2. Challenges of digitalization in the AEC sector

One of the main digitalization in any company, and particularly in those in the AEC sector, is to achieve a clear definition of the objectives of the transformation project and how these changes will create value for the company. During the development of the projects, it is vital to focus as much or more on the operational and business processes as on the technology itself.

Some of the main challenges have to do with aspects such as the fragmentation and dispersion of teams, the participation of multiple subcontractors and suppliers, the scarce digital training of professionals or the lack of standardization in the sector. Some initiatives, such as the implementation of the BIM methodology, try to overcome some of these barriers, but in most aspects, there is still a lot of work to be done.

I.10. BIM in green buildings

Green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life cycle from sitting to design, construction, operation, maintenance, renovation and deconstruction.

Figure I. 17: BIM in green building.

Although green building remains an admirable goal, it is not always easy to achieve. Depending on building techniques and strategies selected, long-term gains and short-term costs all too frequently collide in a tight economy. Additionally, the sheer volume of documentation from two-dimensional paper drawings to spreadsheets of engineering data yields a primordial soup of information that needs a spark to bring sustainable design options to life [39].

The concept of building information modeling (BIM) could be the 'big bang' needed for green buildings. Embraced by architects/engineers (A/Es) seeking higher quality designs and collaboration that is more productive, the technology can help harness the characteristics and performance of design concepts, allowing A/Es to compare sustainable alternatives to balance energy and resource efficiency with project costs [39].

Figure I. 18: What is the role of BIM in green building projects.

Following are top roles of BIM in Green Building projects [39]:

- BIM helps in making sustainable early design.
- With the help of Green BIM, project stakeholders can make early decisions in the design phase.
- Green BIM influences the efficiency and working of construction project.
- Green Building has greater asset value because of its lower lifecycle cost and environmental impact of the building through its construction and operational phase.
- Energy Efficiency can be evaluated by using BIM in design process.
- Using BIM helps in making recommendations for design alternatives that will enhance a building's performance.
- Green Buildings improve occupants living by improving indoor conditions such as lighting and environment of building.
- BIM improves buildings environmental performance by improving facility management.

Figure I. 19: How BIM services can be helpful as green building services.

In figure I.19, you can see BIM services for green buildings.

I.11. BIM for smart cities

A smart city is typically a kind of municipal Internet of Things, a network of cameras and sensors that can see hear and even smell. These sensors, especially video cameras, generate massive amounts of data that can serve many civic purposes like helping traffic flow smoothly.

BIM technology is the key to make cities smarter, as well as their importance in integrating the individual information of each building on a wider scale with geographic systems information and linking it to the life cycle of the building, infrastructure or urban planning. Several specialized teams process this information. the BIM technology offers many long-term benefits as the buildings are not isolated or treated as individual units but are integrated and linked to the city's infrastructure, roads, housing, utilities, heating, water, cooling, electricity networks, etc [40].

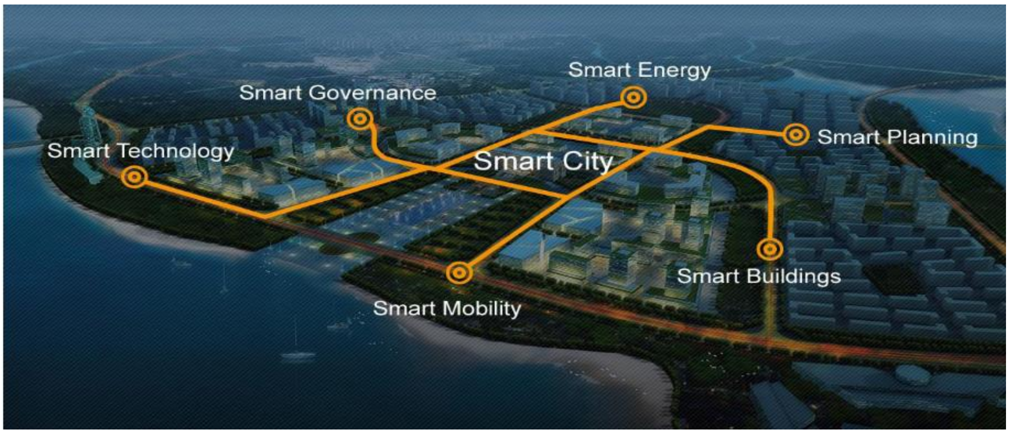


Figure I. 20: Smart city components.

I.11.1. Civil Information Modeling

Figure I. 21: The design of a smart city.

In the application of smart city technology, the term civil information modeling appears. The goal is to establish and maintain the infrastructure by applying the BIM technology during design and maintenance through municipalities, and owners of public facilities and facilities to obtain intelligent infrastructure, intelligent road networks, and then get a smart city.

I .11.2. Geographic information systems

It is a technology designed to monitor, collect and analyze all kinds of geographic information and represent the results of these analyzes with real elements such as roads, land, levels, heights, trees, rivers and others. This information is monitored through the satellite aerial image technology, which is linked to coordinates x, y, z and gives real information of the place has a spatial reference

Figure I. 22: Smart building example.

I .11.3. Challenges for Smarter Cities

The main challenge for the application of smart cities is not only how to obtain data and information, but the biggest challenge is how to analyze large data and obtain results those are used to organize the process and how to formulate it. It mimics the reality of continuous scalability.

I.12.Conclusion

BIM did not appear by coincidence but it was a result of many attempts to catch the accelerated trajectory of construction field. Started by hand drawing to 3D, 4D and 5D models. This evolution reaches all construction phases from design analyzing documentation managing to construction and operation. Through all BIM benefits but it faces many challenges such as legal issues, cultural and financial issues and resistance to change mostly in the third world countries. The implementation of BIM is intended to improve aspects such increased productivity and efficiency, increased speed of construction activities, saving time in the implementation of construction projects and improved opportunities for adhering to construction schedules, Significantly higher quality and safety of construction, and the quality of the accompanying construction documentation. BIM will also allow construction field to acclimate with the changes in the world such as global worming by making green buildings and smart cities.

CHAPTER II:

BIM IN STRUCTURAL ENGINEERING

II. BIM IN STRUCTURAL ENGINEERING

II.1. Introduction

Civil and Structural Engineers has a role across the entire life cycle of assets, from project inception and delivery, to operations and eventual decommissioning. At each stage, engineers rely on robust information to support multi-disciplinary decision making and inform activities, whether design, construction or maintenance. Building Information Modeling (BIM) has been high on the agenda of all organizations involved in the planning, design, construction, ownership and maintenance of the built environment in recent years, influenced significantly by government policy. Advocated as the catalyst for solving many of the industry's shortcomings including quality, collaboration and productivity, BIM is swiftly moving from a niche technology-based concept to the basis for the delivery of projects and asset management across all sectors of the construction industry.

II.2. BIM in civil and structural engineering

The use of new methods and software is one of the most important tools that structural engineers is using nowadays to stay competitive. Engineers are constantly looking for new ways to improve and keep the pace on today's economy, reaching to new heights in the aspects like productivity, coordination and problem solving. Building Information Modeling (BIM) can potentially help with these important aspects. The core feature that BIM offers is the ability to integrate intelligent objects in the model. These intelligent objects contain all the data regarding a specific component, from geometric characteristics to the way they interact with other components, making the entire model full of information.

Structural engineers can take advantage of BIM in different ways, as the model can be constantly updated with any changes in the design or general specifications, keeping all the data as accurate as possible. BIM transforms the way we handle and visualize components. It has grave impact on designing activities like, conceptual design and structural analysis. BIM ensures reduction in design and drafting errors and hence provides with lower designing cost and improved productivity. It also allows for better analysis of situations through simulation.

Building Information Modeling (BIM) helps structural engineers to make more informed design decisions, automate documentation and present more constructible designs, while also improving the collaboration with other stakeholders and making the project delivery faster. In what follows, you can check out some of the uses of BIM in structural engineering:

- **Structural BIM design**

In structural design, we can use very simple conceptual approaches, like tools (e.g. Rhino, Dynamo) for changing geometric shapes in modeled shapes. Automatic calculation of earth movements' Automatic quantification of earthworks is another use of BIM in structural engineering. From the topographic to the shape of the different levels where we can automatically determine the earth's movements. What we should know here is that: The import process from CAD to BIM ground is automated; The CAD-BIM import process only works if the topographic points in CAD have altimetry coordinates, in 3D representation of the ground; Automated Calculation existing between the ground and adapted ground [41].

- **Structural BIM analysis**

Another use, of course, is the structural analysis. The link between the physical model and the analytical model is very important. Ones base the geometric model on a model. These objects relate parametrically, thus linking all the template information. The analytical model absorbs this information to be conveyed to the software structural calculation. The BIM bidirectional link between a platform and a structural analysis tool allows the designer to test various structural solutions (in more primary phases of the project) in a rapid and automated manner. This iterative process of data respects and preserves the information defined in both software [41].

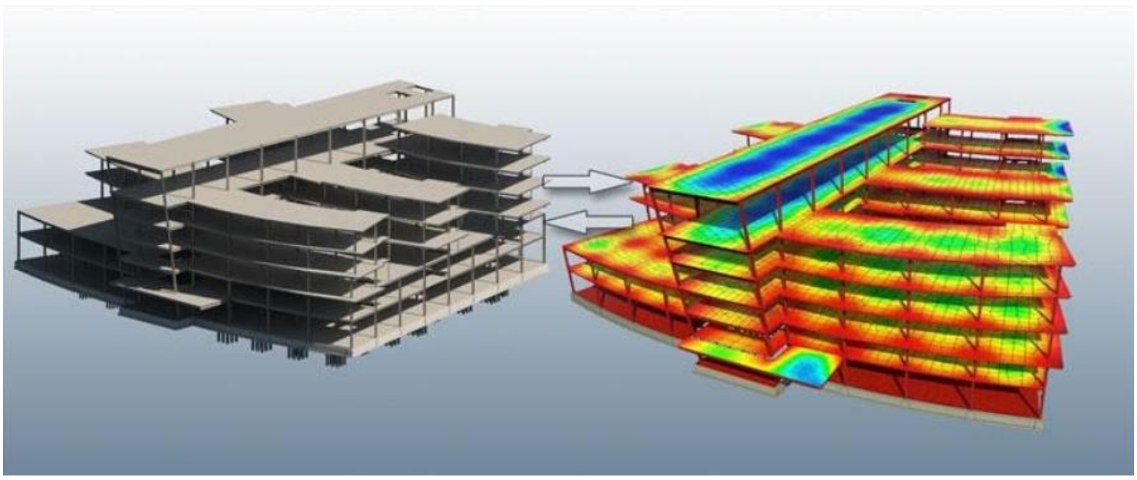


Figure II. 1: Structural model exchange.

In the figure above, on the left side, there is the physical model (the model that represents the geometry). On the right side, there is the analytical model, where we have strains, reactions, deflections, displacements. Example: Revit Structure & Robot Structural Analysis: This connection allows structural engineers to send parts of the structural model for structural analysis tools and vice versa. This flexibility allows engineers to work with the structure in separate analysis models. We used to split the calculations between gravity loads (permanent loads, temperature etc.) and lateral loads (seismic loads and wind loads) [41].

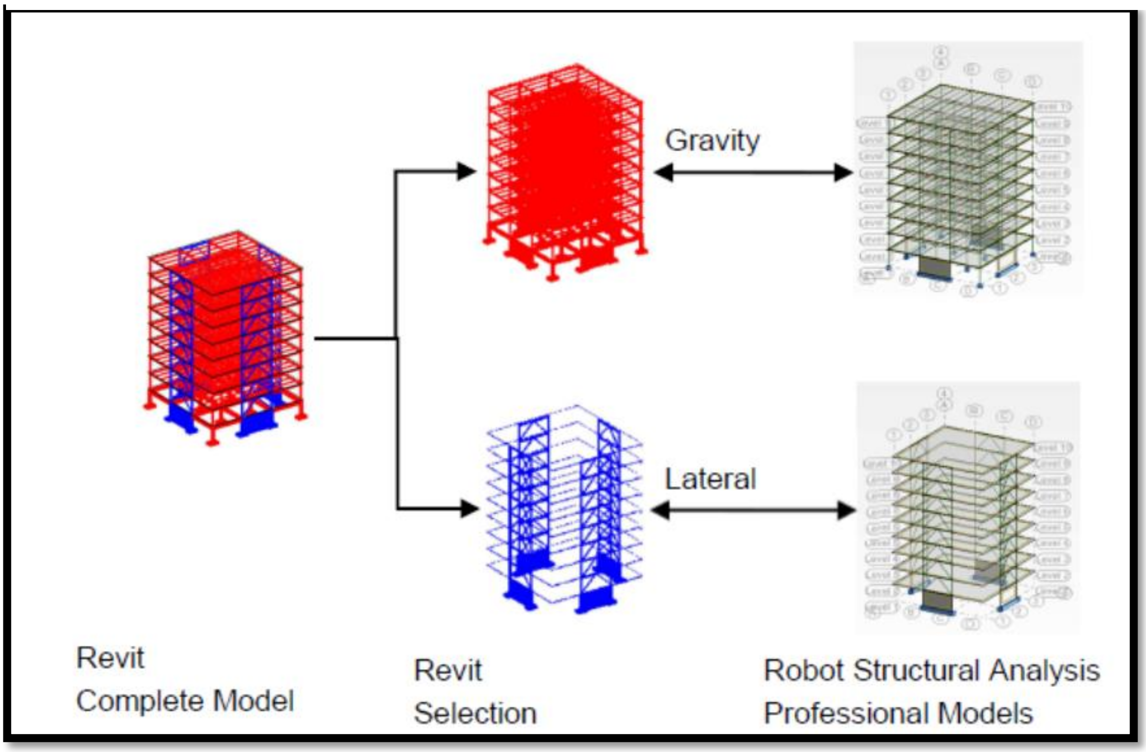


Figure II. 2: The exchange between Revit and Robot.

Situations: Systems of vertical and horizontal loads; metallic systems and reinforced concrete systems; Evaluation of specific elements in the structure.

Automatic production of drawings and views (2D/3D): this use is very advanced in certain types of structures, e.g. steel structures, There's still a lot of work till reaching a proper drawing of automatic extraction of quantities and budget estimate, the quantity takeoff is very relevant for the structural engineer especially in the early phases since the accurate measurement of building materials is becoming increasingly important. Several case studies have concluded that the process measurements in BIM are more reliable compared to traditional methods. BIM tools also allow measuring more in less time. Thank to BIM, we would have the quantities and the budget [41]:

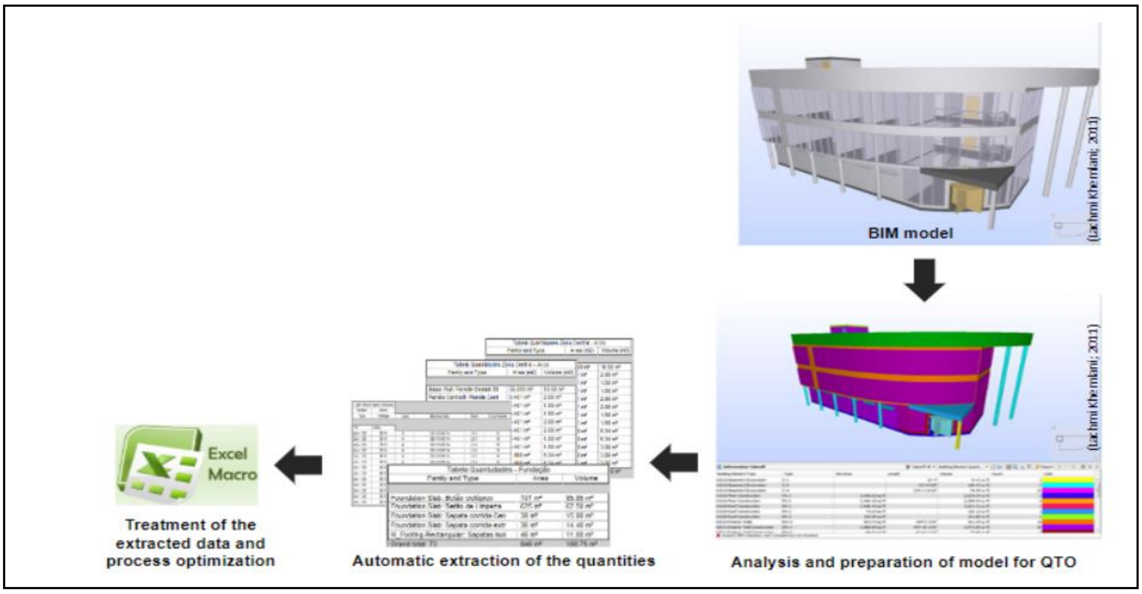


Figure II. 3: BIM Automatic extraction of quantities and budget estimate.

- **Phasing**

Structural engineering sometimes needs phasing as part of the analytical process, for instance in bridges. In bridges, each phase of construction needs to be calculated, needs to be understood for the engineer to have the right stress, deflection, etc. Phasing 4D connected with the management is another practical application of BIM in a project. So BIM permits to verify the compatibility between products and the automatic detection and early resolution of conflicts, e.g. between the architect and the engineer [41].

- **Structural detailing**

Using BIM for steel connections, wood connections, etc. is also a possibility. The example below is of a mixed structure with concrete, steel and wood [41].

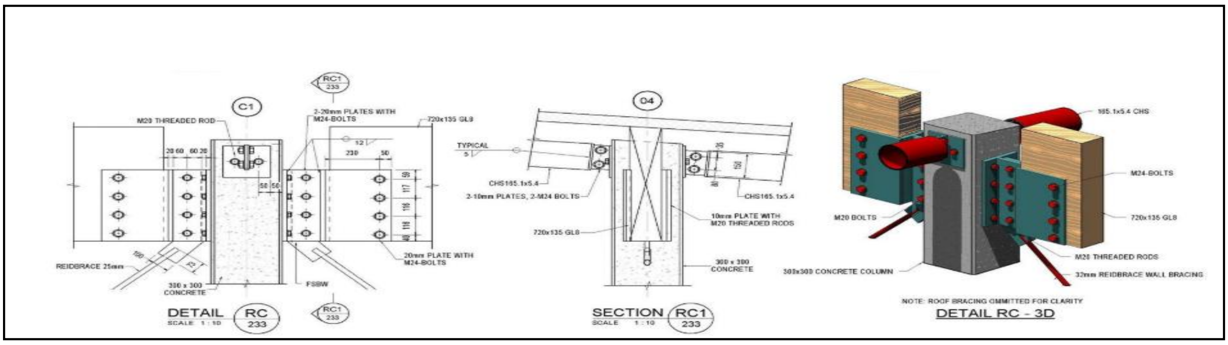


Figure II. 4: Mixed structure with concrete detailing.

In the figure II.5, you can see BIM services for structural engineers.

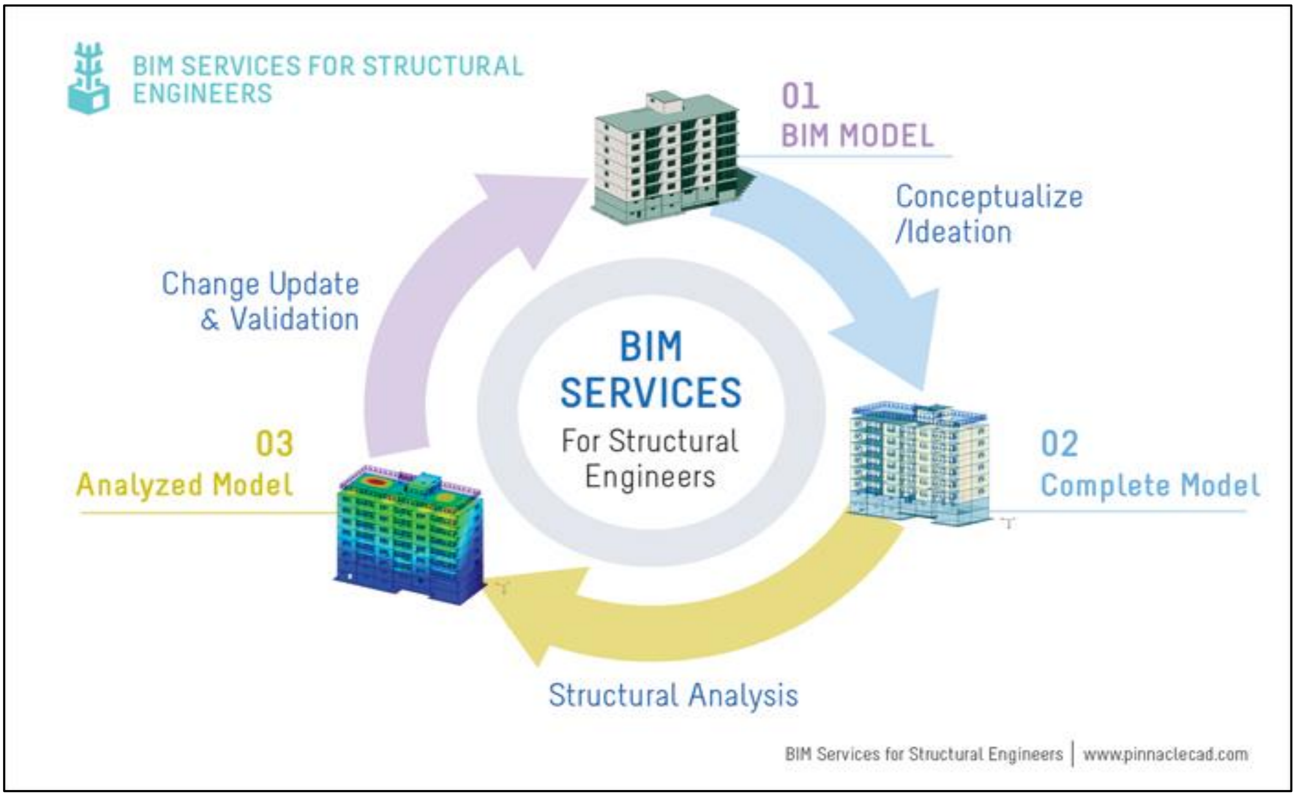


Figure II. 5: BIM services for structural engineers.

II.3.<u>BIM implementation in infrastructure</u>

BIM for Infrastructure is a vague concept. The BIM term was originally devised for the Architectural Industry. It is easy to envisage a 3D model of a building and all of its components contained within a defined structure [42].

Figure II. 6: BIM in infrastructure.

However, Civil Engineering or Infrastructure Projects tend to be diverse and spread over a large geographical area. Therefore, BIM for Infrastructure could be reinterpreted as building an information model for a Civil Engineering/Infrastructure Project [42].

Building an information model (BIM) starts at the planning and conceptual design stage and continues throughout the lifecycle of the asset. It is important that intelligent information is not lost as the project progresses through the various stages of a BIM Infrastructure Project [42].

The Autodesk Infrastructure Solutions for BIM are designed to cater for all disciplines within the civil engineering industry including Road, Rail, Drainage, Utilities and GIS. The Autodesk Infrastructure Tools aid the user to quickly identify potential engineering challenges and enable the user to efficiently supply a solution [43].

The tools have dedicated workflows between one another. As BIM usually requires a model based design solution, Autodesk's Infrastructure Tools can easily create visualization, drawings and documentation from the model. The BIM Model makes it easier understand the project and achieve stakeholder approval. This should minimize risk and cost to a project [43].

The Autodesk Infrastructure Tools include the industry established:

1. **Autodesk Infraworks 360**

Infraworks 360 is a visual 3D design and communication platform for architects, civil engineers, designers, and planners. It is mainly used in the planning and pre-engineering phases of a project [43].

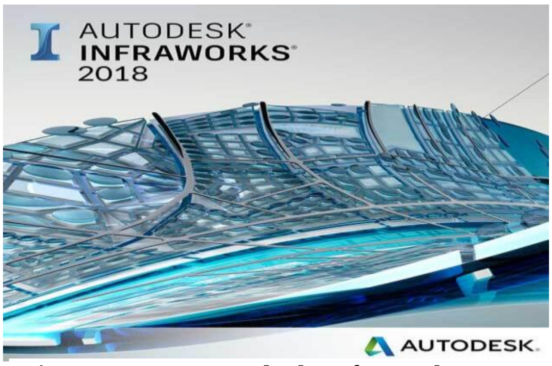


Figure II. 7: Autodesk Infraworks 360.

2. **Autodesk AutoCAD Civil 3D**

AutoCAD Civil 3D is civil engineering design, analysis and documentation software to support BIM workflows [43].

It is primarily used in the planning and detailed design phases of a project. It is easy

Figure II. 8: AutoCAD civil 3D.

to transition AutoCAD users to AutoCAD Civil 3D since it is built on the AutoCAD platform

3. Autodesk Navisworks

Navisworks is project review software for architecture, engineering, and construction professionals to review integrated models and data with stakeholders to gain better understanding and control over project out come. It is principally used in the detailed design and construction phases of a project [43].

Figure II. 9: Autodesk Navisworks.

By investing in BIM for Infrastructure civil engineering businesses will be able to increase the efficiency and profitability within the company as well as being more competitive in the marketplace, and with government deadlines for capital projects to be completed using BIM methodologies fast approaching, business that are BIM ready will no doubt be the first call for supply.

II.4. <u>Internal workflow in BIM for civil engineering</u>

The process of using BIM for different collaborative purposes within different stages of the project is a complex endeavor. It also involves a lot of resources, including both software and employees.

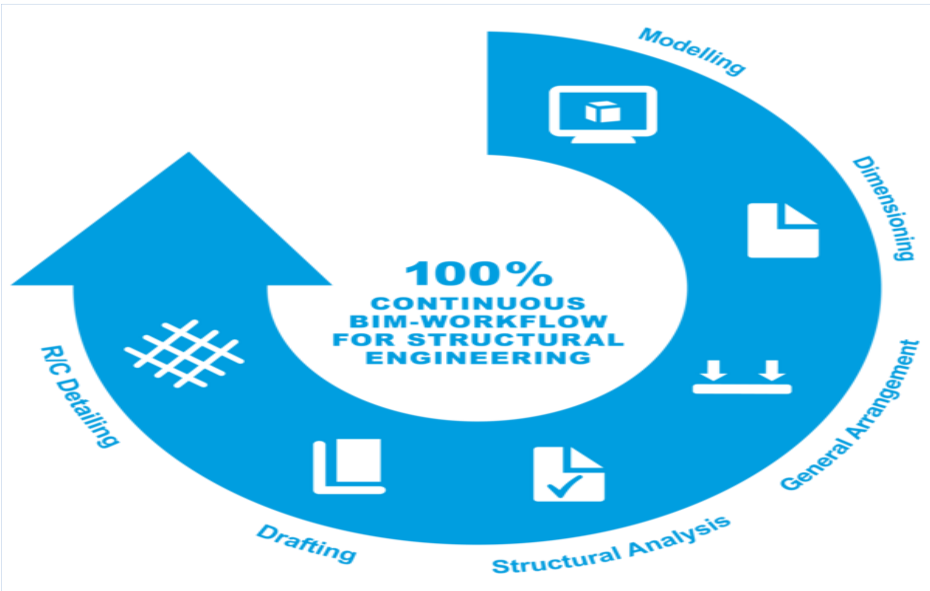


Figure II. 10 : BIM workflow.

1. Pre-design Phase

The pre-design phase is the first step towards the realization of the project, and it usually involves several long-term decisions. One of such decisions is whether BIM should be used in the process or not. At this point, it's extremely rare for companies not to take the many advantages that BIM has to offer, but it's still a choice nevertheless. The schematic model of the project is also created at this step, and made by the architect.

This kind of model is then presented to the project owner, with a sufficient explanation about different facilities, expected costs and the materials involved [44].

2. Design Phase

The design phase is where additional parts of BIM often start to get involved, such as scheduling and estimating (4D and 5D), and sometimes even more. We will go over two of those since they are more common than the others are.
Scheduling is there to assure the building created and ready within the time period that was set before hand and estimating is making sure that the project stays within the boundaries of the predetermined budget. The correct setup of the BIM models would significantly improve the results of these efforts.

For example, the scheduling has to keep in mind the construction process and how it works in the first place. This allows the schedule estimates to be accurate and less prone to mistakes. Additionally, if the scheduling process is kept in mind when the BIM model is created, it would be much easier for estimating to provide more accurate numbers and predictions when it comes to budgets and materials consumed. The existence of information within different parts of the BIM model helps this process be performed correctly [44].

In the age of 2D drawings, it was a very laborious task to try to keep all of the possibilities and elements in mind when performing estimations. Luckily enough, BIM is capable of providing models and objects that are filled with information about their real-life counterparts, making it significantly easier to accomplish both estimating and scheduling.

- **Collaboration and its place in the design phase**

Detailed design is where collaboration is supposed to shine the most. Performing regular coordination meetings with different participants of the project (engineers, estimators, schedulers, architects, project managers, construction managers, etc.) allows for every participant of the project to be involved in the process and provide their feedback on possible issues or setbacks.

Additionally, it is also highly recommended to perform interference checks and clash detections on a regular basis. Some might say that this is a time-consuming process, but correcting a previously undetected error in an existing building takes much more time and resources than finding it at the design phase and fixing it before the construction even gets to that point.

The design phase is also, where the BIM model could be used in several different ways, and not just its original purpose. The existence of BIM process management as a whole allows for a BIM model to be used in scheduling, elevations, walkthroughs, sections, and many other processes – potentially saving a lot of time and money within that project [44].

3. Construction phase

As soon as the design process is complete, it is time to begin the construction process. Assuming that you have estimating and scheduling calculated at the design phase, you should already have a number of long-lead items purchased preemptively and that your schedule is as close to reality as possible. At this point, your work on-site should have already started, with people working on getting ready for the foundations to be poured, among other things.

At this stage of the construction, BIM can still be utilized in many ways to keep the process on the rails, so to speak. A specific piece of software like Navisworks can be used in the field to make sure that the intended design is followed completely, and both the construction manager and the field superintendent are collaborating with the design team for that exact purpose [44].

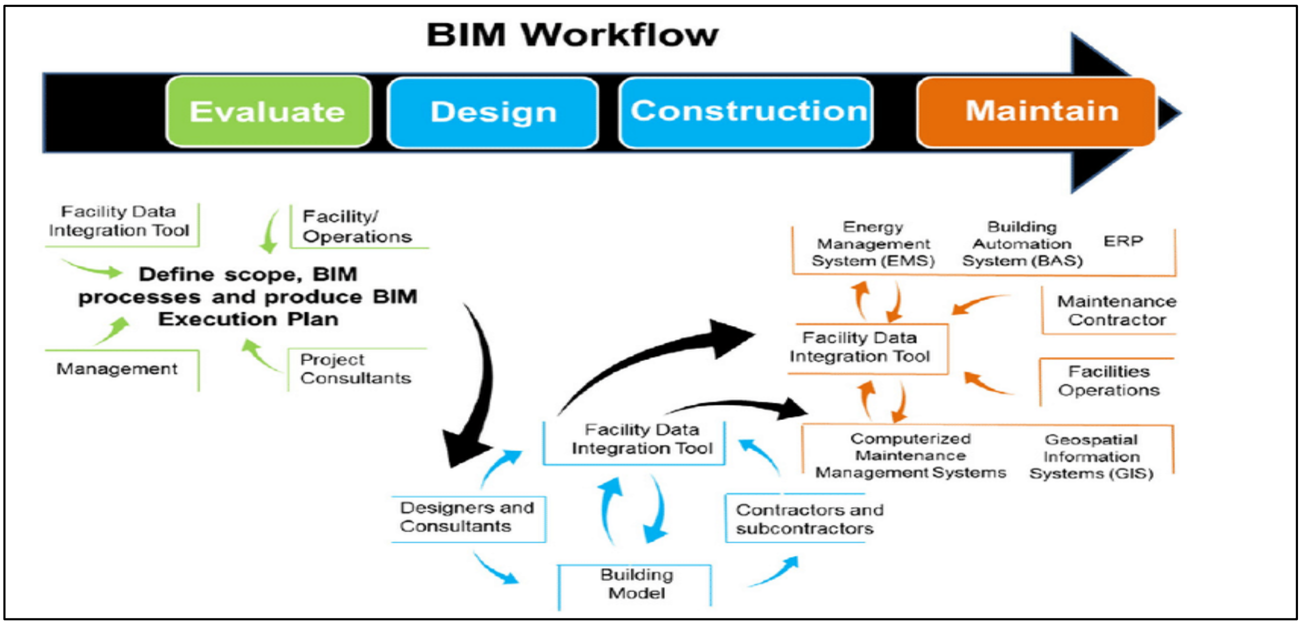


Figure II. 11: BIM workflow.

II.5. Conclusion

The benefits of using building information modeling are evident, especially when analyzing the way that this methodology enhances the structural design workflow. Engineers are realizing the power of BIM for more efficient and intelligent design, and most firms using BIM are reporting strong favor for this technology. The increase in productivity is a significant benefit that BIM provides in structural engineering. Construction documents are generated completely automatic when using a building information model, significantly reducing the time required for detailing. It also reduces the need to make extensive checks, helping prevent errors in the documentation that can affect the construction.

CHAPTER III

STRUCTURAL MODELING AND ANALYSIS USING BIM

III. STRUCTURAL MODELING AND ANALYSIS USING BIM

III.1. Introduction

The process of designing building structure is normally interconnected with that of designing overall building. Since architects and engineers approach the design process in many different ways, a common ground for collaboration is critical for the success of designing building structures. Building Information Modeling (BIM) offers a collaborative solution and advance structural knowledge learning without compromising other principles of structural design. The research aims to stress the value of digital modeling in education as it relates to understanding of the interconnected nature of structural systems and behavior.

III.2. Presentation of some BIM platforms

Figure III. 1: BIM coordinator tools.

BIM software provides a model-based process used for the planning, organization, design, and management of buildings and infrastructures by the construction industry. The software collects data and presents a real-world demonstration of buildings and infrastructure before they are constructed, during construction, and after they are completed.

To accomplish its objectives, BIM software needs to help construction industry professionals complete the various tasks involved in creating a structure. For instance, it needs to facilitate collaboration and communication, provide tools for turning theoretical ideas into concrete ones, and explain what each phase of the project will cost.

Here is a list of the best BIM software:

1. AutoCAD – Best BIM software for automation

AutoCAD speeds up design time by automating everyday actions like inserting doors and bill generation. This software's designers refer to several productivity studies on the different tool sets – architecture, electrical, map 3D, mechanical, MEP, Plant 3D, and Raster Design [45].

- **Advantages**
  - Saves time
  - Precision and accuracy
- **Disadvantages**
  - Long learning curve
  - Expensive for small firms

2. Navisworks – Best software for simulation

Navisworks analyzes and communicates project details using a feature known as 5D analysis and simulation. The software promises to improve the workflow of the project team via integration with Autodesk BIM 360 Glue [45].

- **Advantages**
  - Affordable for all firm sizes
  - Access to previous releases/versions
- **Disadvantages**
  - Mobile devices are not supported
  -

3. Infurnia – Best web-based BIM Design Software

Infurnia is cloud-native BIM design software that enables you to seamlessly implement BIM while creating your architecture drawings, collaborate easily across functions, and manage your data efficiently [45].

- **Advantages**
  - Free for individual architects, and affordable for teams
  - Easy to learn with a modern interface
- **Disadvantages**
  - Not as full-featured as software like Revit, especially for larger designs

4. <u>Vectorworks Architect – Best BIM software for coordination</u>

Vectorworks is flexible enough to support a construction project through its entire life cycle: from conceptual design to coordinated BIM models and construction papers. This software solution is loaded with designer-focused tools and features, allowing workflow to enjoy great freedom and flexibility [45].

- **Advantages**
  - Quick in rendering 3D models
  - Easy to learn and use
- **Disadvantages**
  - Can be unaffordable for smaller firms
  - Requires high-performance PCs

5. <u>Autodesk Revit – Best software for floor plans</u>

Autodesk's Revit is a BIM solution that helps architecture and construction firms design floor plans. It allows for collaboration with professionals across different disciplines. It can be used for construction management for the entire life cycle of a construction project [45].

- **Advantages**
  - Seamless integration with other Autodesk solutions
  - Great for project management
- **Disadvantages**
  - High-performance PC required
  - Users must create their own object libraries.

6. Autodesk BIM 360 – Best BIM software for connecting project teams

BIM 360 is a unified platform that connects in real-time with project teams, data, and workflow throughout the project's entire life cycle. This leads to informed decision-making [45].

❖ **Advantages**
- Great for project management
- Live design updates between project teams

❖ **Disadvantages**
- Interface isn't user-friendly
- High learning curve

7. ALLPLAN – Best all-around building information modeling software

ALLPLAN is a solution for architects that incorporate the whole design process. It provides support from the initial draft presentation to the production of working drawings, detailed layout presentations, and the construction project has cost [45].

❖ **Advantages**
- Short learning curve
- Doesn't require high-performance hardware

❖ **Disadvantages**
- Interface is not user-friendly
- Detailed automatic drawings sometimes need to be supplemented manually

8. Tekla BIMsight – Best free BIM software solution

Tekla BIMsight is a free BIM solution that provides an environment for professions to combine 3D models, data and information sharing, resolves conflict, and checks for clashes in the design stages [45].

❖ **Advantages**
- Mobile platform supported
- Doesn't require high-performing hardware

- **Disadvantages**
  - Sectional views of drawing cannot be printed.
  - Not available on Windows

9. Trimble Connect – Best software for connecting team members to appropriate data

Trimble Connect is a free collaboration tool that promises to enable decision-making and enhances project efficiency by connecting the right team members to the right data at the right time [45].

- **Advantages**
  - Free version available for a personal account
  - Free trial available for a business account
- **Disadvantages**
  - Requires a strong internet connection
  - Doesn’t support 2D drawing

10. DataCAD – Best BIM software for beginners

DataCAD is Windows-based CAD software that allows drafting, designing, 3D modeling, and preparation of documents by architects, engineers, and construction professionals. This software solution provides integration with SketchUp’s 3D modeling tool for its production drawing and model development [45].

- **Advantages**
  - Easy to learn
  - Easy to use and intuitive
- **Disadvantages**
  - Supports only Microsoft Windows OS
  - 3D capabilities are not great

But apparently the most widely used BIM software is Autodesk's Revit which was initially released on April 5, 2000. Since then, Autodesk has successfully brought this tool to the mainstream and now has it positioned as the most popular design tool in the AEC industry. Autodesk now seems to be focused on pulling the construction side of our industry into this massive ecosystem by providing new features and tools for fabrication and detailing.

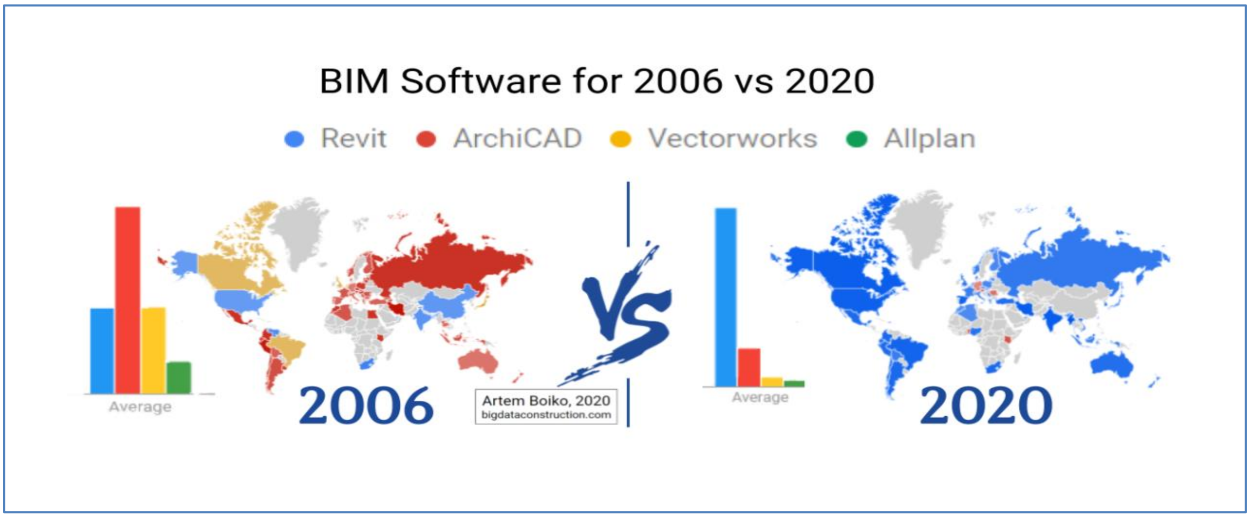


Figure III. 2: BIM software for 2006 versus 2020.

III.3. <u>The choice of a platform</u>

III.3.1.<u>Autodesk Revit</u>

Figure III. 3: Autoesk Revit.

Autodesk Revit is Building information modeling software for architects, structural engineers, and contractors. It allows users to design a building and its components in 3D, annotate the model with 2D drafting elements and access building information from the building models database.

Revit is 4D BIM capable with tools to plan and track various stages in the building's lifecycle, from concept to construction and later demolition. Revit is available in 32-bit and 64-bit versions, localized into multiple languages including German, French, Italian, Spanish, Czech, Polish, Hungarian and Russian [46].

Revit brings all architecture, engineering, and construction disciplines into a unified modeling environment, driving more efficient and cost-effective projects, Project teams can work together anytime, anywhere using Revit [46].

Figure III. 4: Autoesk Revit logo.

- **<u>Why Revit</u>**

What is the big deal about Revit for architecture and engineering? Well, it is like McDonald’s for the food industry or Nike for shoe one. When it occurred in 1997, it brought a real breakthrough into architecture, engineering, and constructions on so many levels. First, it has revolutionized the approach the building specialists use to interact and run the modeling workflow. In addition, this brand new visualization opportunity needs additional accolades.

We are also going to use robot structural analysis professional to analyze our structure.

III.3.2. Robot Structural Analysis Professional:

Robot Structural Analysis Professional is structural load analysis software that verifies code compliance and uses BIM-integrated workflows to exchange data with Revit. It can help you to create more resilient, constructible designs that are accurate, coordinated, and connected to BIM [47].

Figure III. 5: Robot Structural analysis professional logo.

Autodesk’s structural design software, Robot Structural Analysis Professional is finite element analysis software suited for engineers who require a structural analysis solution that allows them to model, analyze and design a range of materials such as steel structures and concrete structures to Eurocodes [47].

III.4. The integration between Revit software and Robot structural analysis

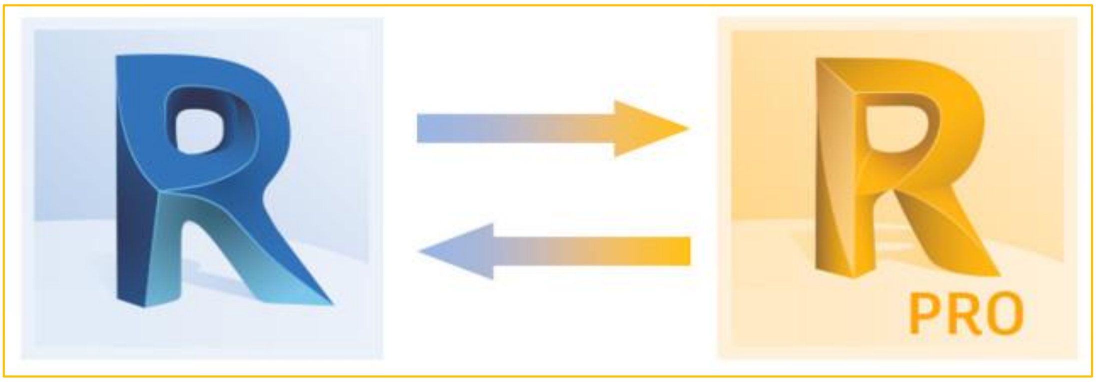


Figure III. 6: Integration between Revit and Robot.

The Integration with Robot Structural Analysis or Integration with Revit link is a tool, which allows bidirectional data exchange between Autodesk Robot Structural Analysis Professional and Autodesk Revit.

With this tool, you can:

- transfer a structure model from Revit to Robot or from Robot to Revit
- update a structure model in one program after making changes in the model in another program
- Transfer the results of static analysis and required reinforcement calculated in Robot to the Revit model.

This tool allows you to work on a part of large structure models. You can load a whole structure in one program, select a part of it and transfer this part to another program [48].

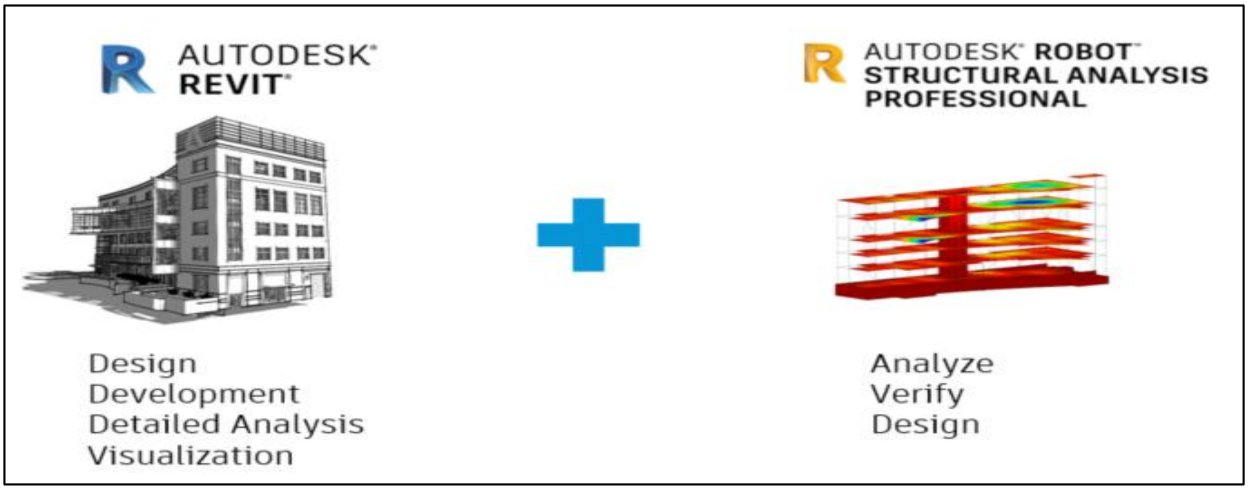


Figure III. 7: The integration between Robot and Revit.

III.5. Structural modeling and analysis using S-BIM

The participants in the structural design phase are architects, engineers and draughtsman. The architects dominate the conceptual phase whereas the engineers dominate the details and analytical part. The efficient structural design depends on collaboration and data exchange between all participants.

This chapter focuses on the structural engineering part in the building process, different BIM tools are used to each phase. to demonstrate the BIM mechanism we will study a building with ground-floor and 5 storey with metal framing used as a offices apartment located in the state of BLIDA classified as a high seismicity region according to the Algerian payment parasismic RPA99 VERION 2003.

III.5.1. The structural design in Revit

Revit software capabilities enable structural designers to enrich the physical model with information such as physical properties, proposed analytical model definition, and expected loads conditions. This makes the physical model more complete and also enhances collaboration with structural engineers.

1. **Choose a structural- analysis template or to create one. The template usually contains all necessary elements to create a structural model.**

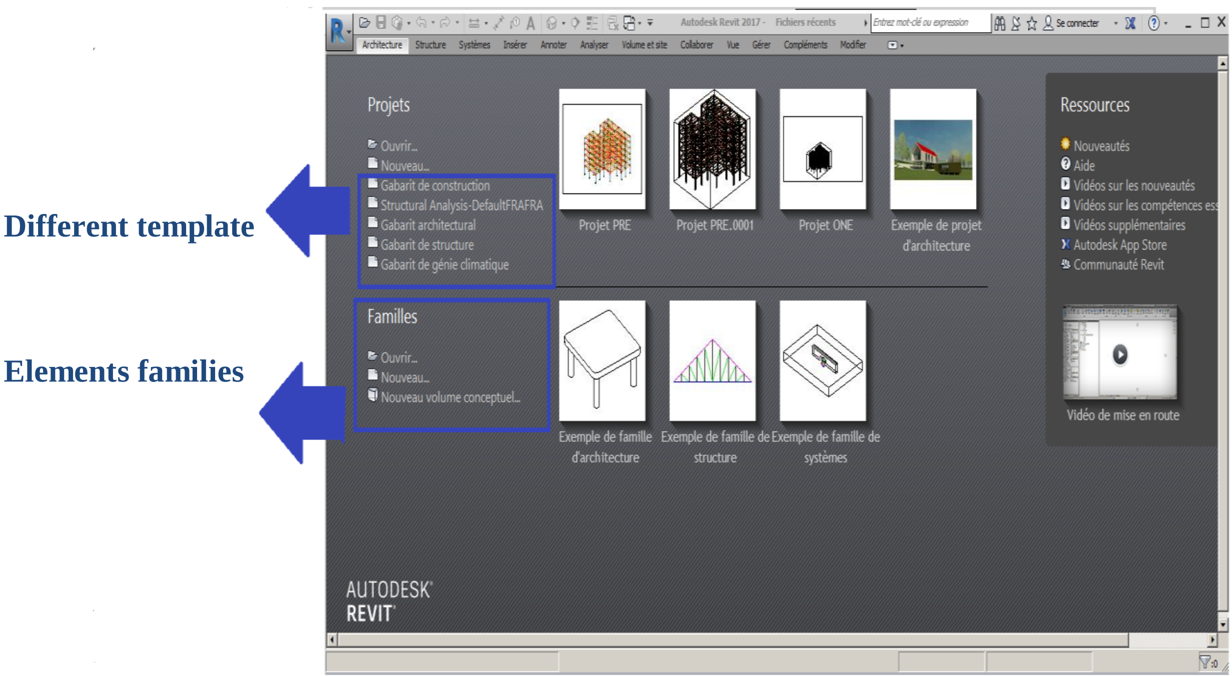


Figure III. 8: Revit different template and elements families.

2. **Create materials needed in the structure with a specific characteristic such as geometry, cost and strength...ect.**

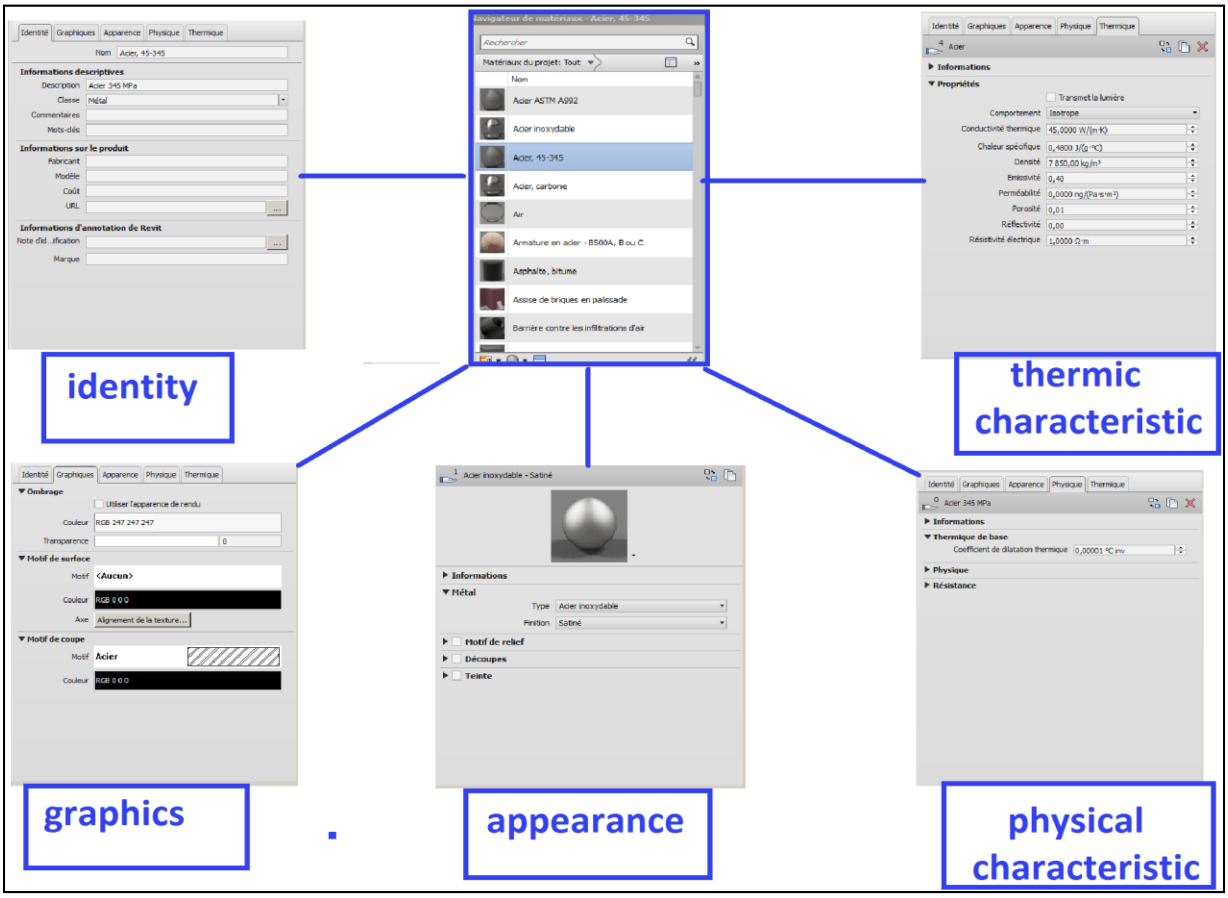


Figure III. 9: The creation of materials needed in the structure.

3. **draw primary elements based on the pre-dimensioning**

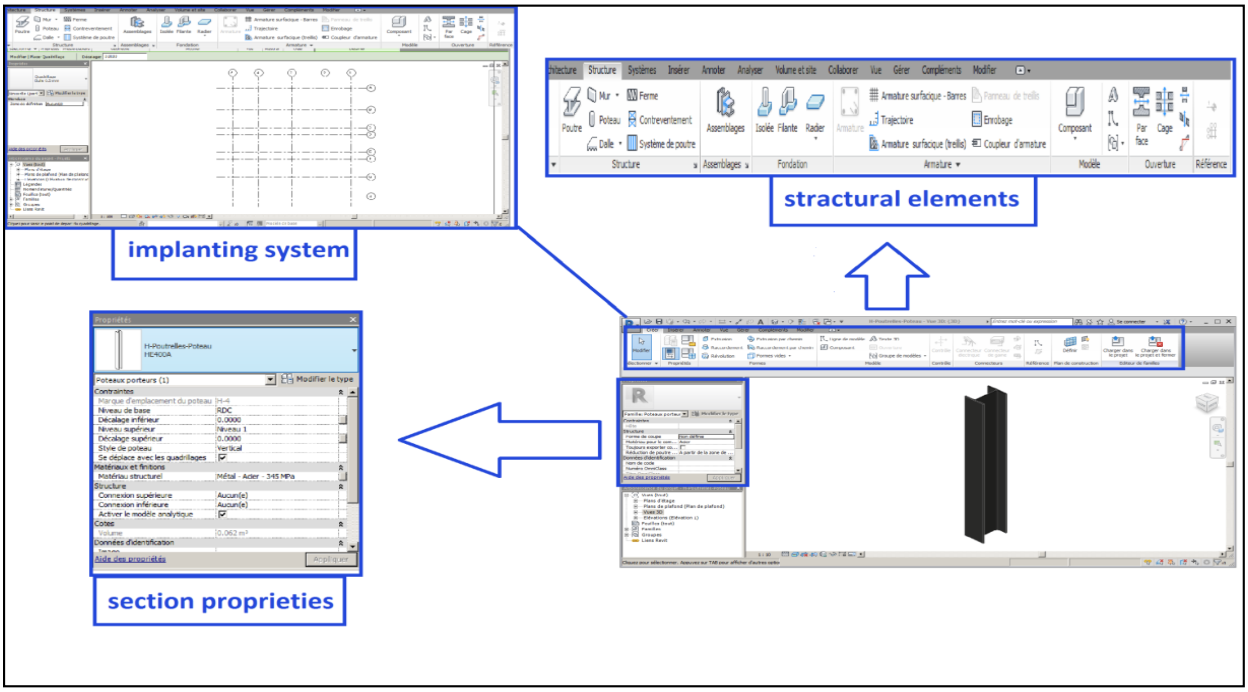


Figure III. 10: Primary elements drawing.

Modeling a structure in Revit software helps the user visualize the relationship between a real physical structure and its analytical simplification, which is needed for analysis.

Furthermore, this physical structural model is the basis for documentation as well as code checking (which focuses on physical elements and attributes such as section sizes, materials, rebar, and so on).

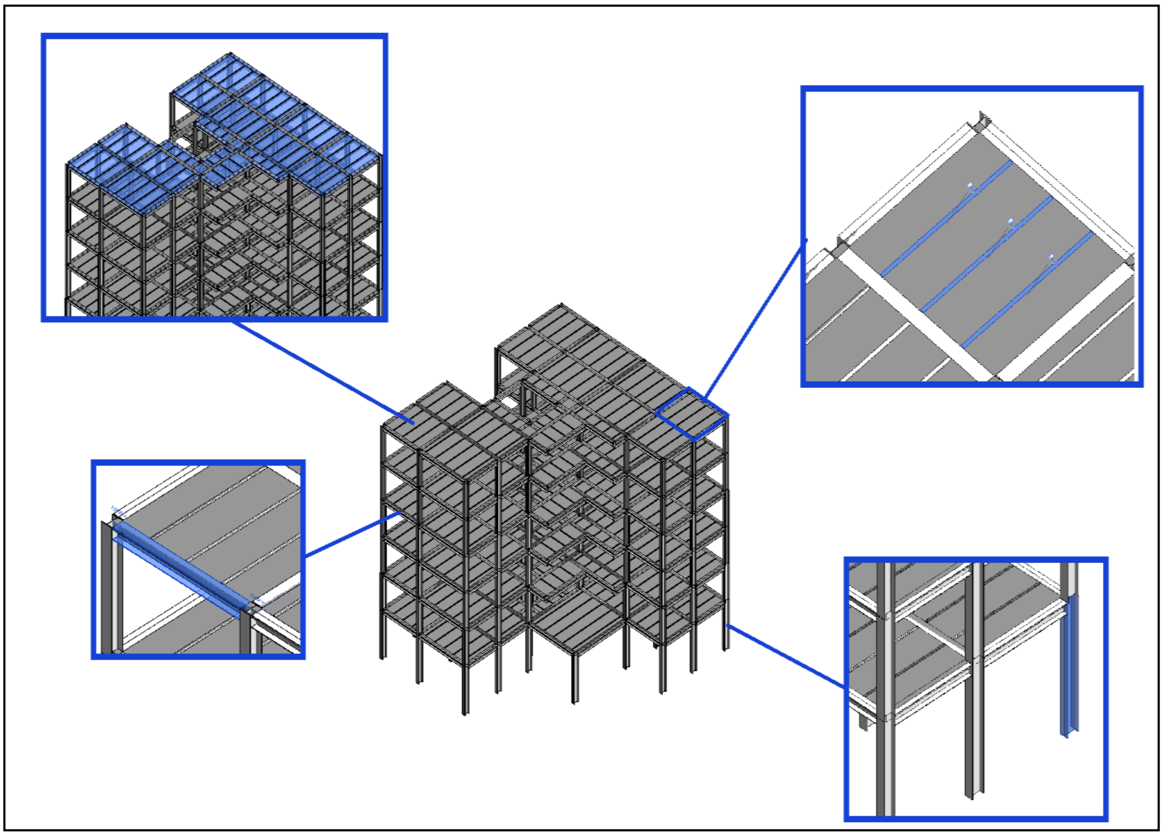


Figure III. 11: The 3D view of the structural elements.

4. Defines load and load cases and bindery conditions to the statically model

Loads, Load Natures, Load Cases, and Load Combinations are transferred between Revit software and Robot Structural Analysis Professional. Load elements created in Revit software and transferred to Robot Structural Analysis Professional are editable. However, Changes made in Robot Structural Analysis Professional are not propagated back to Revit Software. Loads created in Robot Structural Analysis Professional are transferred to and Preserved in the Revit model.

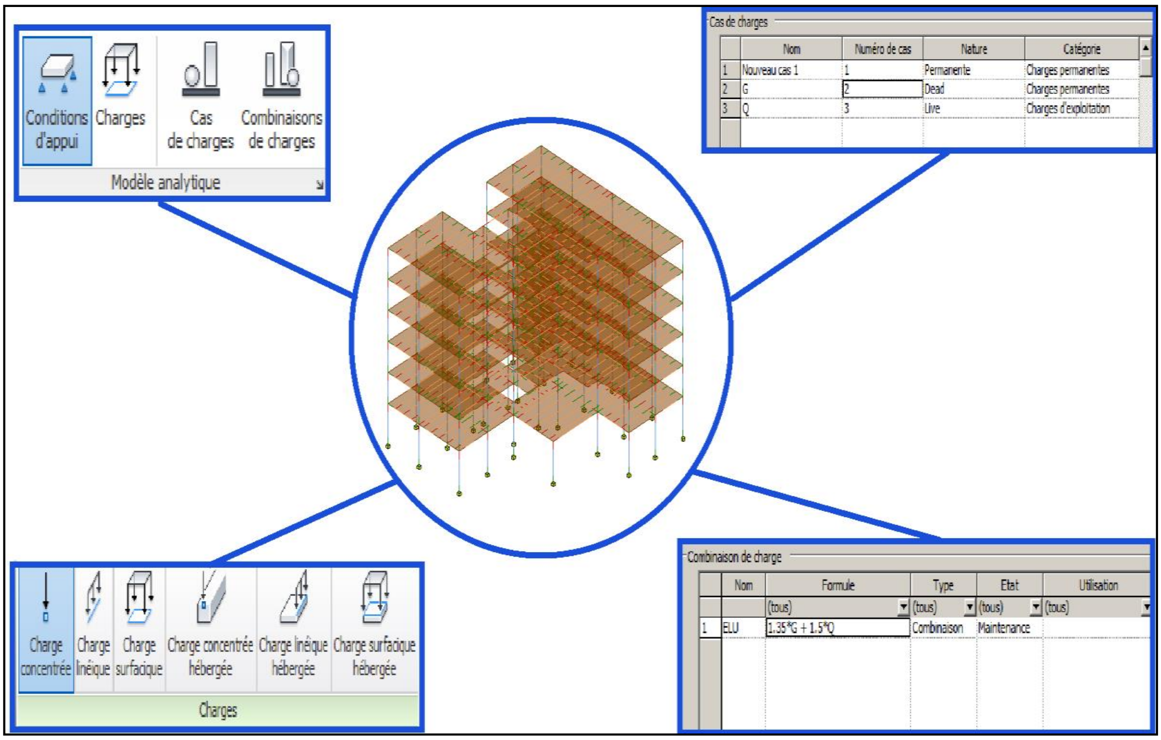


Figure III. 12: The loads and loads cases and bindery conditions definition.

5. Direct link between Revit and Robot

The link between Revit software and Robot Structural Analysis Professional allows engineers to send selected portions of a Revit model to Robot Structural Analysis Professional, and vice versa. This flexibility allows the engineer to work with the structure in separate analysis models.

When Robot Structural Analysis Professional is installed on the same computer as the Revit software, new commands are added to the Revit user interface that provides a link between the two products. This link enables the Revit user to send a Revit model to Robot Structural Analysis Professional for analysis and design, and update the Revit model based on the results of the analyses. All analyses and design is performed in Robot Structural Analysis Professional, except for composite steel framing. The Composite Design Extension is used to analyze and design composite steel framing directly in Revit software.

6. The sending

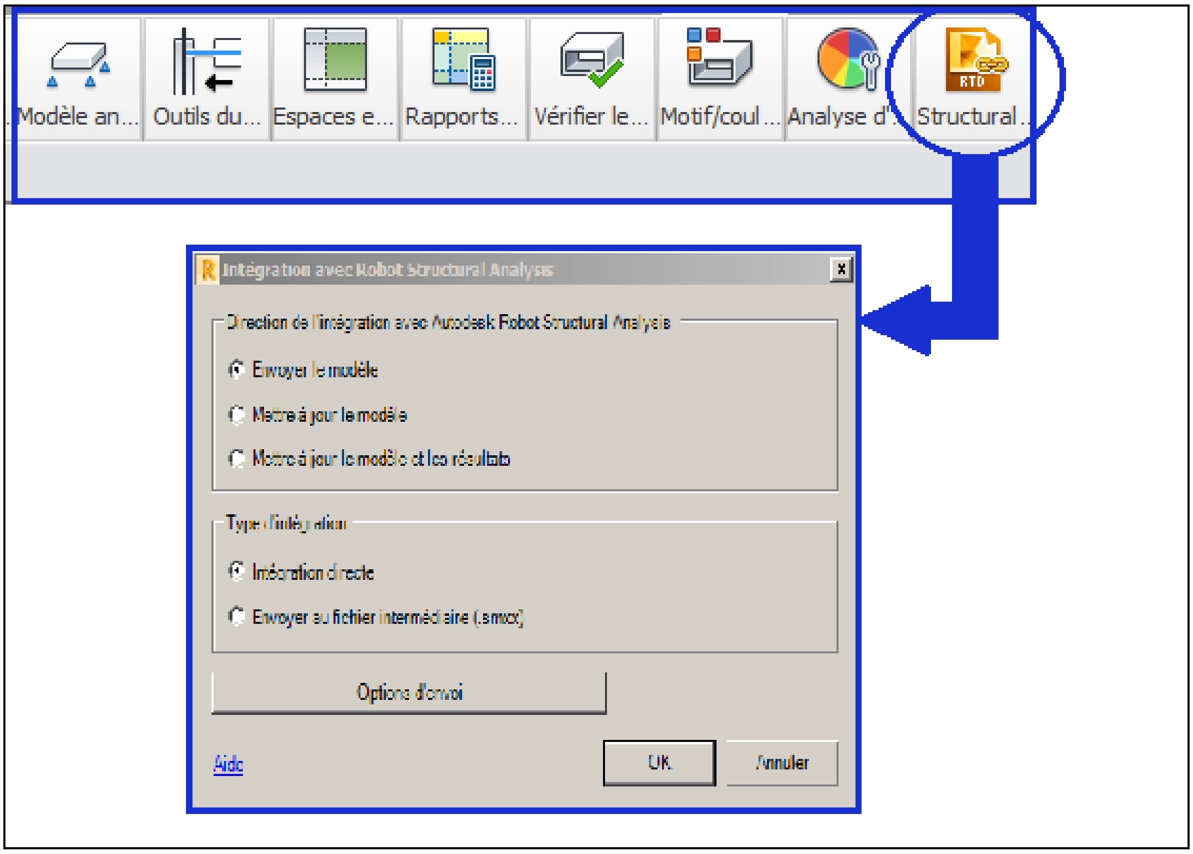


Figure III. 13: The direct link between Revit and Robot.

There are a few basic options to consider when sending a model to Robot Structural Analysis Professional. The designer can send the entire model or select a specific portion of the model to be sent. Sending only a selection of the model is useful when performing analysis and design for certain elements or structural systems, or when making small modifications in layout or design.

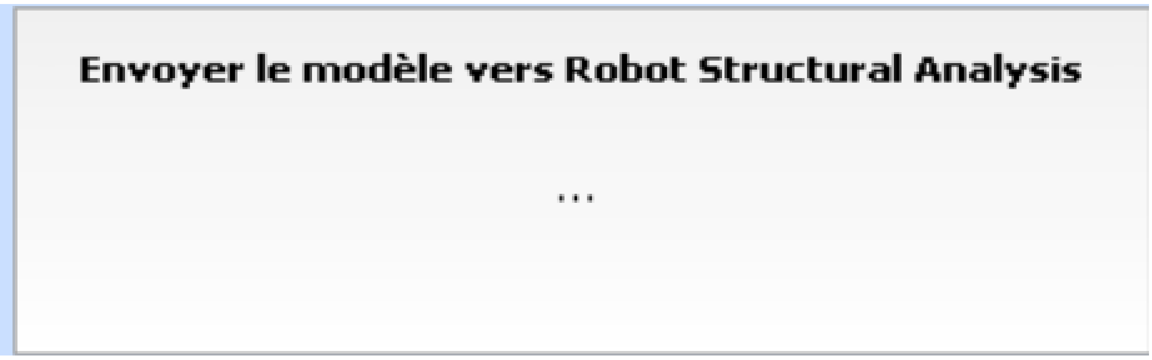


Figure III. 14: Sending of the model to Robot Structural Analysis.

7. Analyses circulation in robot

The next step is to perform the structure analyses based on the current applicable Norms... The structure elements are represented as linear finite elements (beams and columns) or as finite element mesh surface (slabs and walls). The mechanical characteristics associated to each structure elements are those that result from their geometry and physical proprieties of the materials. All structure analyses software allows the application of loads, including the seismic action. Thus, all loads and the mandatory load combinations were applied over consistent structure models.

• The permanent loads relating to the structure own weight (PP) is automatically assumed based on the unit weight of the steel sections.

• The variable load (PS) considers the type of use in each floor.

• The seismic action (E) is quantified according to the medium spectral response of the building and the seismicity coefficient associated to the house location.

We can see that robot only show the structural elements with a active analytical mode (beams, columns, slaps) with the same properties as revit. Load and loads cases and combination are also automatically brought.

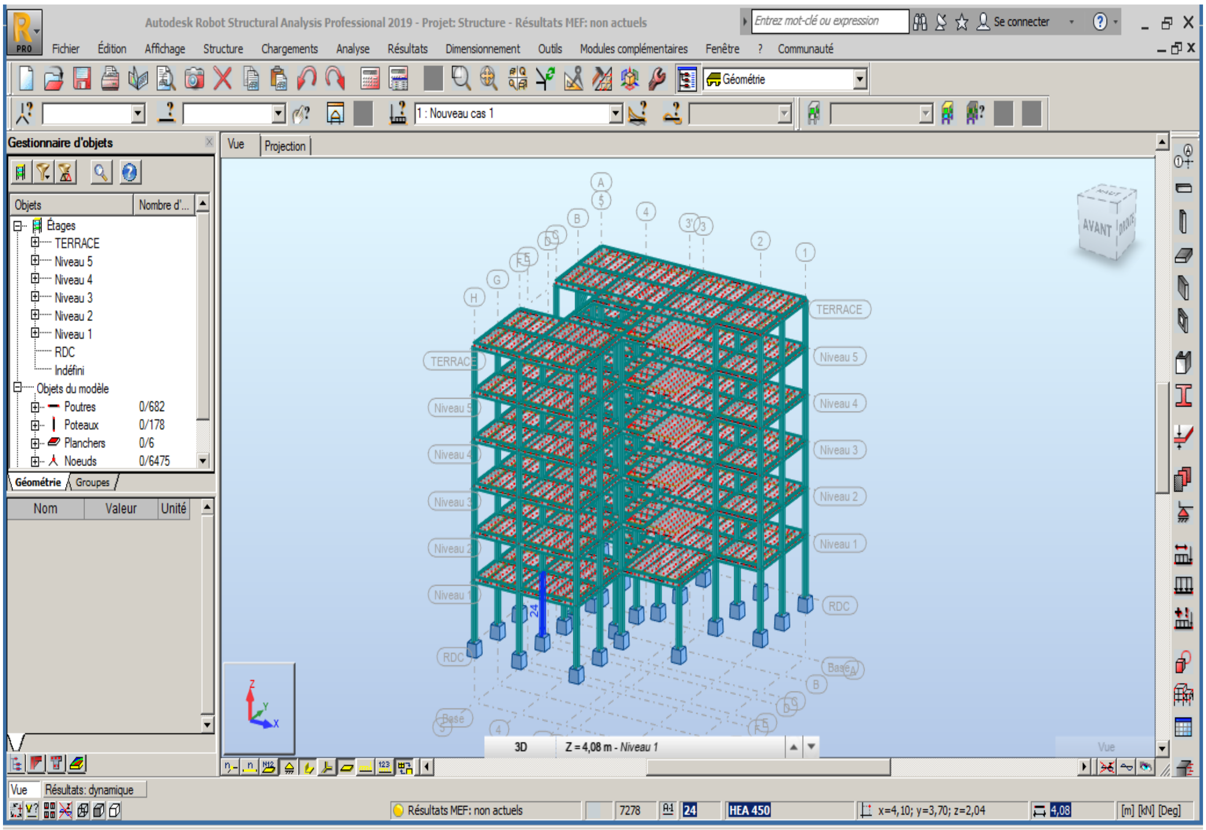


Figure III. 15: The 3D model on Robot Structural Analysis.

- Check materials and conception norms the calculation in this project is performed according to: BAEL99- DTRC2- RPA99 mod2003.

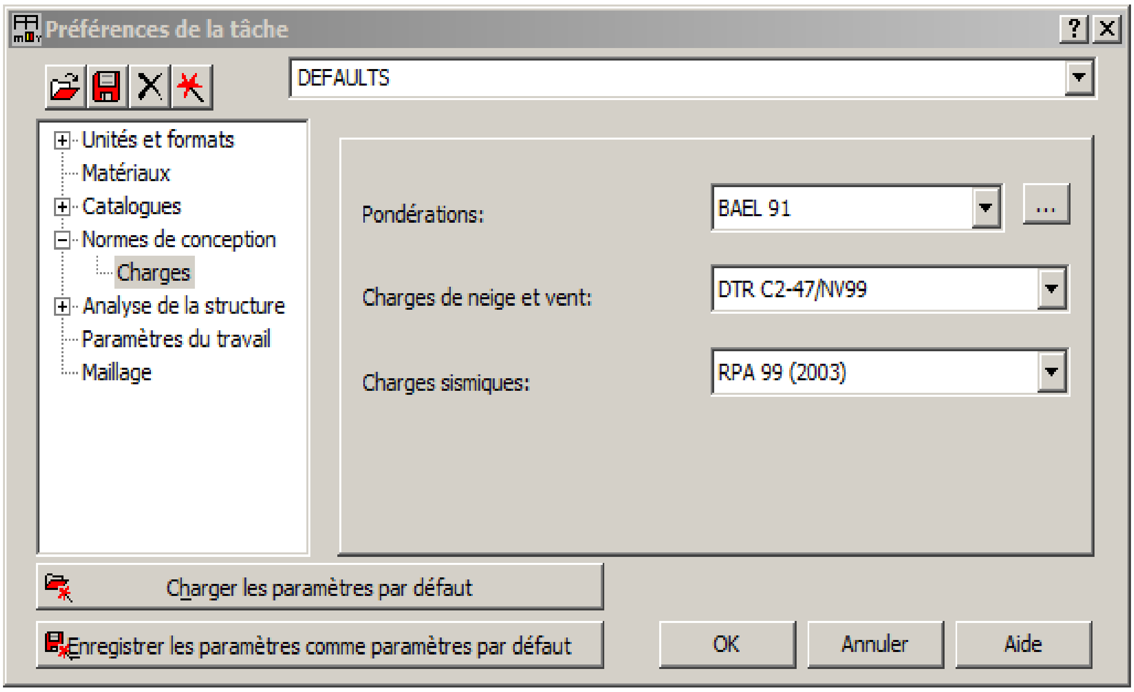


Figure III. 16: The norms used on this project.

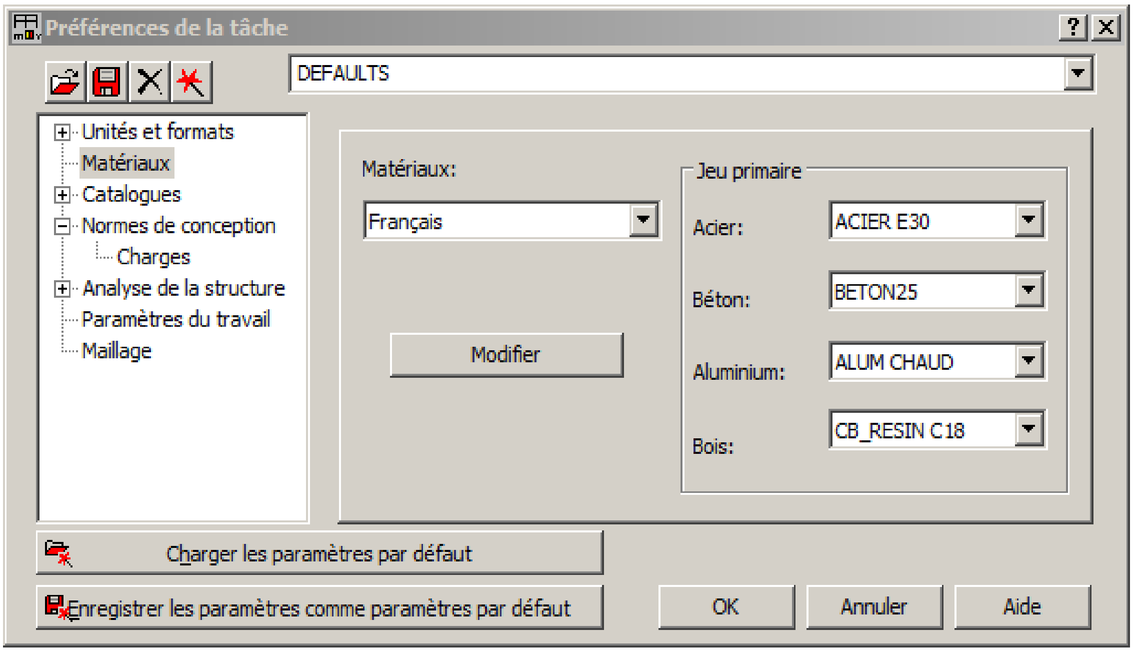


Figure III. 17: The materials used on this project.

❖ **Static analyses**

To verify the stability and mass distribution of the structure a modal analyses is required.

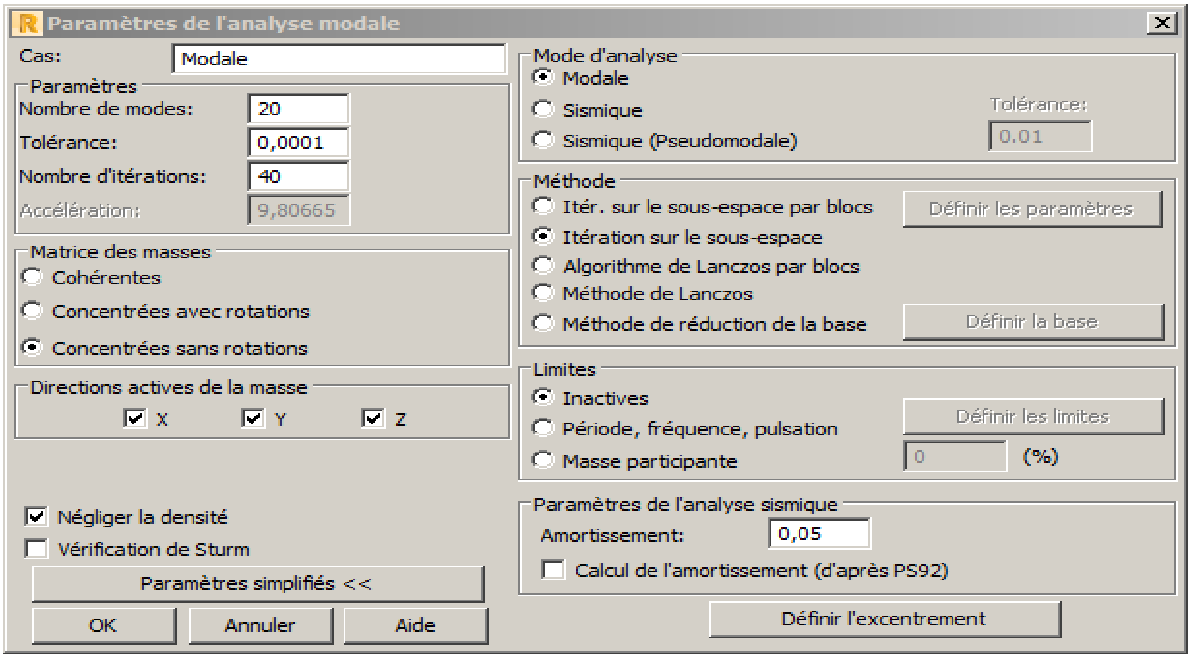


Figure III. 18: Modal analysis.

❖ **Dynamic analyses**

The seismic action is represented by number of combinations to simulate the earthquake phenomenon. A support application is used to get the spectral response (app RPA99).

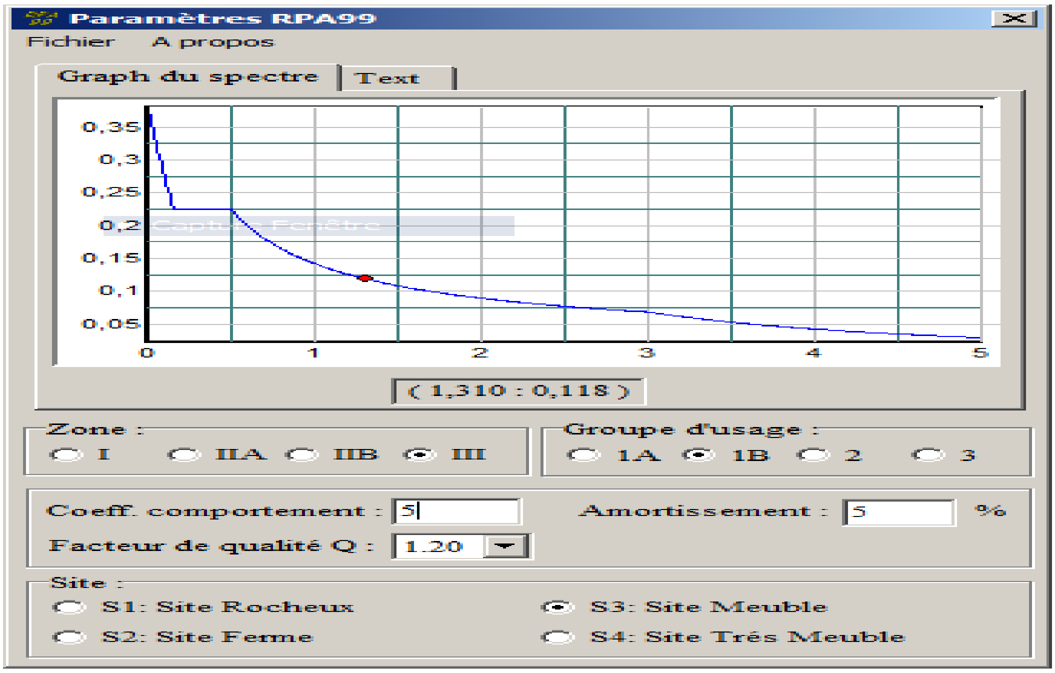


Figure III. 19: The spectral response.

N°	Nom	Type d'analyse
4	Modale	Modale
5	E Dir. - masses_X	Spectrale
6	E Dir. - masses_Y	Spectrale
7	E Dir. - masses_Z	Spectrale
8	W	Combinaison linéaire
10	EX X	Combinaison linéaire
11	EX Y	Combinaison linéaire
12	0.8EX X	Combinaison linéaire
13	0.8 EX Y	Combinaison linéaire

Figure III. 20: Number and type of analyze.

We made some adjustment on the cross section elements (beams and columns) and a bracing system was added to assure the stability of the building.

The efforts and deformations obtained as a result allows determining the necessary quantity in each structure component. Finally, using the functionalities available in the systems the modification we can see the period has been decreased to 0.77 second and mass distribution become more harmonic.

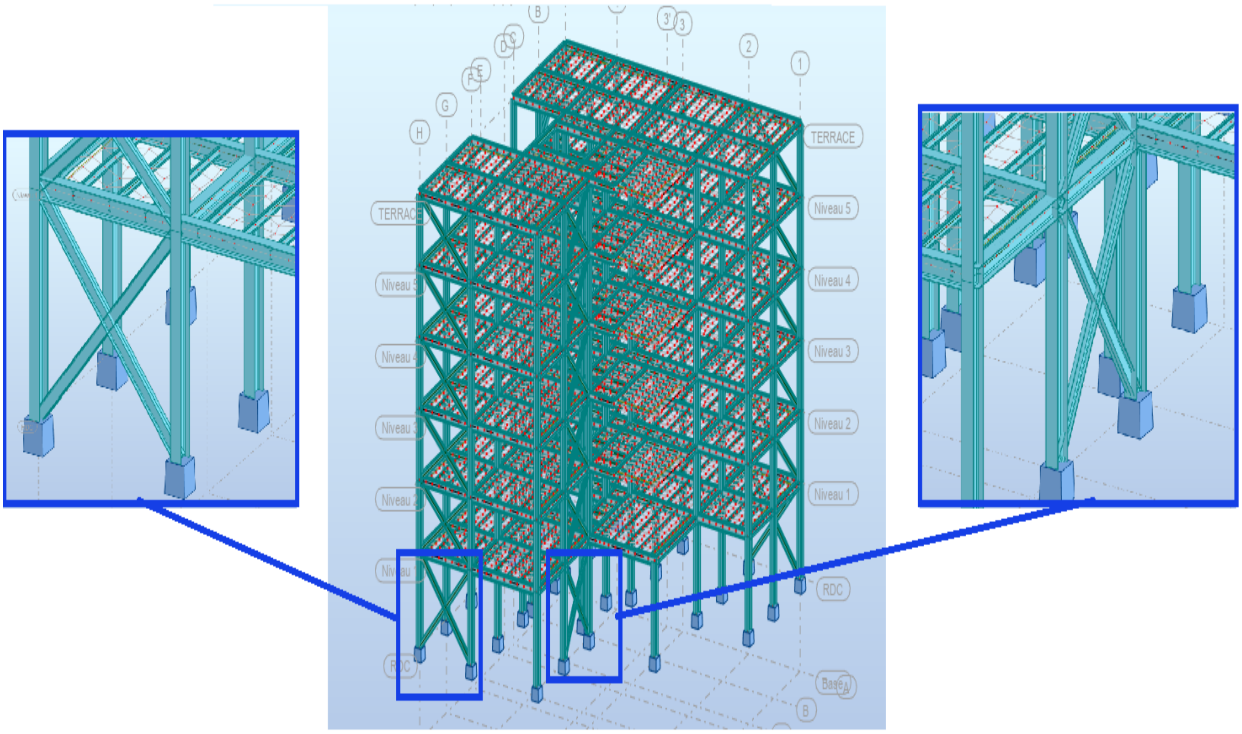


Figure III. 21: The 3D view of the bracing system.

8. The data from robot structural analyses

The structure analyses results are presented in the form of diagrams and 3D modelsof deformations and stresses, as well as notes and reports. The analyses results allow establishing, the structure element section each system defines automatically the respective bar detailing the drawings required as graphical documents of a structure project:

- **<u>3d Diagrams</u>**

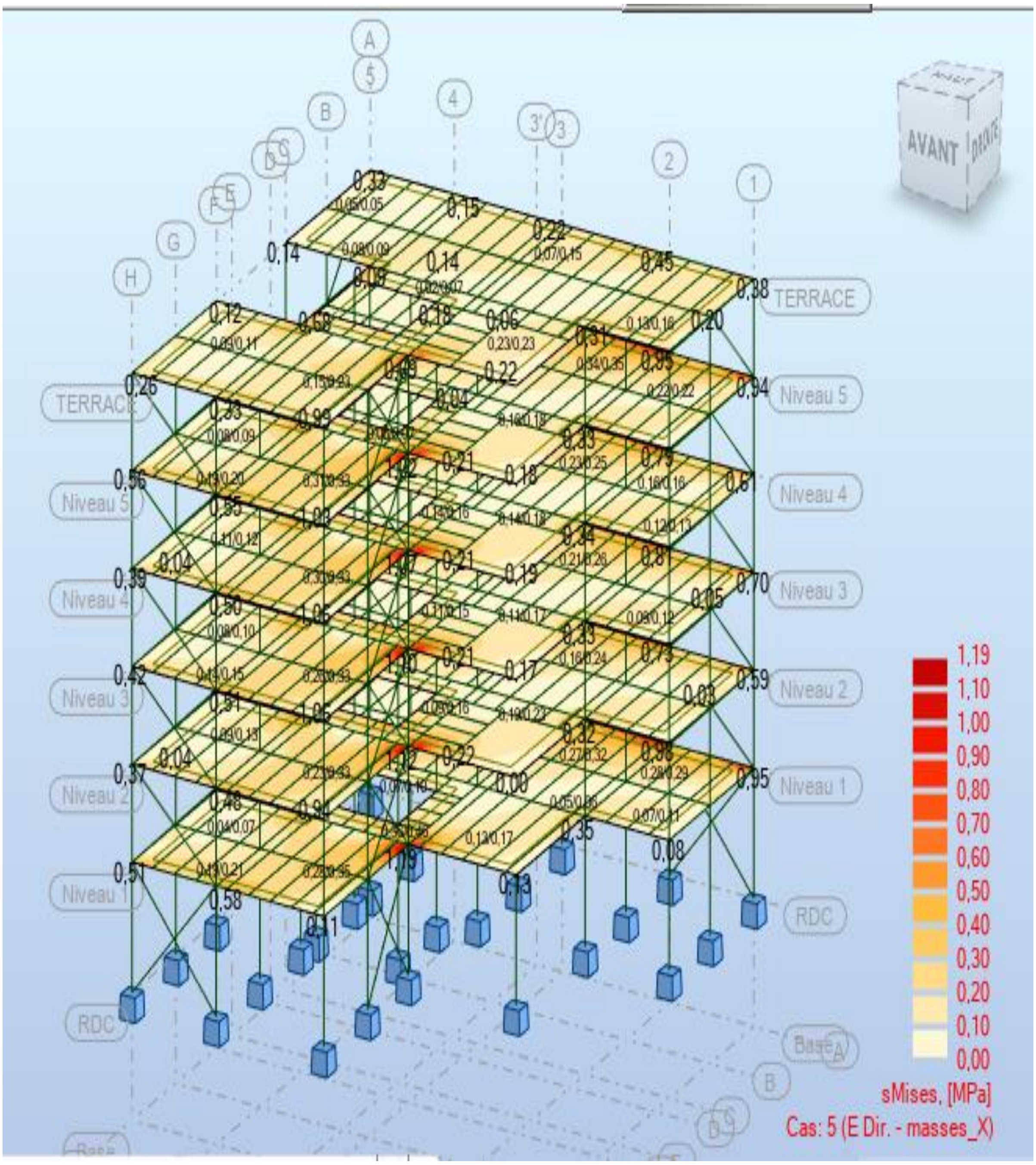


Figure III. 22: 3D diagrams of the structure with highlighted stress and load areas.

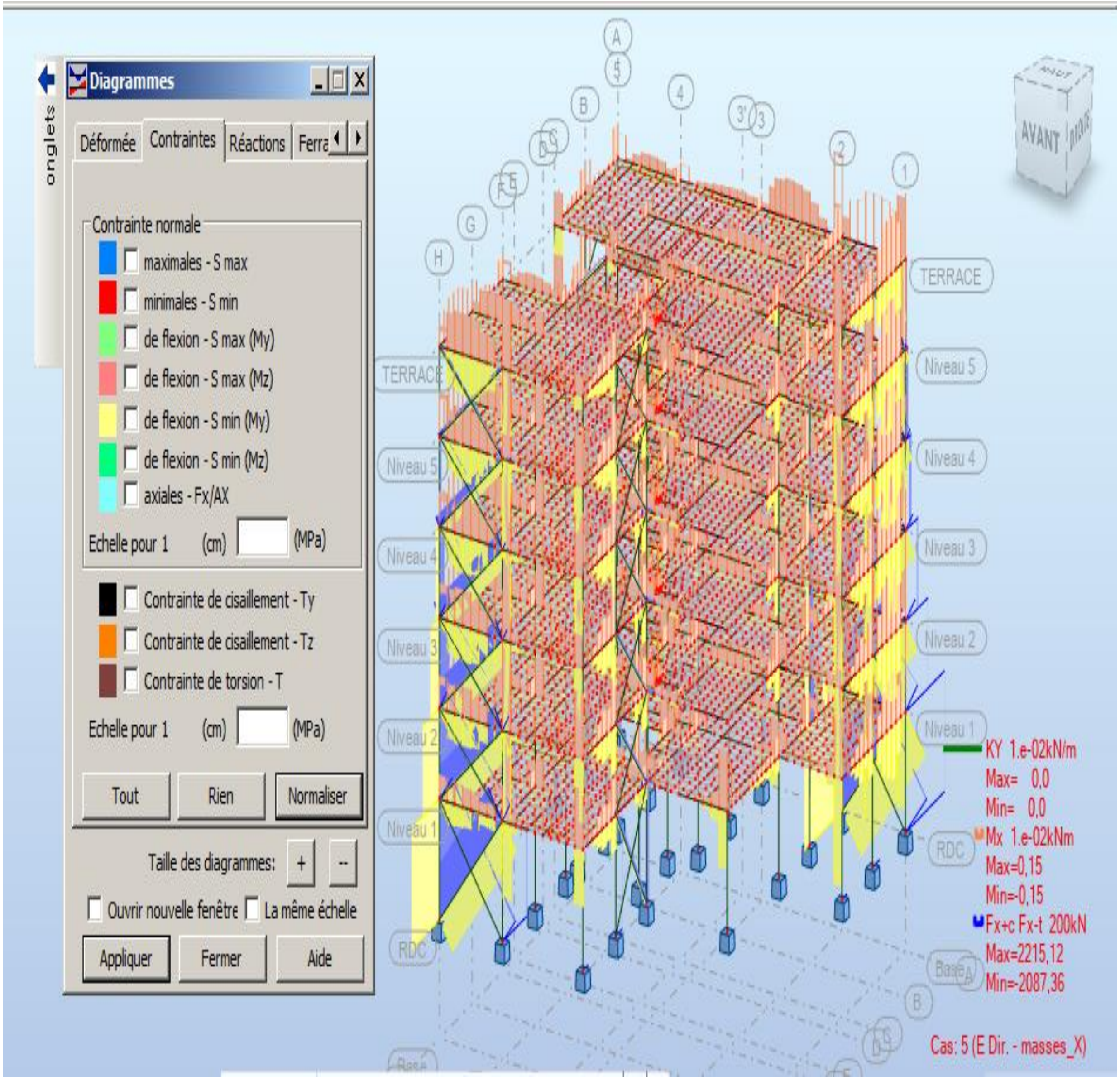


Figure III. 23: 3D diagrams of the structure with diagrams of moment ,traction …ect.

- **Period and mass distribution between axes**

Table III.1: Period and mass distribution.

Cas/Mode	Fréquence [Hz]	Période [sec]	Masses Cumulées UX [%]	Masses Cumulées UY [%]	Masses Cumulées UZ [%]	Masse Modale UX [%]	Masse Modale UY [%]	Masse Modale UZ [%]	Tot.mas.UX [kg]	Tot.mas.UY [kg]	Tot.mas.UZ [kg]
4/ 1	1,30	0,77	77,67	0,50	0,00	77,67	0,50	0,00	2014687,47	2014687,47	2014687,47
4/ 2	1,59	0,63	78,99	66,31	0,00	1,33	65,81	0,00	2014687,47	2014687,47	2014687,47
4/ 3	2,04	0,49	79,59	80,57	0,02	0,59	14,26	0,02	2014687,47	2014687,47	2014687,47
4/ 4	4,29	0,23	95,55	80,57	0,04	15,96	0,00	0,02	2014687,47	2014687,47	2014687,47
4/ 5	5,01	0,20	95,57	91,83	0,27	0,02	11,26	0,24	2014687,47	2014687,47	2014687,47
4/ 6	5,19	0,19	95,61	92,14	6,39	0,04	0,32	6,12	2014687,47	2014687,47	2014687,47
4/ 7	5,55	0,18	95,61	92,16	7,25	0,00	0,01	0,85	2014687,47	2014687,47	2014687,47
4/ 8	5,63	0,18	95,61	92,16	7,40	0,00	0,01	0,16	2014687,47	2014687,47	2014687,47
4/ 9	5,67	0,18	95,61	92,17	7,54	0,00	0,01	0,13	2014687,47	2014687,47	2014687,47
4/ 10	5,70	0,18	95,62	92,18	7,67	0,01	0,01	0,14	2014687,47	2014687,47	2014687,47

- **Mass distribution in every story**

Table III.2 : Mass distribution.

Cas/Etage	Nom	Masse [kg]	G (x,y,z) [m]	R (x,y,z) [m]	Ix [kgm2]	Iy [kgm2]	Iz [kgm2]
5/ 1	RDC	Aucun	Aucun	Aucun	Aucun	Aucun	Aucun
5/ 2	Niveau 1	343130,26	8,18 11,77 3,96	7,50 12,88 3,83	12479937,59	8775370,15	20921943,93
5/ 3	Niveau 2	338001,96	8,18 11,79 7,07	7,25 13,00 6,99	12159705,81	8469458,57	20486704,82
5/ 4	Niveau 3	336576,56	8,19 11,79 10,1	7,24 12,60 10,0	12093543,01	8407743,19	20371598,44
5/ 5	Niveau 4	336576,56	8,19 11,79 13,2	7,24 12,60 13,1	12093543,01	8407743,19	20371598,44
5/ 6	Niveau 5	335362,91	8,19 11,79 16,2	7,22 12,27 16,2	12037187,55	8355151,21	20273566,33
5/ 7	TERRACE	335362,91	8,19 11,79 19,3	7,22 12,27 19,2	12037187,55	8355151,21	20273566,33

- **Story displacement**

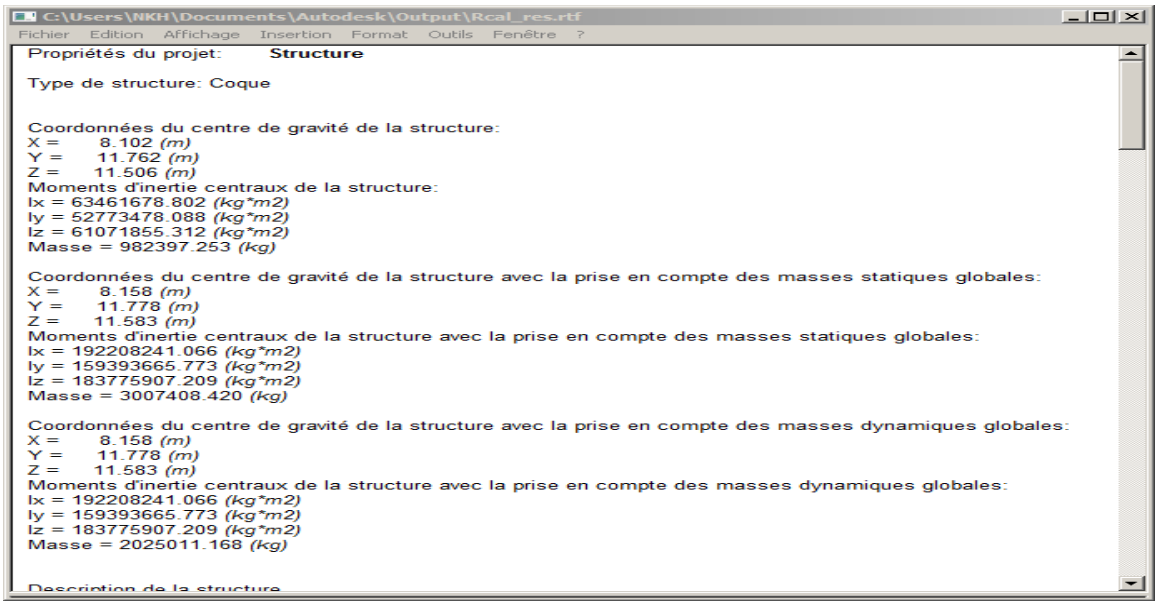
Table III. 3 : Story displacement.

Etages

Cas/Etage	UX [cm]	UY [cm]	dr UX [cm]	dr UY [cm]	d UX	d UY	Max UX [cm]	Max UY [cm]	Min UX [cm]	Min UY [cm]
5/ 1	0,0	0,0	0,0	0,0	0,0	0,0	Aucun	Aucun	Aucun	Aucun
5/ 2	0,6	0,1	0,6	0,1	0,00	0,00	0,6	0,2	0,4	0,0
5/ 3	1,1	0,1	0,5	0,1	0,00	0,00	1,2	0,3	0,8	0,1
5/ 4	1,7	0,2	0,6	0,1	0,00	0,00	1,9	0,5	1,3	0,1
5/ 5	2,3	0,3	0,6	0,1	0,00	0,00	2,7	0,7	1,8	0,2
5/ 6	2,9	0,4	0,6	0,1	0,00	0,00	3,3	0,9	2,3	0,2
5/ 7	3,4	0,4	0,5	0,1	0,00	0,00	3,9	1,0	2,7	0,3

The software provide maximum amount of data related to the structure for example the mass distribution of the leads in all points displacement of the stories, the period of the building...ect

- **Calculation reports**


C:\Users\NKH\Documents\Autodesk\Output\Rcal_res.rtf

Fichier Edition Affichage Insertion Format Outils Fenêtre ?

Propriétés du projet: **Structure**

Type de structure: Coque

Coordonnées du centre de gravité de la structure:
X = 8.102 *(m)*
Y = 11.762 *(m)*
Z = 11.506 *(m)*
Moments d'inertie centraux de la structure:
Ix = 63461678.802 *(kg*m2)*
Iy = 52773478.088 *(kg*m2)*
Iz = 61071855.312 *(kg*m2)*
Masse = 982397.253 *(kg)*

Coordonnées du centre de gravité de la structure avec la prise en compte des masses statiques globales:
X = 8.158 *(m)*
Y = 11.778 *(m)*
Z = 11.583 *(m)*
Moments d'inertie centraux de la structure avec la prise en compte des masses statiques globales:
Ix = 192208241.066 *(kg*m2)*
Iy = 159393665.773 *(kg*m2)*
Iz = 183775907.209 *(kg*m2)*
Masse = 3007408.420 *(kg)*

Coordonnées du centre de gravité de la structure avec la prise en compte des masses dynamiques globales:
X = 8.158 *(m)*
Y = 11.778 *(m)*
Z = 11.583 *(m)*
Moments d'inertie centraux de la structure avec la prise en compte des masses dynamiques globales:
Ix = 192208241.066 *(kg*m2)*
Iy = 159393665.773 *(kg*m2)*
Iz = 183775907.209 *(kg*m2)*
Masse = 2025011.168 *(kg)*

Description de la structure

Figure III. 24: Calculassions report.

9. Updating the model

The options for updating a Revit model from Robot Structural Analysis Professional are similar to the options for sending a model. Note that in addition to updating the entire model, selected elements in either Robot Structural Analysis Professional or Revit software can be updated. The Revit software will highlight all the new or revised elements that were updated from Robot Structural Analysis Professional, enabling the user to more easily review the model.

Within the analytical model, the software can:

• Update section definitions

• Update analytical line locations

• Add or remove structural elements

In addition, the software can transfer reactions and internal forces calculated in Robot Structural Analysis Professional to Revit software for use in documentation.

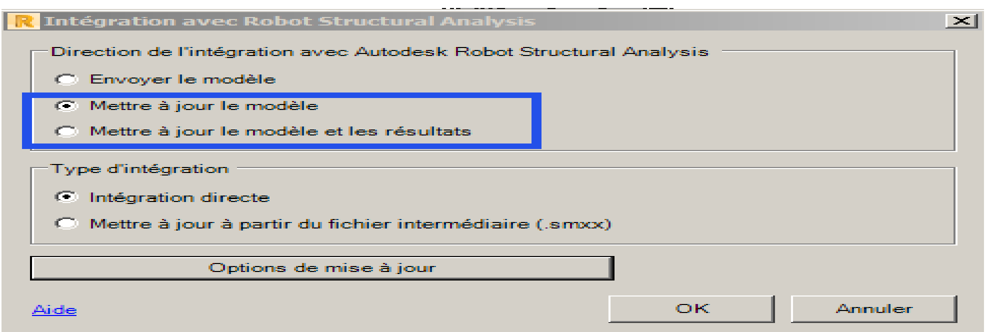


Figure III. 25: Options for updating a Revit model from Robot Structural Analysis.

III.5.2. Advance 3D view of the structure

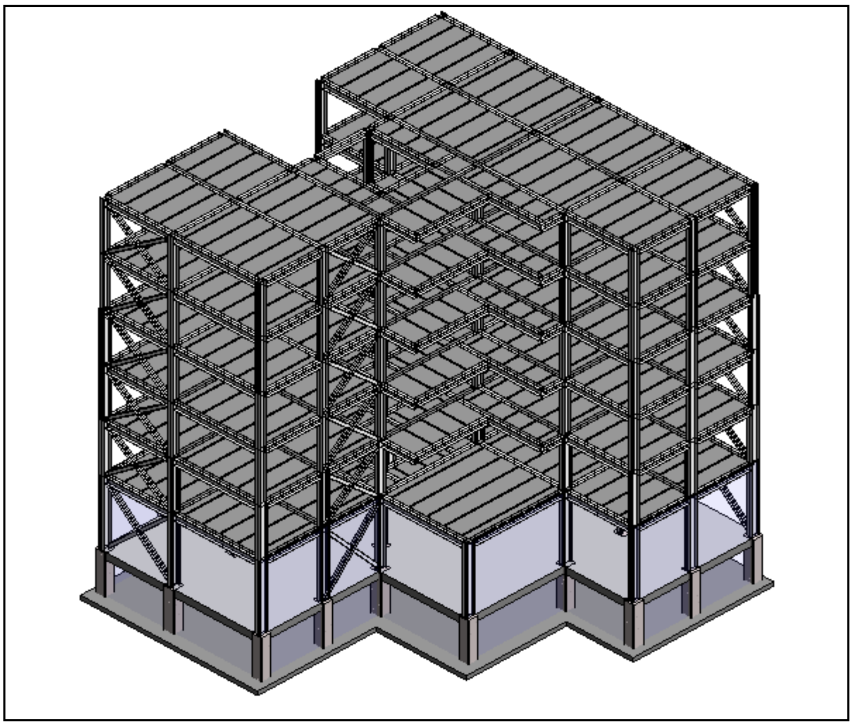


Figure III.26: 3D view of the structure.

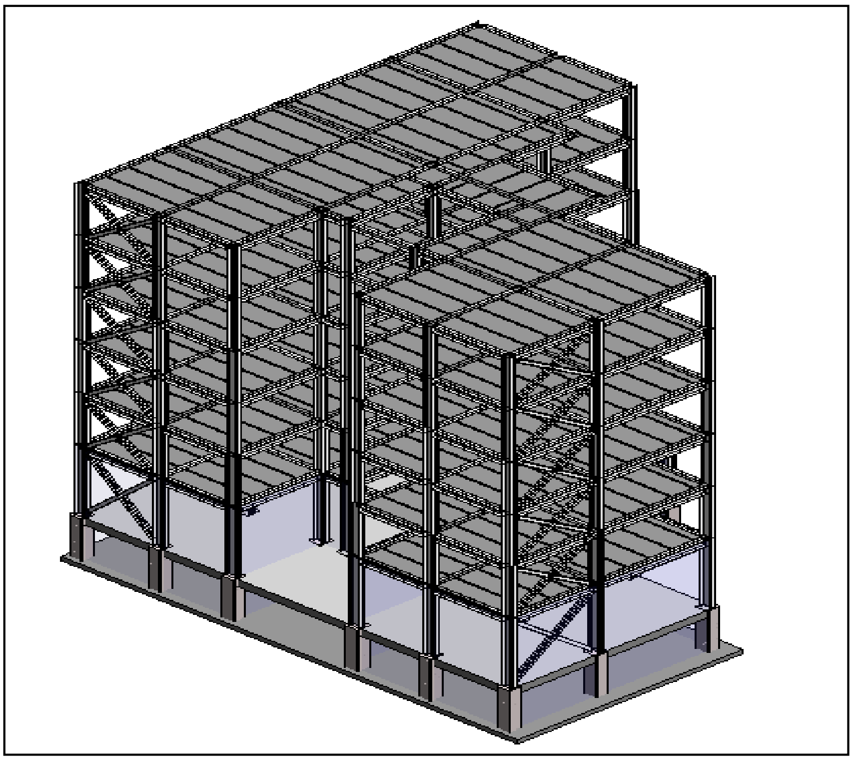


Figure III. 27: 3D view of the structure.

Revit give as a close look of what the building will be, with realistic view of constructed elements and the intervenient between columns, beams slaps bracing system, and with the option of hiding deferent levels of the structure.

III.5.3. Detailed plans of the building

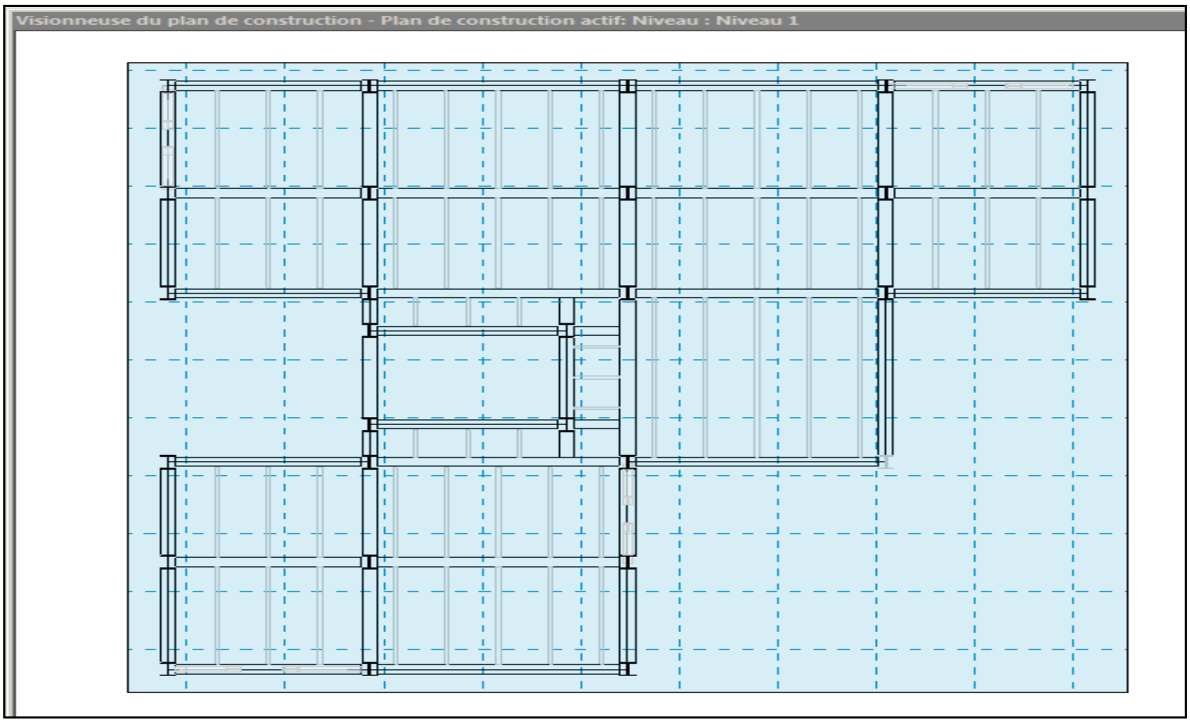


Figure III. 28: Detailed plan of the building (first floor).

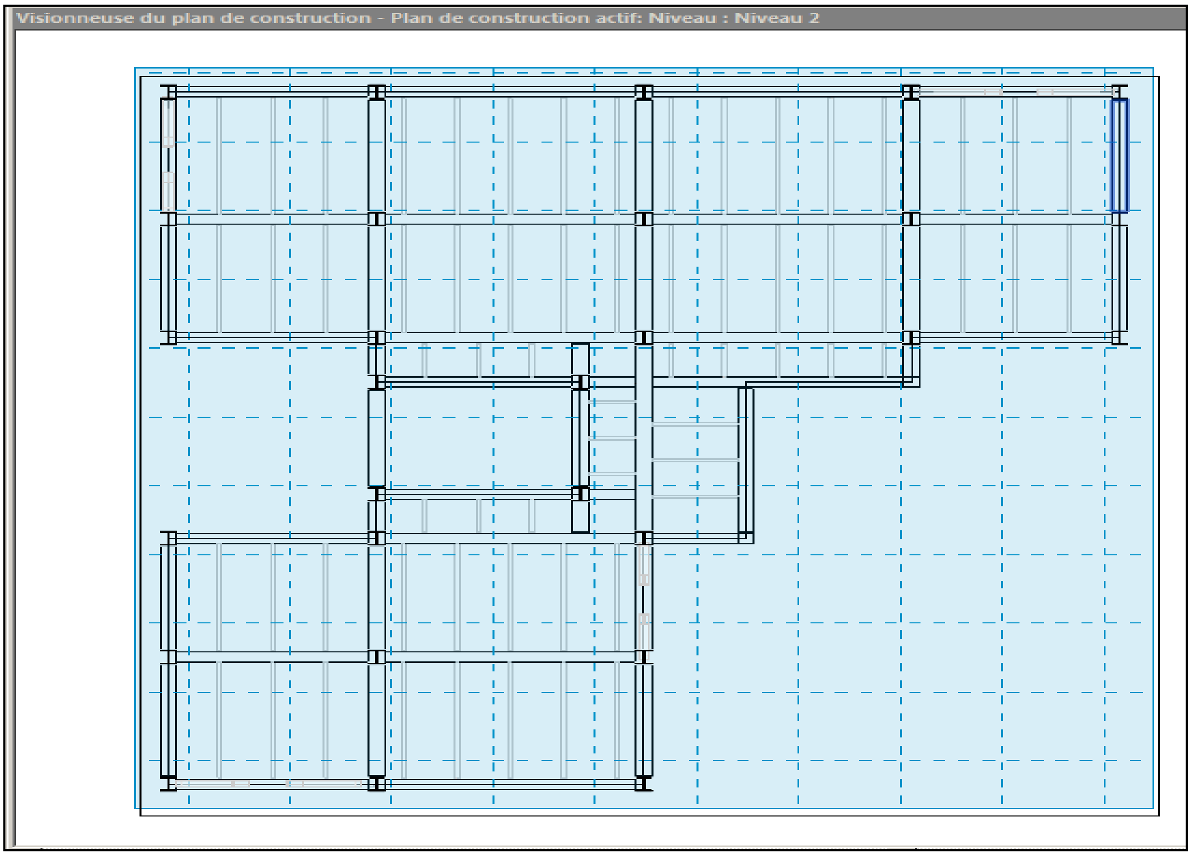


Figure III. 26: Detailed plan of the building (second floor).

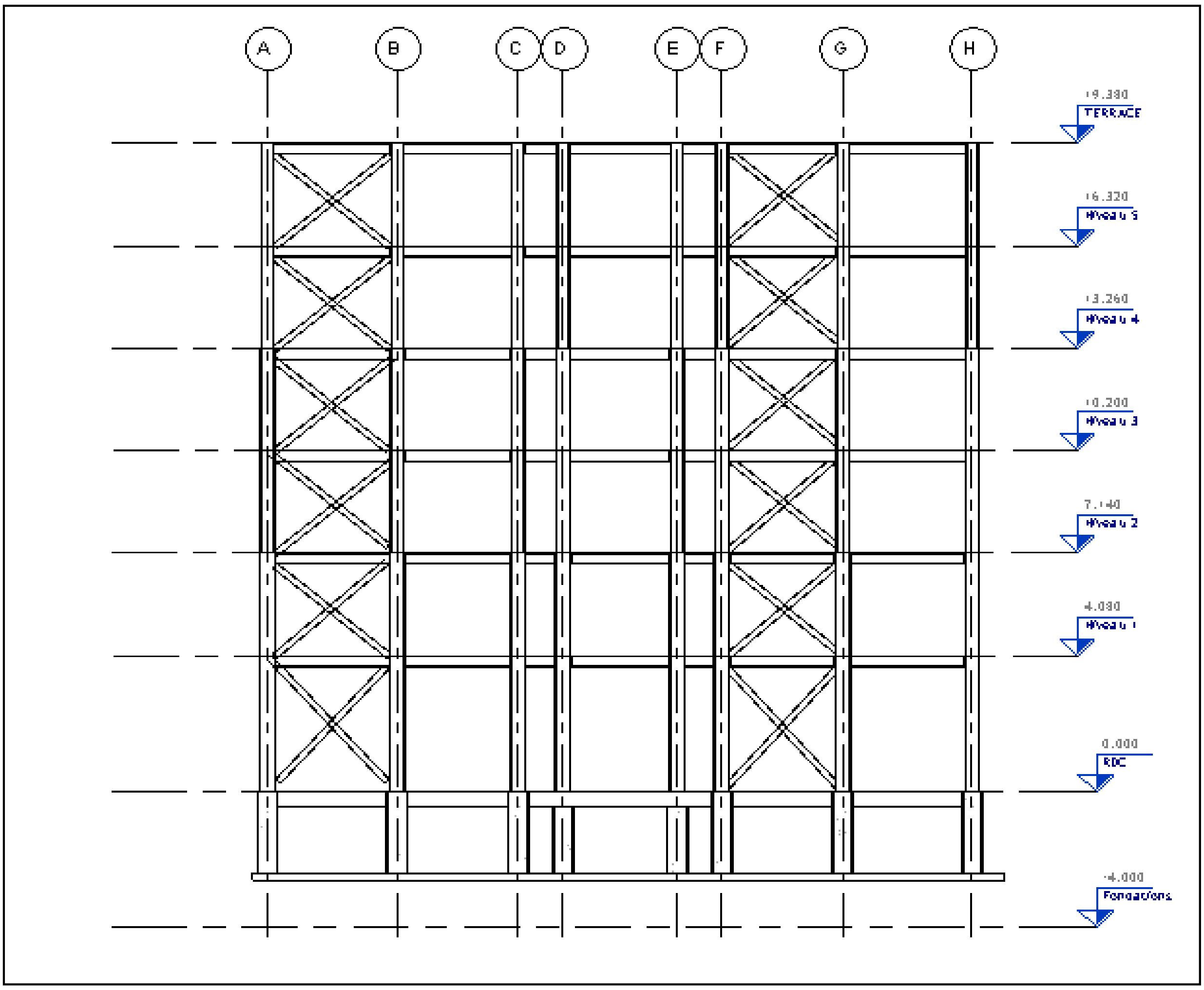


Figure III. 27: Elevation plan.

One of the biggest advantages of the Revit modeling is the possibility of extracting all kinds of plans of the project and with no flops in the design.

III.5.4. Connection detailing with analyses option

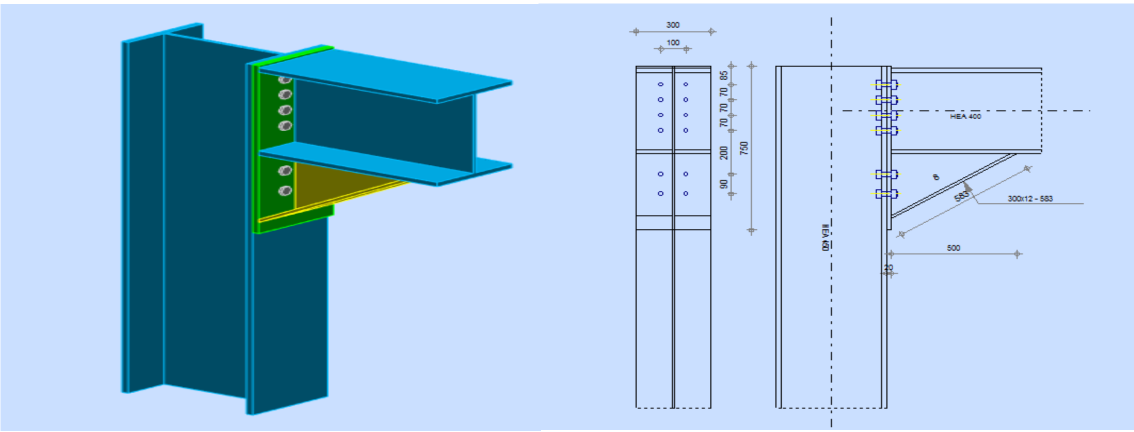


Figure III. 28: Column beam detailing.

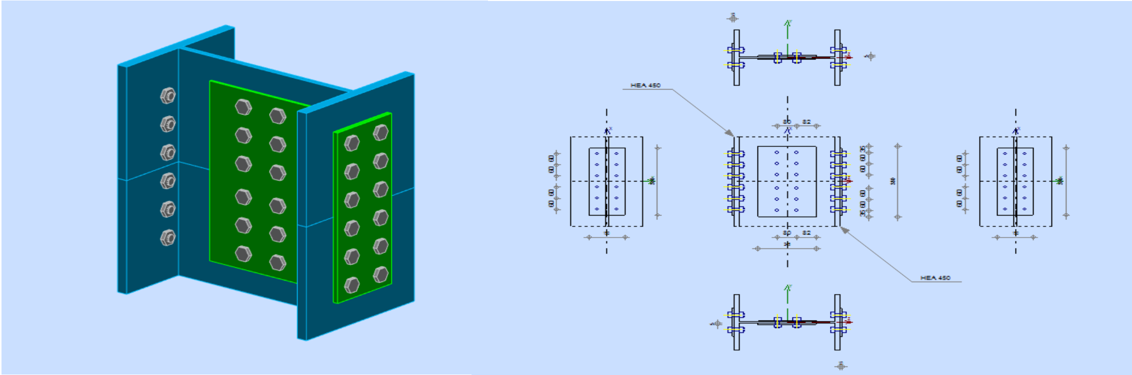


Figure III. 29: Column-column detailing.

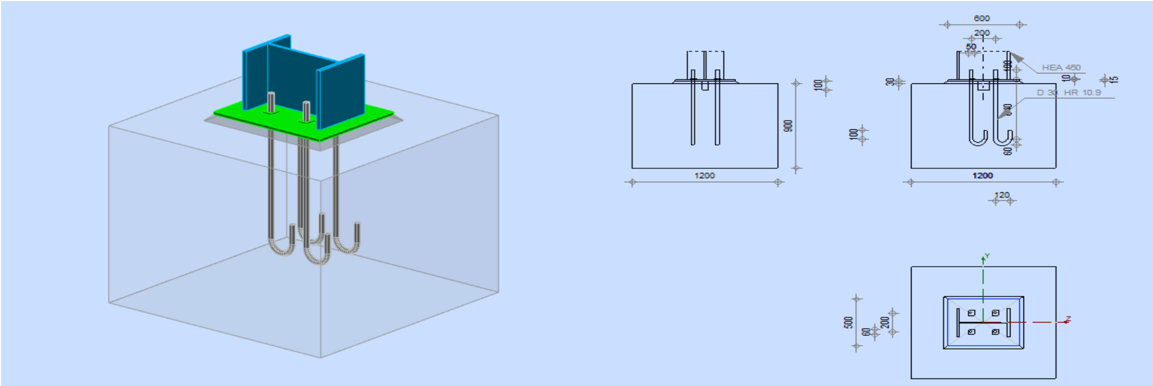


Figure III.33: Column-foundation detailing.

The robot structural analysis provide the option of analyzing the connection separately from the structure, with deleted information

III.6. Conclusion

The structural modeling using BIM is very deferent from traditional process we used to work with, the use of software's make the phases extremely organized and smooth to the engineers and architects through all phases. In the purpose of experiencing BIM, we studied a building with ground floor and five storey with metal framing used as an offices apartment located in the state of BLIDA. We started by modeling the structure in Revit this software capabilities enable structural designers to enrich the physical model with information such as physical properties, proposed analytical model definition, and expected loads conditions. This makes the physical model more complete and enhances collaboration with structural engineers. Then we linked it with robot. This link between Revit and Robot Structural Analysis allows engineers to send selected portions of a Revit model to Robot Structural Analysis. This flexibility allowed us to work with the structure in separate analysis models. BIM also provide more options in the time management and the financial part of a building.

GENERAL CONCLUSION

The previous study allowed us to redefines the construction process using building information modeling (BIM) technology and the benefit of it in the main project phases. We realized that BIM is more than a bunch of software's, but is a way of thinking and treating the entire life cycle of a building. From planning to demolition through a digital model that continues, all related data and make it evaluable to the participators in every phase. We conclude that the advantage of BIM for civil engineering is massive and immeasurable in all fields no matter the type or complexity of the structure.

We can say that the future of construction is building information modeling (BIM). In addition, that the future is bright only if the next generation of engineers is versed in this skill and overcome the different obstacles' that prevent Algerian construction society from using building information modeling in the field and taking the building to another level of complexity and sophistication.

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