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4D comparitive analysis of construction approaches twords industrialization: traditional vers total prefabrication

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BIM A+

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Universidade do Minho
Escola de Engenharia

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BIM A+ European Master in Building Information Modelling

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European Master in Building Information Modelling

Work conducted under supervision of:
Isabel Valente
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Thanks to my beloved parents, their existence, and their daily support. I am fortunate to have my sisters and brother in my life, especially for the way you inspire me to keep working.

STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

RESUMO

O objetivo desta investigação é encorajar uma maior produtividade na indústria AEC, representando e promovendo uma análise comparativa de abordagens de construção muito diferentes: construção tradicional versus pré-fabricação total rumo à industrialização.

A construção de um edifício cujo projeto foi realizado em BIM, totalmente orientado para a industrialização, apresenta-se como uma oportunidade para realizar uma análise 4D abrangente que compara soluções tradicionais e industrializadas (abordagens de construção no local e fora do local).

A investigação concentra-se na análise deste caco de estudo prático, baseado em BIM e está centrada na avaliação dos impactos no planeamento das várias fases de construção, e na exposição dos impactos detalhados da solução industrializada quando comparada com uma solução tradicional. A construção do edifício em estudo começou em 2022. A sustentabilidade e a circularidade estão implícitas.

O estudo de caso sugerido é um hotel em Guimarães que ultimamente tem recebido a atenção dos meios de comunicação devido à sua inovadora metodologia de pré-fabricação. Os módulos pré-fabricados são utilizados para a construção do edifício. Esta abordagem será avaliada e comparada com as alternativas tradicionais existentes. Considerando isto, foi desenvolvido um quadro teórico propondo um quadro baseado numa análise comparativa BIM 4D para ambas as abordagens de construção: construção tradicional e pré-fabricação total. Quantificando as vantagens da utilização da pré-fabricação em relação à construção convencional, utilizando a grande extensão da tecnologia de modelação de informação de construção (BIM), e os benefícios potenciais da utilização de um motor de programação inteligente para a análise comparativa 4D.

Palavras chave: (Análise 4D; BIM; programação inteligente; estudo de caso prático; pré-fabricação; Construção fora do local)

ABSTRACT

The purpose of this research is to encourage higher productivity in the AEC industry by promoting a comparative analysis between very different construction approaches: traditional construction versus total prefabrication towards industrialization.

The construction of a building whose project was carried out in BIM, totally oriented towards industrialization, presents itself as an opportunity for a comprehensive 4D analysis that compares traditional and industrialized solutions (onsite and offsite construction approaches) in terms of time and needed resources.

The research concentrates on proposing a BIM-based framework to quantify the 4D analysis of this practical case study. It is focused on assessing the impacts on the planning of the execution stage, both off-site and on-site, and on exposing the detailed impacts of the industrialized solution when compared to a traditional one. The effective construction of the building in the study began in 2022. Sustainability and circularity are implied.

The suggested case study is a hotel in Guimarães that has lately received media attention due to its innovative pre-fabrication methodology. Prefabricated modules are used to construct the building. This approach will be evaluated and compared to existing traditional alternatives. Considering this, a theoretical framework was developed by proposing a framework based on a 4D BIM comparative analysis for both approaches of construction: traditional construction and total prefabrication. Quantifying the advantages of using prefabrication over conventional construction, By using the large extent of building information modelling (BIM) technology, and the potential benefits of using an intelligent schedule engine for the 4D comparative analysis.

Keywords: (4D Analysis; BIM; intelligent scheduling; practical Case study; prefabrication; Offsite construction)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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1. INTRODUCTION

The growth of prefabrication in the construction industry is a significant and recent trend in construction. Modular buildings are produced and manufactured offsite, in factories, as an alternative to traditional buildings. The site is prepared for assembly process after the modular buildings have been transported.

"A lot of developers like the idea, but because they haven't done it before, there are a lot of unknowns and a hesitancy to jumpstart a new project, but as people are getting more comfortable and the industry is maturing, more and more developers are getting comfortable with the idea," said Josh Kimmel (vice president at Chicago-based Project Management Advisors Inc.). According to Kimmel, there is a lack of awareness among people or stakeholders about prefabrication and the advantages of using the offsite construction rather than total onsite, despite the fact that many developers like the prefabrication idea of saving time and money and producing less waste. This study focuses on the time effect of using total prefabrication in construction, instead of using traditional systems built onsite and tries to quantify the benefits of using offsite construction, especially considering time and resources.

Building information modelling (BIM) is the technology that has been developed for dealing with engineering processes, material quantities and quality, costs, and time (Kim et al., 2010). A 4D BIM connects the 3D model to the schedule, simulating the construction process. It helps a wide variety of users to execute the construction in the right direction by anticipating the time and the resources that will be needed. 4D BIM analysis will be useful for modular construction by helping the user to visualize the construction information and resources as a process with a micro time frame. Therefore, the work focuses on how much time is saved in comparison to the traditional construction, and a framework is developed to enable the 4D analysis on a case study that is being built in Guimarães, using the total prefabrication CREE system.

The construction scheduling is usually carried out manually. Integrating wide BIM applications and 4D visualisation can be done automatically. By connecting the logical relationships of the construction tasks to the BIM objects in visual representation results in an automatically generated schedule with minimal human interaction. A software can offer this integration using an intelligent schedule engine.

Furthermore, a framework is generated to quantify the time saved in the case of using total prefabrication instead of the traditional method, by creating a 4D model using the intelligent schedule engine. It will be precisely shown in the case study how this new method of construction saves time.

This research is organized as follows: first, the definition of offsite construction is briefly explained, followed by the identification of key benefits and challenges of the offsite construction. Then, types of offsite construction, the difference between offsite and onsite construction processes, and their effect on time are described. 4D BIM, as the technology that integrates that type of construction into the whole process, allows us to quantify the benefits of using offsite construction. Furthermore, a comparative analysis is conducted, with the proposed framework, on a case study of a hotel in Guimarães that is being built using total prefabrication. and This study concludes with a 4D quantitative analysis of both construction methods.

1.1. Scope and motivation

The present work has been carried out by combining theory and practice in a real case study of a building project constructed in total prefabrication way. A deep understanding in several areas is required: the offsite construction, the offsite construction process, the benefits of using offsite construction, the use of BIM to carry out building projects, using the 4D modelling to reach the research aim and quantify the benefits of using the total prefabrication instead of the basic traditional construction throughout the suggested case study.

1.2. Research Objectives

The specific objectives of this research are:

- To have knowledge on offsite construction and on the different types of offsite construction systems;
- To identify the potential benefits and challenges of using off-site construction;
- To clarify the technology of BIM and the effect of using 4D simulation on offsite construction;
- To establish a framework to enable a 4D comparative analysis between a traditional way of construction and the CREE total prefabrication system;
- To develop a 4D BIM-based analysis on the suggested case study;
- To quantify the benefits of using total prefabrication compared to the traditional way of construction in terms of time and use of resources.

1.3. Structure of the research

This research is divided into five main chapters:

- **Chapter 1** provides the background of the project and introduces the scope of the research, states the problem, defines the research goal, objectives and the general purpose of the study.

- **Chapter 2** focuses on the review of literature related to the main topics discussed in this research: offsite construction, building information modelling and 4D BIM schedule.

- **Chapter 3** develops a theoretical framework by proposing a concept 4D BIM comparative analysis for both approaches of construction; traditional and total prefabrication.

- **Chapter 4** develops a 4D BIM comparative analysis applied on the suggested case study, exposes the findings, and discusses the results obtained from the case study, including the traditional 4D model, and the total prefabricated 4D model.

- **Chapter 5** summarizes the important findings and conclusions of the study that contribute to the body of knowledge and suggests future developments. The limitations of the study are discussed. Finally, suggests further works to enhance this research and the best practices for the prefabrication construction industry sector projects.

2. LITERATURE REVIEW

This literature review discusses several aspects of off-site construction. This chapter provides a detailed explanation of each of the four types of off-site construction. Offsite construction has several advantages that will be mentioned, along with the primary challenges it faces. Traditional and off-site construction vary in their methods and procedures, and this has an impact on how long a project takes to finish. The other objective of the literature review is to gain more knowledge about the 4D BIM in construction and to understand the procedures and level of information required to assess the advantages of using prefabrication off-site building.

"Building in controlled environments makes even more sense in a world that requires close management of the movement and interaction of workforces. Such a rationale further strengthens the case for offsite construction, beyond the existing quality and speed benefits. In fact, we expect to see contractors gradually push fabrication offsite and manufacturers expand their range of prefabricated subassemblies." (Biörck *et al.*, 2020)

We are in an era where industrialization and construction industry have a vital role in our lives nowadays. The industry needs to change to modular industry during the life cycle of the project, planning, design, and execution to make the maximum use of the reduced capital cost and project time, and many other benefits that are brought to a project using this type of construction.

With the increased industrial focus on enhanced safety, lower energy consumption, and creating a circular economy with less waste, improved safety, and higher quality, capital projects must rely on a combination of modularization, standardization, lean, and unique efforts.

However, the AEC has a little understanding of what needs to be done to execute modularization successfully. As a result, companies fail to realize the impact of saving cost and time by implementing modularization incorrectly and late on a project. The construction industry institute (CII) indicates that there will be an annual growth rate of 9.6% in the offsite construction market as shown in Figure 1 – An annual growth rate in the offsite construction market (CII - Planning for the Future with Modularization and Offsite Construction)

The usage of off-site construction is estimated to rise significantly as society and the construction industry fight to handle important issues such as the availability of affordable housing, a skilled labor shortage, material use and sustainability, job site safety, and industry productivity. Therefore, off-site construction will play a significant role in the future of the construction sector.

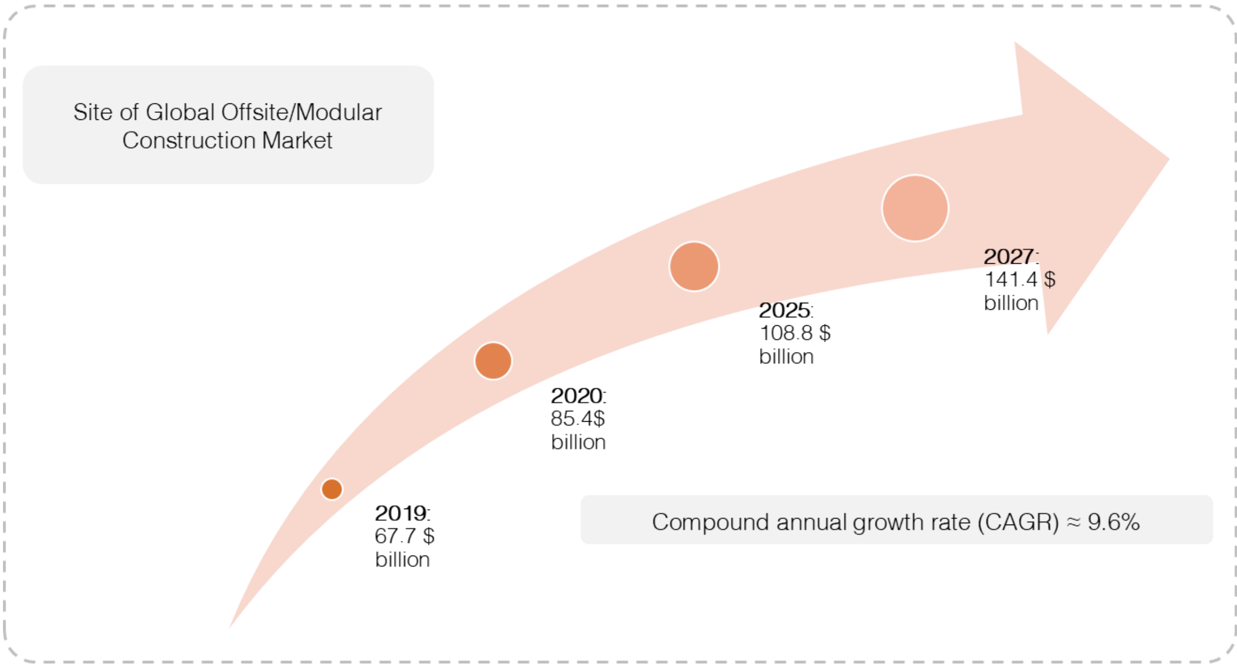


Figure 1 – An annual growth rate in the offsite construction market (CII - Planning for the Future with Modularization and Offsite Construction)

2.1. The definition of offsite construction

Construction is moving in a new direction, requiring manufacturing equipment that makes the process easier to control, more precise, and safer. One option is to modify the materials used for construction to facilitate handling, transfers, and installation of components with reduced weight. (*Advancing the competitiveness and efficiency of the U.S. construction industry*, 2009)

Off-site construction is a method of construction that comprises the planning stage, design, fabrication, transportation, and assembly of prefabricated building components on-site at a rapid rate and with a high level of finish. This level of accuracy is better than on-site construction. (What is Offsite Construction? - The Constructor, n.d.)

Offsite construction uses a variety of materials and systems, as well as innovative manufacturing and fabrication techniques and current assembling techniques.

There are various types of offsite construction. Modular, panelized, and modularized parts are used as structural elements, enclosure and service elements, or interior partition systems in the output of an offsite construction. Off-site construction can be optimized by integrating these systems with the supply chain, as well as conducting thorough extensive research, design, testing, and prototypes.

The following are some reasons why off-site building can be the best option:

1- The project must be completed within a certain amount of time.

2- The site is suffering serious weather, which is causing the project to be delayed.

3- The structure of the building has a number of repeating parts, as does the construction process.

4- Space limitations in the site.

5- Theft and damage are causing problems and putting people in danger.

6- Due to the extreme heat, cold, and heights, there are safety considerations.

2.2. Types of offsite construction

There are different forms of offsite construction: volumetric construction, panelized construction, hybrid construction, and sub-assemblies and component systems.

2.2.1. Volumetric Construction

Volumetric modules are available in a variety of configurations, such as basic structural shells or with interior and external finishes and services. The modules can be made up of a timber or concrete frame, light gauge steel, or composite materials, as shown in Figure 2.

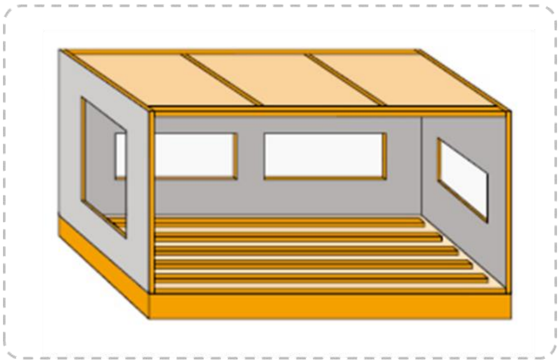


Figure 2 - Volumetric Construction. (Taylor, 2010)

There are two-part types in volumetric construction:

a. Modular Construction

Factory-made pre-engineered building components are delivered to the construction site. After that, the modules are put together as huge volumetric components or significant pieces to form the building, as shown in Figure 3.

Figure 3 - Modular construction. (Modular Construction, Advantages and Challenges | Real Projectives)

b. Pod Construction

Non-structural elements combined with a load-bearing structure are called pods. They are mostly used in the construction of hotels and other hospitality services. A timber frame, concrete frame, steel frame, or load-bearing framework can be used to create the enclosure.

Three-dimensional features are used in the building's superstructure in this form of building. These prefabricated modules can be connected to create a complete setting. A light steel framework holds them all together. All the final building services are pre-installed on site, leaving only the final connection to complete. The construction of hotel bathrooms, accommodation buildings, and kitchen units are good examples. Figure 4 shows installing a module bathroom using this type of offsite construction.

Figure 4 - Pod Construction. (Projetos Inovadores e Sustentáveis - Blufab)

2.2.2. Panelized Construction.

These are flat panel modules that are utilized to make a complete structural shell as walls, floors, or roof panes. These panel modules are created in the factory and brought to the job site to be assembled as a three-dimensional structure or to fit into an existing structure. Factory-built structural floors and roofs are referred to as "cassettes." These "cassettes" can be both load-bearing and non-load-bearing structures.

Timber, insulated panels, light gauge steel, concrete, or non-structural in-fill walls can be used to construct these structural panel modules. These panel units can be used in any sort of structure. Windows, timber frames, insulation, and windows are examples of building components manufactured using panelized methods. Open panels, closed panels, concrete panels, insulated panels, composite panels, and infill panels can all be used in panelized construction. Figure 5 shows an example of panelized construction as type of offsite construction.

Figure 5: Panelized construction. (Panelized Modular Building Systems Market research & forecast during 2020-2025)

2.2.3. Hybrid Construction

In order to create a single building, hybrid construction uses both volumetric, and panelised technologies. As a result, this structure is also known as semi-volumetric. Building facilities that are totally constructed or prefabricated in the factory are hybrid systems. These units have a finished look.

Once the hybrid systems have been finished, they are brought to the job site. For example, highly serviced spaces such as toilets and kitchens are initially built as volumetric units, while the remainder of the house is built using panels, as shown in Figure 6.

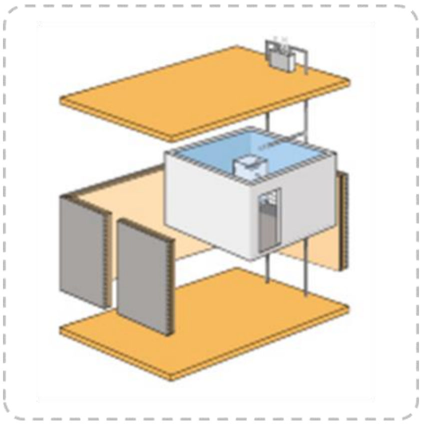


Figure 6: Hybrid construction. (Taylor, 2010)

2.2.4. Sub-Assemblies and Component Systems.

The sub-assembly system is the procedure through which building components are first created offsite before being permanently placed on the job site. Building components, materials, equipment, and prefabricated parts are here included. Small building components such as roof trusses, flooring pipes, staircases, precast concrete beams, and columns are manufactured in this type of construction. Prefabricated foundations, floor cassettes, and roof cassettes make up the sub-assembly system. Figure 7 shows an example of panelized construction as type of offsite construction.

Figure 7: Component system construction. (Component Building Systems, Inc)

2.3. The key benefits of offsite construction

Prefabrication and modular construction offer numerous advantages and positive effects on the project itself, the environment, and the overall society, as will be further explored.

Despite the benefits in time and money when compared to traditional onsite construction, the construction industry has only recently focused its interest on offsite construction, since it creates less environmental impact and is more secure. The following are the primary advantages of offsite construction:

a. Efficiency.

As presented in Table 1, less than 5% of building in the UK uses offsite techniques, compared to roughly 9% in Germany, 12 to 15% in Japan, and 20% in Sweden. Offsite building, which includes manufacture and assembly, can provide greater efficiency in fitting more correctly and quickly on site than the traditional method.

Table 1 – offsite construction in numerous high-income countries. (Steinhardt and Manley, 2016)

Country	UK	Germany	Japan	Sweden
Percentage	5%	9%	12-15%	20%

b. Less manpower.

The prefabrication of construction components in a factory can be significantly more automated than the traditional onsite brick-by-brick method. The factory-built kitchen and bathroom pods allow the rooms with the most complex mechanical and engineering components to be prefabricated and transported to the job site without the need to coordinate workers with various skills. Without offsite construction, it is common to have different sub-contractors to build kitchens, small rooms and bathrooms on-site.

According to the Construction Leadership Council's 2016 Farmer Review (*The Farmer Review of the UK Construction Labour Model Modernise or Die Time to decide the industry's future*, 2016), for every worker hired into the construction business, four workers leave. Because about one-third of construction workers are over 50 and will retire in the next 15 years, the shortage of competent labour is projected to worsen. In the next years, the sector will have to work with even fewer personnel, therefore automation offers a way to fill the void left by retiring humans. Figure 8 shows the age profile of the UK construction industry reflects poor recruitment of younger people.

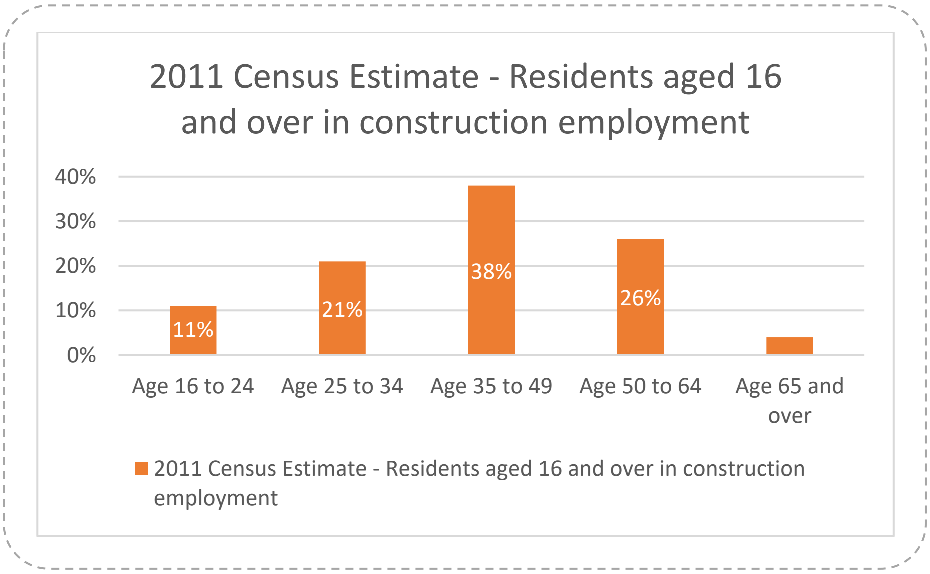


Figure 8 – The age profile of the UK construction industry reflects poor recruitment of younger people (*The Farmer Review of the UK Construction Labour Model Modernise or Die Time to decide the industry's future*, 2016)

Japan has a larger shortage of construction skills than the UK, which is made worse by an aging population with a high retirement age and inadequate recruitment into the industry. (Lessons from Japan: A comparative study of the market drivers for prefabrication in Japanese and UK private housing development, n.d.). The construction sector needs to either adopt less labour-intensive methods like off-site construction or increase recruitment by a factor of more than five.

c. Reduced costs of building services

Modular buildings or such centralized systems may be replaced by more localized systems in modern buildings. For example, rather than centralized plants, demand-controlled ventilation systems in each flat are used, and modern buildings' greater insulation allows central heating systems to be replaced with electric convection and infrared heaters in each room.

Such localized systems require people with specialized expertise, and each one requires a unique set of materials, which are logistically lot easier - and thus less expensive - to manage in a factory than on-site. By incorporating building services into volumetric units, they can be planned with a small number of electrical and plumbing connections that can be easily plugged in after the structure is put together.

d. Less time spent on site

While much of the construction is moved from the construction site to the factory, a developer spends less time on the construction site. The amount of time saved varies on the type of project and how much work is done offsite, but according to the Buildoffsite report (*An Offsite Guide for the Building and Engineering Services Sector,* 2015), it can range from 25% for large buildings like office complexes and supermarkets to 60% for smaller projects like schools.

Aside from the cost savings from not having to hire generators and cranes, anyone who has ever had to perform an environmental impact assessment would appreciate the ability to minimize local disruption. Some planning officials hold the notion that no construction site should ever be noisy or dusty. While offsite construction will not satisfy a planning authority, it can reduce the length of onsite time that must be approved.

e. Improved safety and working conditions

Despite the fact that the construction industry's safety record has improved substantially over the previous three decades, the Health and Safety Executive (*Construction statistics in Great Britain, 2021*, 2021) notes that the construction industry still has a fatal injury rate of 2,310 per 100,000 workers each year that is more than two times that of the manufacturing industry which has a rate of 1,080 per 100,000 workers.

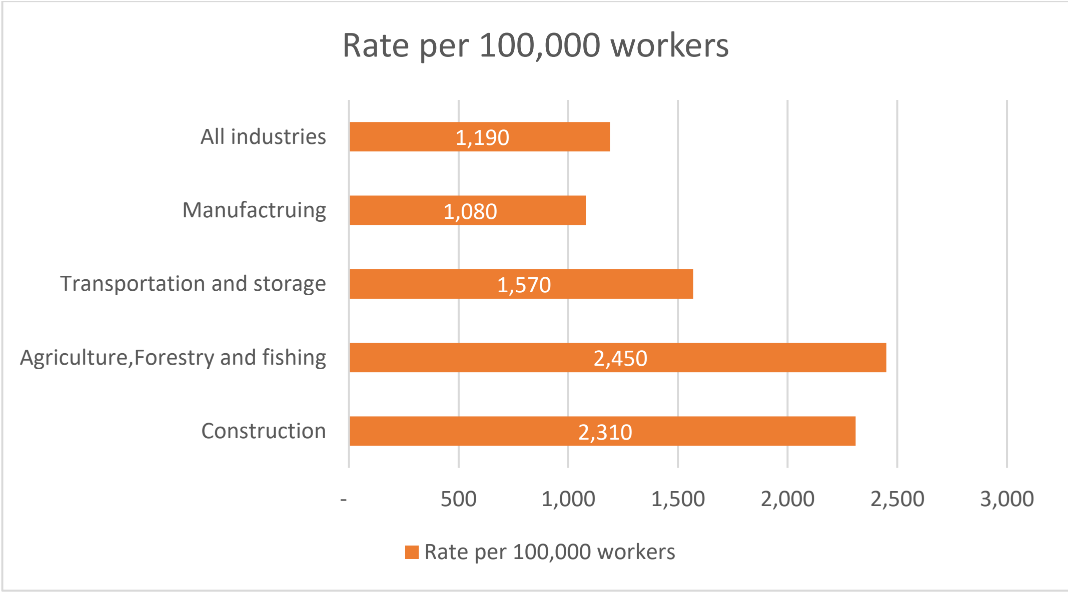


Figure 9 – Musculoskeletal disorders among workers in different industries. (*Construction statistics in Great Britain, 2021*, 2021)

f. Decreased traffic

Although offsite construction cannot eliminate the need for vehicles, it can reduce the time spent on site, which means that residents will not have to face the inconvenience for as long.

Offsite construction tends to replace a huge number of small vehicles with a few large ones. Unless the place is especially difficult to reach, a huge vehicle does not contribute significantly more to a traffic jam than a small one, and it produces far less noise and pollution per tonne of load.

A single lorry, as shown in Figure 10, transporting all the building's wall panels will bother the locals far less than a herd of vans delivering cement powder.

Figure 10 – Truck transports the modular building (¿Cómo se hace una Construcción Modular? | © Neoblock Modular)

g. Less waste

It is important to consider the various waste levels that develop during the two main stages of the offsite process, manufacturing, and assembly.

According to Buildoffsite research (*An Offsite Guide for the Building and Engineering Services Sector*, 2015), traditional construction is very wasteful in material terms. Waste streams can represent anything up to 20% of the raw material tonnages, with 10% being a reasonable average figure across all building types. In money terms, this might represent some 3-5% of the construction cost, so it is a significant number.

2.4. The key challenges to offsite construction

A questionnaire survey, asking about the main barriers to using offsite construction, was completed in the UK. It was used to target the three main groups of stakeholders involved in offsite: suppliers/manufacturers, contractors, and designers/clients. (Goodier and Gibb, 2005)

The survey shows that 67 percent of clients and 77 percent of contractors respond positively to offsite being more expensive. The belief of the stakeholders is that offsite is more expensive than traditional construction, and this is a main barrier in UK.

Longer lead-in times were identified as the second significant barrier. This was also a significant barrier for clients, designers, and contractors. This was a barrier identified by a large number of contractors, because using offsite could delay the start of the project more than traditional construction.

Table 2 shows the different barriers that were mentioned in the same survey, such as client resistance, lack of guidance and information, increased risk, and little codes and standards available.

Table 2 – The different barriers that were mentioned in the same survey. (Goodier and Gibb, 2005)

Barriers	Clients / Designers		Contractors	
	% of respondents	% as 1st choice	% of respondents	% as 1st choice
More expensive	67	54	77	38
Longer lead-in times	46	8	62	8
Client resistance	38	13	31	23
Lack of guidance and information	33	5	46	0
Increased risk	36	0	15	0
Little codes & standards available	33	3	23	0
Other	31	18	15	8
Negative image	28	0	46	8
Not locally available	18	5	15	0

No personal experience of use	18	3	38	15
Obtaining finance	18	3	8	0
Insufficient worker skills	21	0	23	0
Reduced quality	13	0	15	0
Restrictive regulations	13	0	31	0

There were barriers to implementing the offsite construction defined by the national institute of building sciences. In 2014, the NIBS reported a survey which defined the barriers to offsite construction with different defined weights. The rating is the average of the four possible barrier reaction levels: Significant, Moderate, Small, and No Barrier as shown in Figure 11.

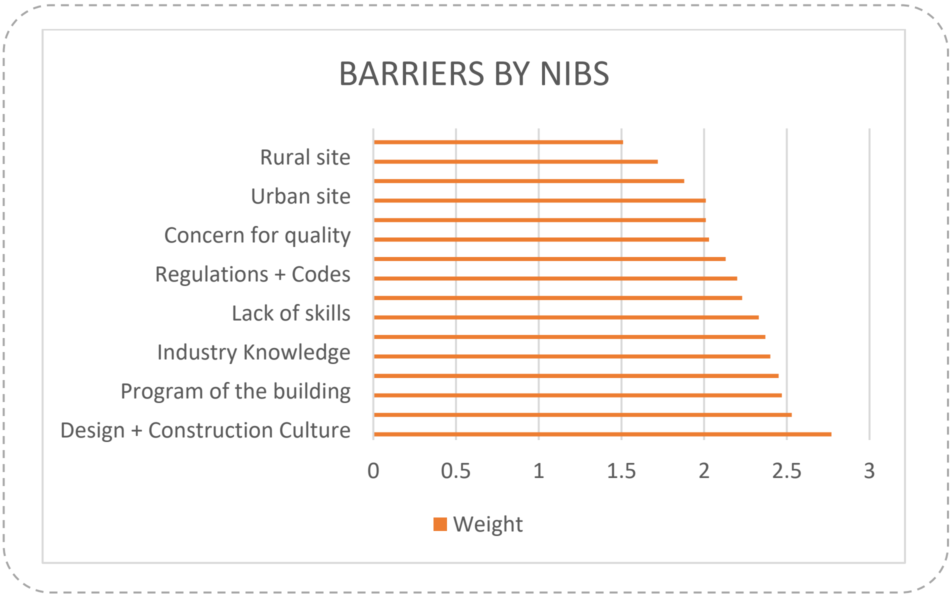


Figure 11 – Barriers to implement offsite construction. (Smith, 2014)

Meanwhile, the McGraw-Hill Construction report shows a different main barrier by putting aside questions for two distinct groups: the users and the nonusers, (Cassino *et al.*, 2011). For example, the architect didn`t start the process of design with the prefabrication approach, owners did not want to use prefabricated elements and the project type was not applicable. The response rates obtained for users and non-users are shown in Table 3.

Table 3 – Barrier*/s to offsite construction by users and non-users. (Cassino *et al.*, 2011)

McGraw Hill Report - Barriers	**Users**	**Non-Users**
Architect did not design for prefab	35%	34%
Owners do not want prefabricated elements	32%	26%
Project type not applicable	30%	34%
Availability of local manufacturing facility	28%	20%
Availability of a trained workforce	19%	
Not familiar with process	18%	34%

2.5. The offsite process

a- Onsite construction process

Before discussing the offsite process, it is important to discuss how the typical traditional onsite construction process proceeds throughout the project life cycle, from the beginning to the end. The standard procedure typically begins with the planning phase. The planning of the entire project is done at this stage to ensure timely delivery of the deliverables. As well as preparing in depth for what will occur during the following project stages.

Designing and engineering the project are included in the second stage. To create the fully complete model and coordinated drawings at this level, engineers from all engineering disciplines work together. Everything happens sequentially in this traditional construction process. Following design and engineering, comes the procurement stage. A schedule for the site work throughout the project execution is included in the procurement plan.

During the procurement stage and before starting the construction onsite stage, which is the execution stage, a material production stage is defined. The procurement plan turns each milestone into material supply to the site which needs to be on time to start the site work which is determined by the scheduled time in the procurement plan.

The material production stage is established during the procurement stage and before to the start of the execution stage, which is the construction on-site. Each milestone is translated from the procurement plan into a material supply to the site, which must arrive on time in order to begin the site work, which is determined by the scheduled time in the procurement plan.

Since the traditional onsite approach is sequential, the construction stage begins after. Each work package is supposed to start at a certain time in order to be finished according to the project's timetable. The project management team establishes the timeline for the project. The traditional onsite construction is shown in Figure 12.

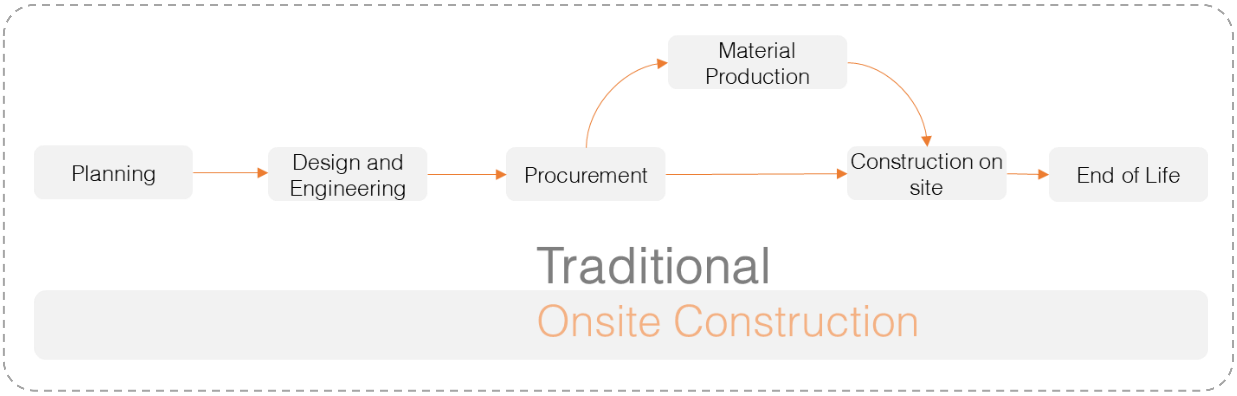


Figure 12 – Traditional onsite construction process. (TATUN, 1986)

b- Offsite construction process

Since the complexity and connectivity go much beyond those of the traditional way, planning is the most important activity in the offsite construction approach. In the modular construction situation, using the reverse process is mandatory since "*the eventual method of transportation sets upper limitations on the size and shape of modules*". (TATUN, n.d.)

Thus, all phases of the project should be put into consideration at the first planning phase. For example, all the transportation permits need to be handled before. In addition, modular prefabrication increases the interaction between activities and reviews the relationships that in traditional terms would normally be independent. For example, if there is any site works, it should be done in parallel with the manufacturing and prefabrication elements in order to make the maximum use of the modulation technique.

As described in Figure 13, there is a strong relationship between planning, design and engineering, and procurement. Moreover, the fabrication elements in the factory should evolve in parallel with any onsite activities. Afterwards, transporting the prefabricated elements to be erected on the site which will take less time than in the traditional way.

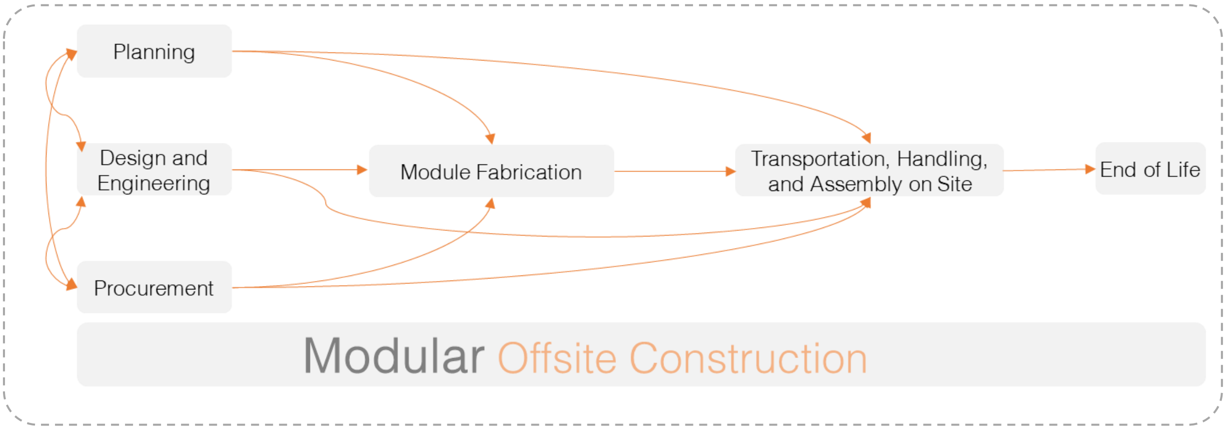


Figure 13 – Offsite construction process (TATUN, 1986)

c- The prefabrication logistic process

In prefabrication, there is a logistical phase. It deals with moving the prefabricated component from the factory to the construction site. A straightforward prefabrication process is one that begins with the production of the prefabricated components in the factory and ends with their assembly at a specific location. The prefabricated components are produced in the factory, and it is necessary to transport the prefabricated components to the location. Workers will be required to assemble the building using the crane. When the assembly step is complete, the procedure is finished. The prefabrication logistic process is described and shown in Figure 14.

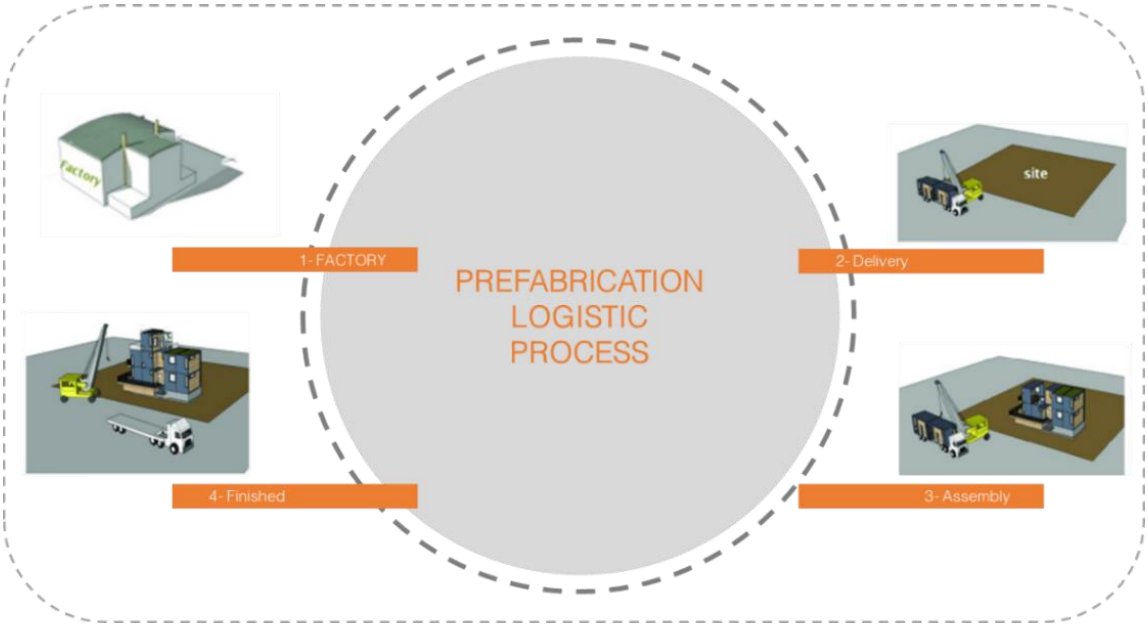


Figure 14 – Prefabrication logistic process.

2.6. The effect of the offsite construction on schedule

If a comparison is established between the traditional construction and the prefabrication, in terms of time, offsite construction will save 20 to 50 percent of construction time. For example, in modular construction time saving takes place when the modules are manufactured in the factory and, at the same time, site preparation such as foundation or podium is completed before starting the onsite assembly of prefabricated elements.

After the manufacturing process is complete and the components are transported to the site, stacking, connecting, and assembly will take place till the project is complete. This process does not take time to finish and yet it will be finished earlier than if it is used in traditional construction, as it shown in Figure 15.

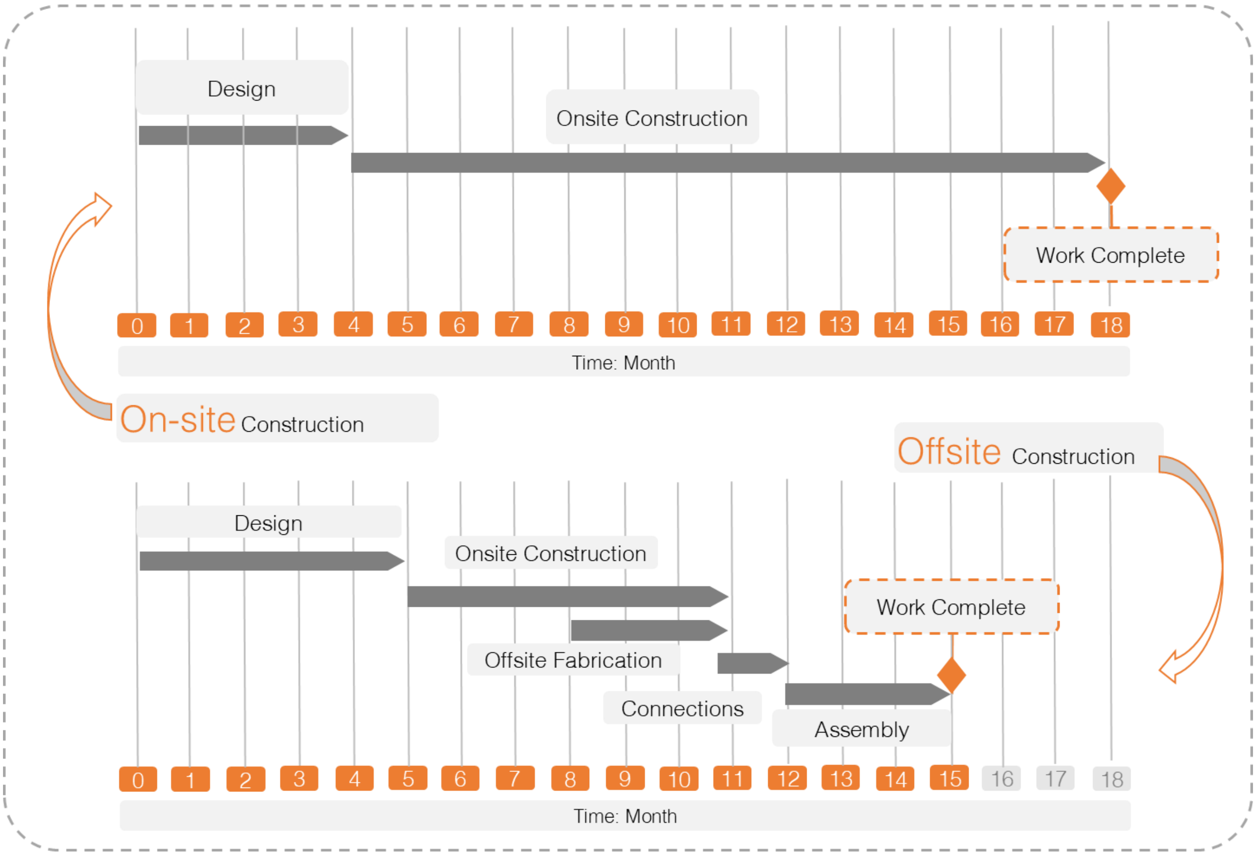


Figure 15 - The process of construction approaches over the time (Double Time Your Build: Podium + Modular - Base4)

2.7. BIM in offsite construction

2.7.1. BIM

Building information modelling, as defined by (Borrmann *et al.*, 2018), is a detailed digital representation of a facility that contains a high level of information. This three-dimensional model has geometric information and non-physical information, such as spaces and zones. The term Building Information Modelling (BIM) refers to both the process of developing the digital model as well as the process of keeping and exchanging it over the project life cycle.

In addition, building information modelling is defined by UK`s national building specification (NBS) as the process for creating and managing the information and data represented in a model throughout the project life cycle. "*As part of this process, a coordinated digital description of every aspect of the built asset is developed, using a set of appropriate technology. It is likely that this digital description includes a combination of information-rich 3D models and associated structured data such as product, execution, and handover information*". (About NBS | NBS, n.d.)

The BIM process and associated data structures are defined in ISO 19650 and 12006 series of standards. These are the standards that define building information modelling information structure and process, at an international level.

According to Eastman (Eastman, 2008), a lot of information is lost throughout the project life cycle, in conventional process projects. Using digital information workflows increases the project's overall time commitment. Figure 16, by (Eastman, 2008), shows the difference between digital and conventional workflow of information.

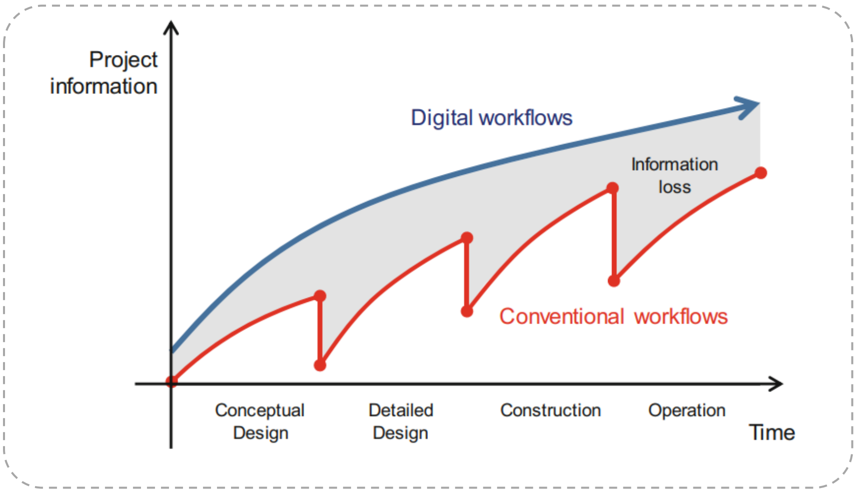


Figure 16 – Loss of information caused by disruptions in the digital information flow (Eastman, 2008)

Furthermore, BIM in offsite construction can help manufacturing in many different ways. BIM allows accuracy and precision in specifying material requirements, which can reduce over-ordering and reduce construction site waste, which is the main aim of using prefabricated construction. By providing the geometrical and non-geometrical information from the 3D model, BIM can help the contractor and fabricators. It can also accurately represent the geometry, properties, and information needs of each individual element that forms the building or the volume. By exchanging the information within BIM models, the possibility for more interfacing and communication between designers, manufacturers, suppliers, and users could happen. (Ezcan, Isikdag and Goulding, 2013)

Ezcan argued that the most helpful and advantage in using BIM, is bridging the offsite manufacturing implementations gaps, avoiding long lead times, high costs and modification issues. As well as by using BIM, it is able to provide an improved design, more collaboration, and exchange the information need precisely. Offsite manufactured projects will be more efficient if BIM is used to represent the all offsite construction elements.

2.7.2. BIM project life cycle

These are all the different stages of the building process where it is possible to use BIM information, from conceptual design, through construction, to operation and back in the form of renovations and maintenance.

The BIM information model goes through various stages that follow the project's life cycle, starting with the planning stage and moving through the design, construction, and operation phases.

According to the BIM's lifecycle, the level of information it contains should be acceptable. For instance, until the asset has advanced to the "Build" stage, it is probably not acceptable to represent construction logistics like cranes and hoists.

The model begins with the idea, during the design phase, and all team members, from all disciplines, work together to produce the precise coordinated drawings. Following the stages of analysis and documentation, fabrication begins. In this scenario, the factory may begin the production process. After that, the 4D/5D stage of construction involves factoring in time and integrating the BIM model with task planning that originates from the project management team. In this step, the building simulation and assembly process are specified.

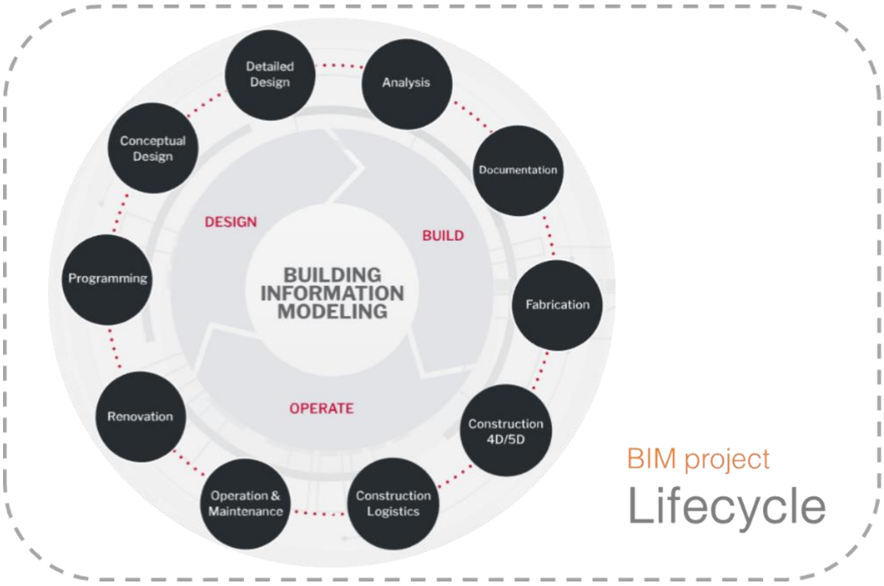


Figure 17 – BIM project life cycle.

According to MacLeamy`s curve, the BIM based planning process is almost the same as the conventional one with some shifting on time which is earlier in BIM-based, and the maximum planning effort is almost the same. In case of the integrated approach, the team's decreasing ability to affect project variables such as cost, schedule, and functional capability as the project progresses, however the traditional process shows how the cost of making changes increases as the project progresses.

Therefore, BIM shifts planning effort and design decisions to an earlier phase. This makes it possible to influence the design, performance, and costs of the resulting facility before design changes start to become costly to implement.

Figure 18 illustrates the relationship between design effort/cost (Y-axis) and the traditional phases of design and construction (X-axis).

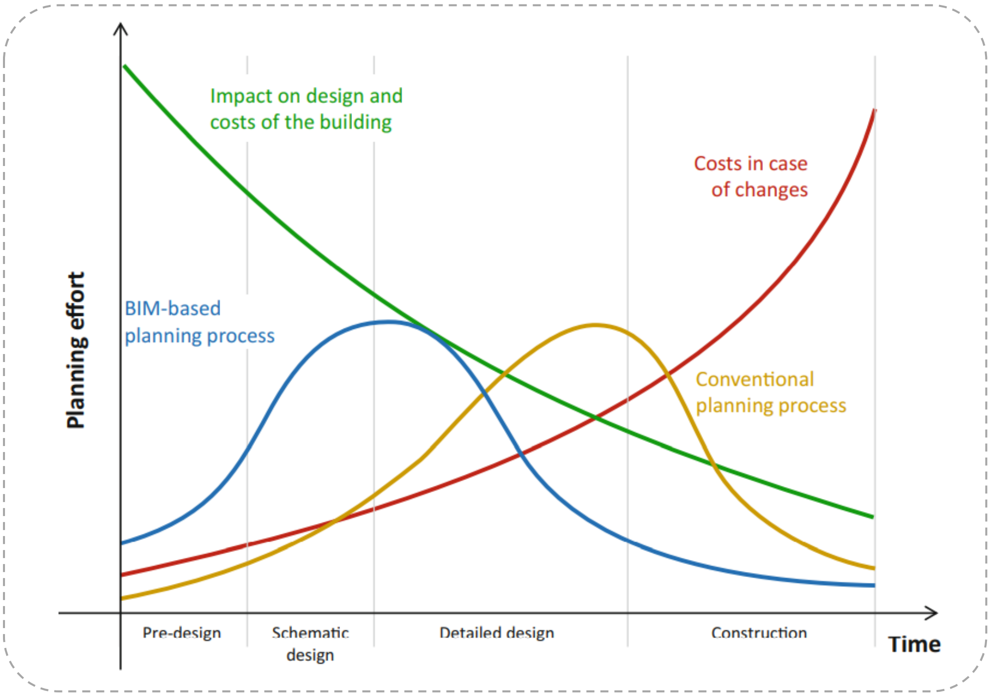


Figure 18 - The "MacLeamy Curve" - difference between BIM-based planning process and the conventional planning process.

2.7.3. Level of information need

The level of information need is the framework which defines the level of information that will be exchanged. There should be several concepts used to describe the level of information: geometrical information, alphanumerical information, and documentation. It is a combination of geometrical information, alphanumerical information and/or documentation as shown in Figure 19.

In terms of the need to demonstrate such as a 4D BIM model, the level of information need, such as the geometrical information needs to be defined before beginning. Since, the representation of the detail of the building needs to be defined in which stage it needs to be planning stage, early design stage, and detail design stage as shown in Figure 20. Therefore, in accordance with the 4D BIM modelling process the detail of the building needs to be in detailed design phase which can help the planner to find the elements of the model that represent an activity or more according to the schedule.

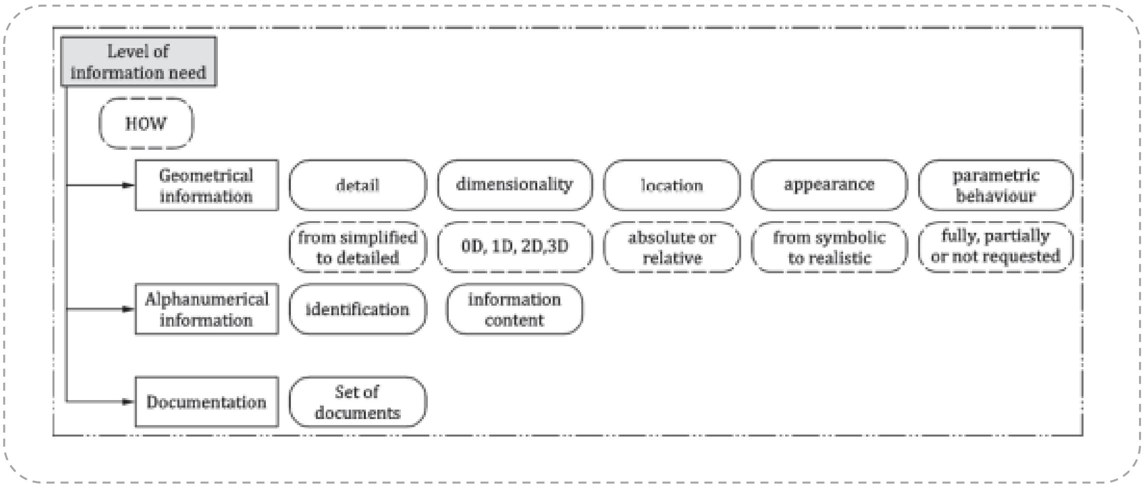


Figure 19 – Relation diagram for the level of information need. (*BSI Standards Publication Building Information Modelling-Level of Information Need*, 2020)

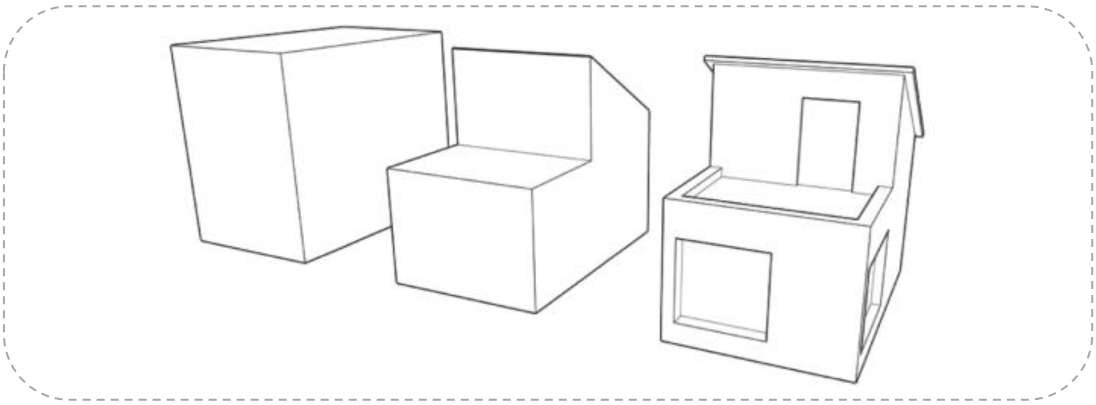


Figure 20 – Three different representation for the detail of the building. (*BSI Standards Publication Building Information Modelling-Level of Information Need*, 2020)

Moreover, an accurate and complete 3D model is needed in order to demonstrate 4D modelling. The primary requirement is a data checklist that is accurate and comprehensive. Modellers has to check and review the 3D model and make the needed adjustment according to the purpose of 4D modelling. That will lead the 4D modeller to get a proper 4D model.

2.7.4. BIM 4D schedule

Building information modelling is a dynamic process of information exchange that takes place during the life cycle of the project. According to the project requirements and the stage of this project, specific parameters are added in BIM regarding time, costs, sustainability, and facility management. BIM dimensions 3D, 4D, and 5D are defined as follows:

- 3D dimension: It represents the three geographical dimensions (x,y,z) of a building. The 3D geometry helps the stakeholders to navigate the building in three-dimensional view before starting the real project. In terms of 3D BIM, it means developing the 3D model and sharing the information using the same common data environment (CDE).

- 4D dimension: It is a 3D model adding to it a new dimension which is time. It helps outlining the duration of the project. This dimension is related to the scope of this research and further benefits from using a 4D model will be discussed, as shown in Figure 21.

- 5D dimension: 5D BIM is used when the budget and cost estimation are required before starting the project. It enables project owners to analyze the costs that will occur over time throughout the project activities.

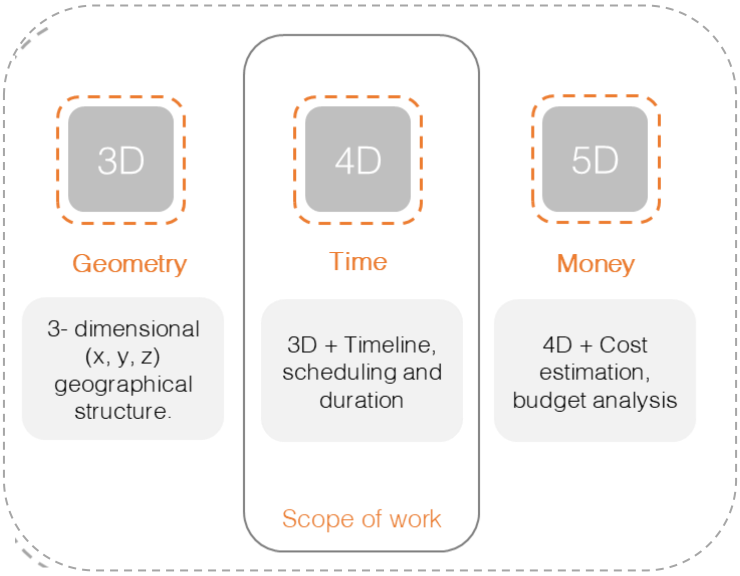


Figure 21 – BIM uses (*DIFFERENT DIMENSIONS, DIFFERENT USES*, 2020)

4D includes time in the analysis and the planning of the construction site by establishing the relationship between the site tasks and the building elements. The time schedule of the building helps to identify how long the project will take to complete and how it will change over time. 4D BIM tools organize on-site tasks by showing the effect of modification made over the whole life cycle of the project, and it is possible to predict early site clashes before starting the project. There are a lot of benefits to using the 4D in construction projects, at the preconstruction stage such as:

- Improving the site works, planning, and scheduling efficiency.
- Coordination among engineers, contractors, and sub-contractors on site works.
- Helping in early clashes among site tasks.

- Better planning for the following milestones in each stage of construction.
- Increasing the productivity and safety of site works regarding the time schedule.
- Before beginning the job on site, visualize the tasks and their logical relationships.

The process of manufacturing is dynamic and needs to be fully coordinated with all operations, that takes place in terms of time. The decision of using BIM based on the 4D simulation to optimize the manufacturing output. 4D simulation for the prefabricated output represents the time schedule, quantity, and quality of the output. (Chou, 2011)

Concerning the 4D simulation, using the critical path method is a useful and widely used technique, that makes it easier to describe, examine and update the process of construction (Arashpour *et al.*, 2016) . There is clearly explanation for using the simulation for the short-term management and long-term management. Short-term management can detect the clashes that occur over time, resolve them quickly and precisely by knowing the task procedures and assigning certain resources relative to the building quantities and getting the suitable module for the short process. Long-term process provides parametric information to achieve the output related to the module manufacturing schedule, material quantity and quality. (Nasereddin, Mullens and Cope, 2007)

The BIM 4D developed model is based on a BIM model with high level of detail, detailed time schedule information and with detailed activities, to be easily mapped. A site environment with factory BIM models and equipment sets can be created using various module manufacturing activities in a brief amount of time, enabling both short- and long-term simulations. (Lee and Kim, 2017)

However, a 2020 assessment on the effects of prefabrication and modular construction is available. Dodge data and analytics shows the impact of modular construction on schedule performance. Schedule Performance on Figure 22 which describe the percentage of schedule performance improvement that respondents report experiencing over the past three years before 2020 from modular construction.

■ Almost all (88%) of general contractors and construction managers' report positive impact with 60% better than 5% schedule gains.

■ Nearly two thirds (65%) of design firms agree on its positive impact, with 20% reporting the highest level (over 10% improvement).

■ While over one third (36%) of trade contractors report improvement in schedule performance, they are less enthusiastic overall than design firms or general contractors and construction managers.

Figure 22 – impact of prefabrication on project schedule performance (percentage reporting each of three levels of improvements) (Bibeau *et al.*, 2020)

Successful prefabrication requires a comprehensive coordination between the systems and disciplines therefore using BIM enhances the accuracy, detect the clashes, improve the coordination and saving time and cost. The Dodge data and analytics shows the impact of using BIM in prefabrication on schedule with the companies which do not use BIM, companies that use BIM on less than 50% of projects, and Companies that use BIM on 50% or more of projects over the last three years from 2020 as shown in Table 4.

Table 4 - Percentages Reporting Improved Schedule Performance from Prefabrication (by Level of BIM Usage) (Bibeau *et al.*, 2020)

	Companies that do not use BIM	Companies that use BIM on less than 50% of projects	Companies that use BIM on 50% or more of projects
Percentage reporting improved schedule performance	46%	46%	59%
Percentage reporting improved Cost performance	21%	44%	46%

3. FRAMEWORK

3.1. Introduction

This chapter's goal is to establish the workflow and procedure for completing the research endeavour, which is a 4D comparison of prefabrication and conventional methods for constructing the same building. Since there are more advantages on adopting prefabrication, the goal is to quantify those advantages in terms of time.

This work provides a macro workflow for both the prefabrication and the traditional way of construction, in order to generate a 4D model for each of them and define a 4D analysis for the two approaches. A comparison and an overview of traditional and prefabricated elements are intended.

Moreover, there is another micro workflow for this study. This workflow acts as a framework used for the proposed case study to demonstrate a quantitative 4D BIM comparative analysis between these two methods of construction. The first one is for traditional construction and the second is for prefabricated construction using the CREE system.

Furthermore, a case study of a building is used to apply this framework, considering both the conventional and the prefabricated approaches. The CREE system, which will be illustrated in the next part, is used to construct this building in a prefabricated way. Then, after creating a 4D simulation for each approach, the 4D comparative analysis is established. The literature review has already shown how to create a 4D simulation. In the case study application, presented in chapter four, the different resource assignments will be defined.

So, the workflow for this chapter is defined as shown in Figure 23, and it is organized as the following steps:

- Defining the structural elements that are used for traditional construction;
- Defining the prefabricated elements that are used in the CREE system;
- Proposing a Framework to generate a 4D model based on two different 3D models;
- Defining the case study that will be used to apply the 4D framework;
- Defining the 4D analysis for traditional construction and for total prefabrication.

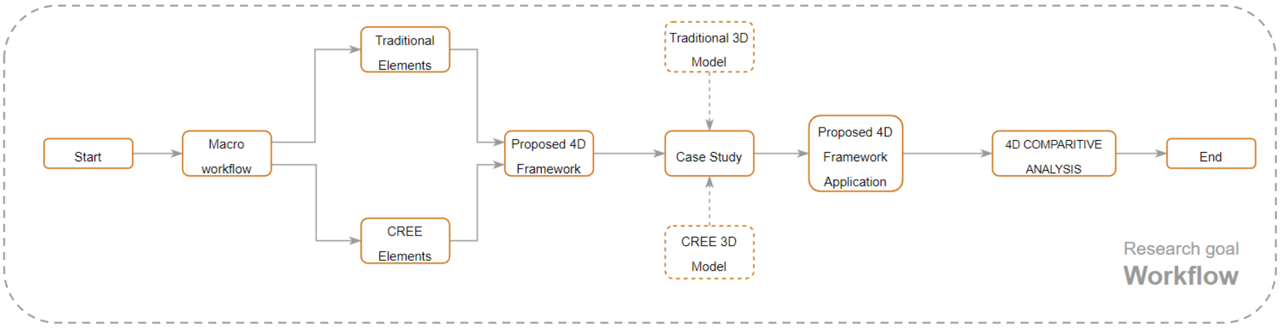


Figure 23 – Research workflow.

3.2. Macro workflow concept

The aim is to create a workflow that is used to make a 4D analysis for both construction systems applied to the same project, in order to quantify their benefits, as well as optimize the data and information workflow to generate the 4D model.

From the database, the company developed a 3D model that has all the data and information needed. It is important to decide on the level of information needed to facilitate the 4D process. The first step is to establish the Work Breakdown Structure (WBS) for the model elements, in both models. The company should establish this WBS for the elements levels in their database, so that they can reuse it in each new project. The level of information need is defined in detail in the micro workflow that help the user in the 4D modelling.

Moreover, to start the 4D BIM process, the user needs the exported IFC file from the 3D model. Regarding creating the 4D model, the user needs a WBS for elements to make the links between the elements and the tasks easier. Therefore, a user defined property sets could be considered while exporting the IFC file. The macro workflow to generate a 4D analysis is shown in Figure 24.

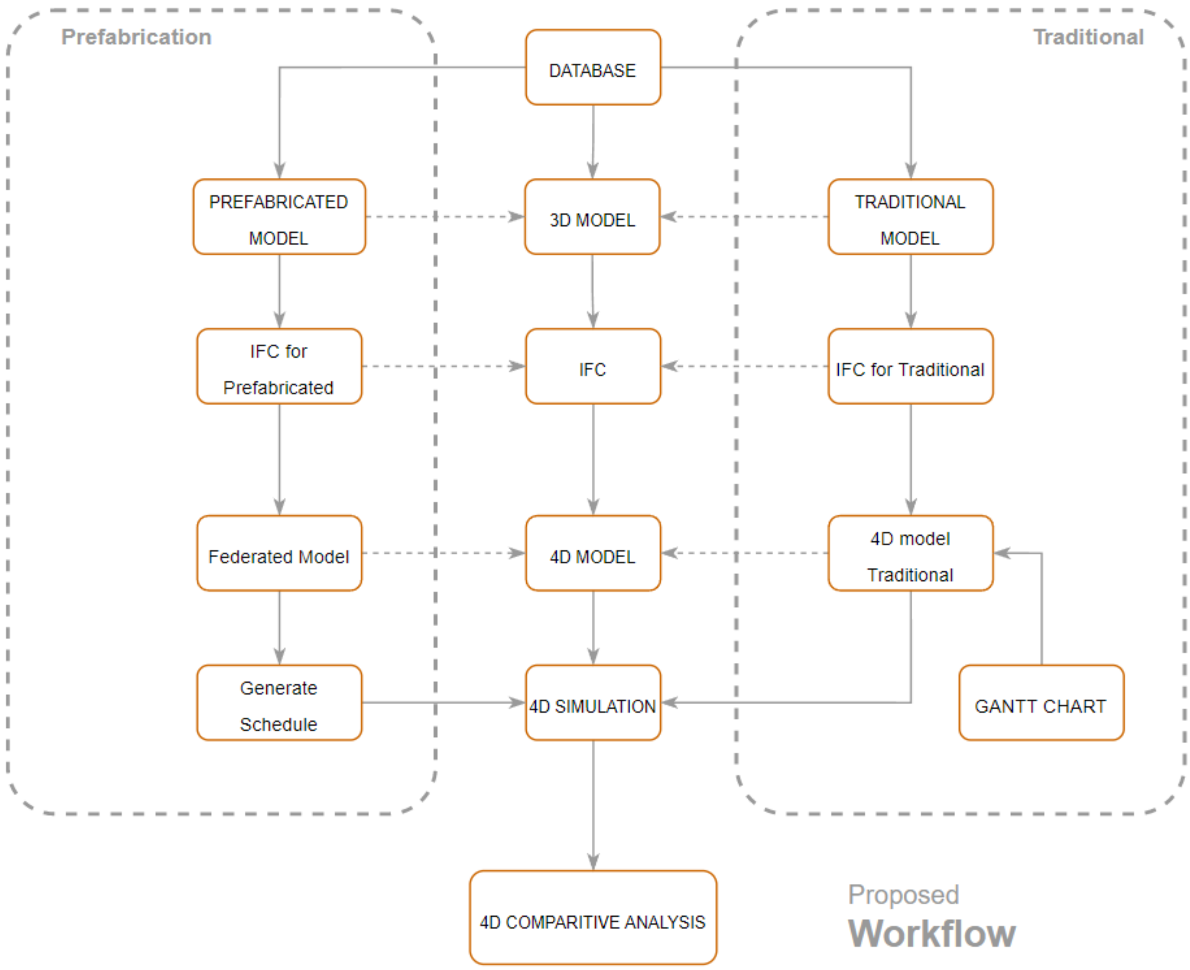


Figure 24 – The Macro proposed Workflow.

3.3. Elements used in traditional construction

In this study, the traditional construction elements refer to the reinforced concrete framed structure, which is very common in this type of buildings. Columns are vertical elements and beams are horizontal ones. Other elements used in concrete building construction are base, floor and roof slabs. Columns bear most of the weight of the building and shear walls should also be able to withstand various loads that are applied to them. (Major Parts of Reinforced Concrete Buildings | Framed Structures Components – CivilDigital -, 2017)

3.3.1. Traditional construction elements

- **Columns in traditional construction**

The vertical elements that support any elements above them and bear beam loads. It is the most critical element of this structure. Columns are highlighted in Figure 25.

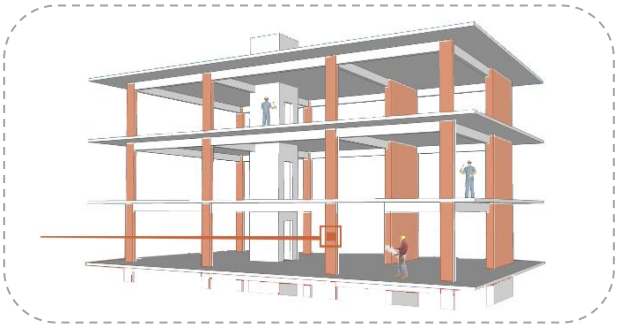


Figure 25 – The highlighted shows the columns in the traditional construction.

- **Slab in traditional construction**

These are the surface elements that rely on flexure to transport the weights. Typically, they support the vertical loads. Due to their high moment of inertia, horizontal loads have the ability to carry substantial wind and earthquake forces before transferring them to the beam. Slabs are the elements that are highlighted in Figure 26.

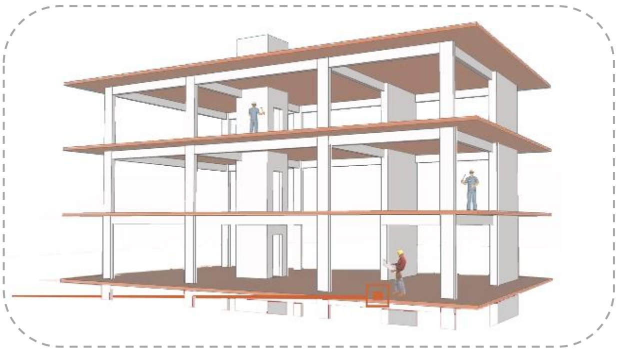


Figure 26 – The highlighted shows the slab in the traditional construction.

- **Beam in traditional construction**

The beam elements in this structural system carry the loads from slabs to columns. The beams may be supported by other beams or by columns that are essential components of the structure. Beams are the elements that are highlighted in Figure 27.

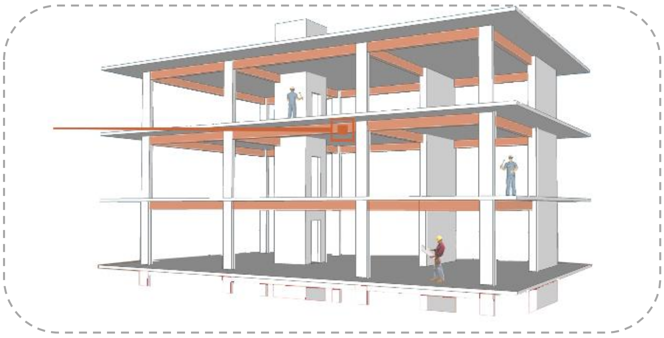


Figure 27 – The highlighted shows the beams in the traditional construction.

- **Shear wall in traditional construction**

Shear walls, which look more like walls than columns due to their size, are actually very huge columns. These respond to the horizontal loads, such as those from wind and earthquakes. The vertical loads are also carried by the shear walls. Shear walls are the elements that are highlighted in Figure 28 .

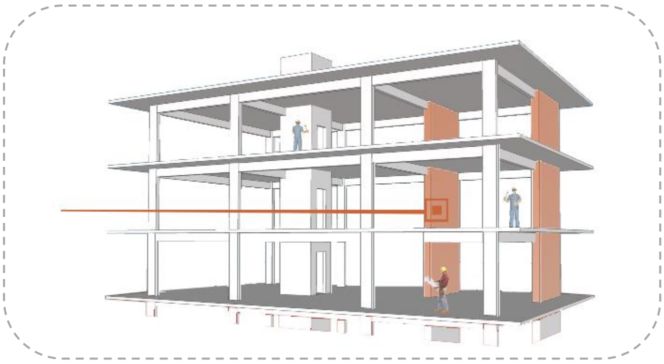


Figure 28 – The highlighted shows the shear walls in the traditional construction.

3.3.2. The way of construction and needed resources

Traditional building construction uses cast-in-place concrete, also known as poured-in-place, which is a concreting technique developed on site. Cast-in-place concrete is the preferred choice for concrete slabs and foundations, as well as components such as beams, columns, walls, floors, and roofs.

The concrete is typically transported to the site in an unhardened state, often using a ready mixed concrete truck. A chute extends from the back of the truck to place the concrete either in the required location or into a dumper or pump as is shown in Figure 29.

Figure 29 – Pump using concrete mixer (Concrete Pump, 2022)

Therefore, there are many tasks associated with the reinforced concrete construction that must be completed on site. For example, a slab for one floor requires a variety of tasks to be completed, including the following (Concrete Floor Slab Construction Process - The Constructor):

- To assemble and erect formwork;
- To prepare and place the reinforcement;
- To pour, compact and finish the concrete;
- To cure the concrete and remove the formwork.

3.3.3. Resources needs

When planning in the traditional way of construction, there are resources that must be taken into account and allocated to the activities. Examples of these include the following equipment and labor teams:

Equipment needs:

- Concrete Batching Plant
- Concrete Pump
- Concrete Mixer
- Concrete Vibrator

Workers needs:

- Carpentry crew
- Concrete crew
- Rebars crew

3.3.4. Advantages of using reinforced concrete

There are benefits associated with casting *in situ* and using reinforced concrete:

- It has been a tried-and-true technique for more than a century;
- Cast-in-place concrete has a high level of strength which is its main advantage;
- Reinforced concrete requires less trained labor.

3.3.5. Disadvantages of using reinforcement concrete

There are also disadvantages associated with casting *in situ* and using reinforced concrete:

- Cast-in-place concrete requires a significant amount of labor;
- Before mixing and pouring the concrete, builders must fabricate and install forms for the columns and the slabs they intend to cast;
- It takes time to pour the concrete and wait to remove the forms, which increases the length of project time,
- It produces a lot of waste;
- Reinforced concrete buildings generally weigh more than other alternative types of construction.

3.4. CREE system used in prefabrication

The CREE System is an impressive and advanced timber-hybrid system for the construction of high-rise versatile prefabricated buildings. It is a hybrid construction method that makes use of both volumetric and panelised technologies, such as pods and panels, as previously mentioned in the literature review.

- **CREE Grid**

In a CREE structure, each floor is made up of a grid of prefabricated timber-hybrid slab panels. The building's dimensions are indeed numerous slabs in each direction. The ribbed timber-hybrid panel's width can range from 2.50 m to 3.00 m, but it is optimal for the panel's length to be two or three times the width. The CREE Grid are highlighted in Figure 30 .

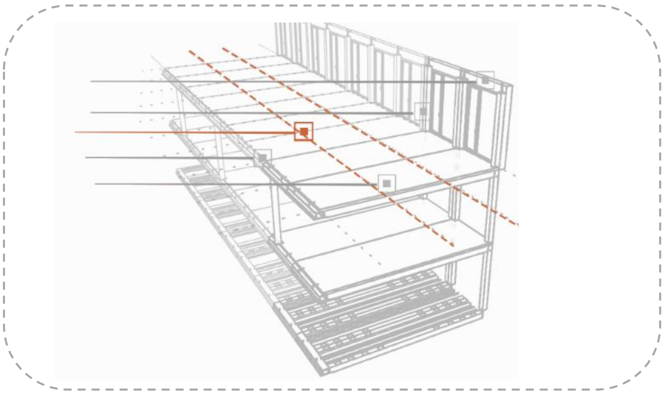


Figure 30 – The grid of the prefabricated timber-hybrid slab panel. (Sustainable building systems | timber hybrid office buildings - CREE Buildings,)

- **CREE Glulam columns**

Vertical stresses from double timber posts are transmitted through the floor to the pair of posts below. It is possible to install multiple pairs of posts at once with a single façade component. Because wet building materials and the corresponding curing durations are avoided, this combination of primary and secondary construction processes speeds up the construction process. The CREE columns are the elements that are highlighted in Figure 31.

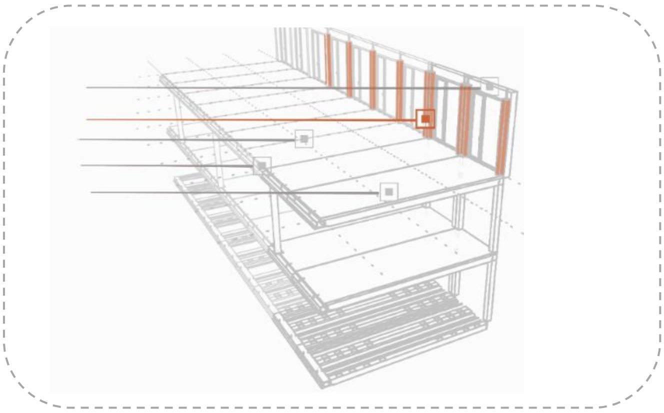


Figure 31 – Double timber posts transmit the vertical loads. (Sustainable building systems | timber hybrid office buildings - CREE Buildings)

- **CREE Hybrid slab panel**

The slab panels, which combine concrete and wood, offer the necessary fire protection between stores while also utilizing renewable resources. A lot of flexibility in designing interior layouts is possible due to the panels' wide span. It is advised to keep these wood elements exposed in the interior space. The CREE slabs are the elements that are highlighted in Figure 32.

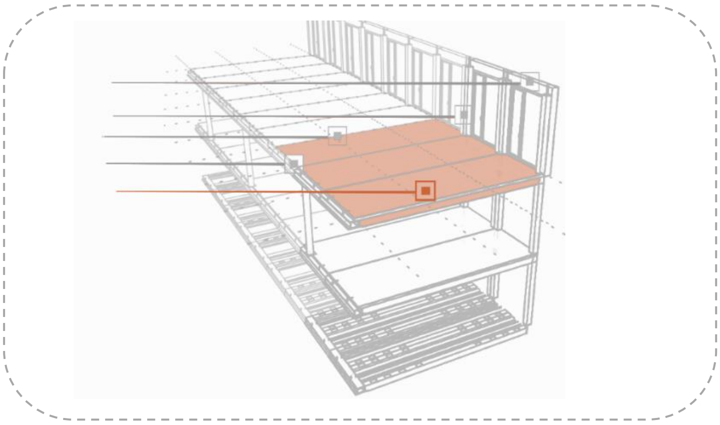


Figure 32 – The slab panels combine concrete and wood. (Sustainable building systems | timber hybrid office buildings - CREE Buildings)

- **CREE Façade elements**

The façade components of a CREE structure are not integrated into the core structural framework, but rather mounted atop it, unless additional stiffening elements are necessary. Weatherproofing is sped up, the interior fit-out may start earlier, and there is no need for scaffolding on the job site because the structural framework columns and pre-mounted façades are put together in one process step. The CREE façade elements are the elements that are highlighted in Figure 33.

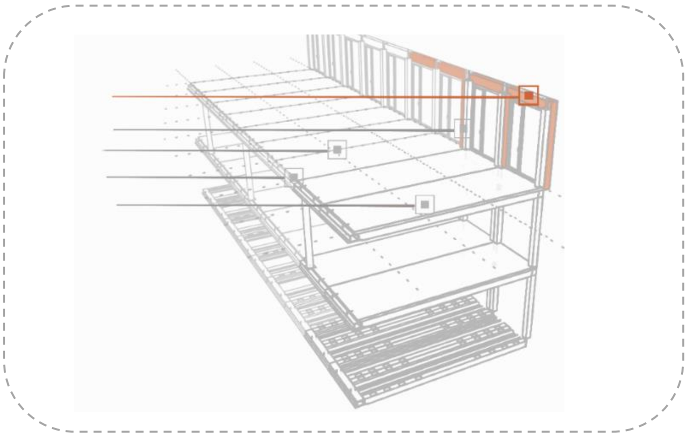


Figure 33 – The CREE façade element. (Sustainable building systems | timber hybrid office buildings - CREE Buildings)

- **CREE Central girder**

A grid extension is required for many floor plans in order to develop deeper buildings. To do this, central support girders are added, and these are ideally made of steel to reduce dimensions. Greater spacing between supporting columns is possible with these girders, up to 2-3 grid lines along the girder. The CREE central girder is highlighted in Figure 34.

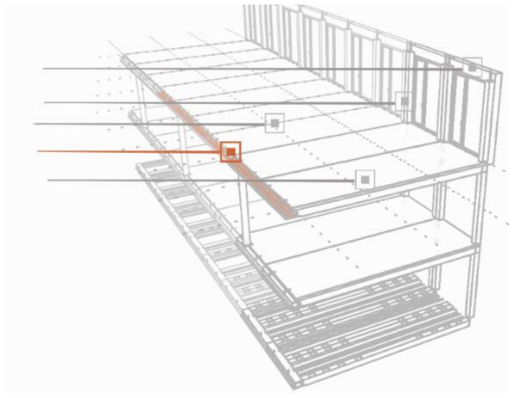


Figure 34 – Steel girder at CREE system. (Sustainable building systems | timber hybrid office buildings - CREE Buildings)

3.4.1. The way of construction in CREE system

To begin the erection operation, all CREE components are carried to the location. starting the assembly process while holding the components with a crane tower and a portable crane. A trained team is in place to supervise the procedure and link the various parts. The following Figure 35 shows how the CREE system was assembled on-site.

Figure 35 – How the CREE system was assembled on-site. (Sustainable building systems | timber hybrid office buildings - CREE Buildings,)

3.4.2. Resources needed by CREE

Less resources are required in this case than in the traditional construction. The needed resources for assembly process on-site for CREE elements are as following:

- Trained crew
- Portable crane
- Tower crane

3.4.3. Advantages of using CREE system

There are certain advantages to using CREE construction instead of the conventional way of construction:

- 400-500 m2 of air- and water-tight floor area each day;
- Greater productivity per worker and therefore fewer workers needed;
- Prefabrication can increase workplace safety;
- Less dependent on site conditions;
- No unforeseen costs following construction.

3.4.4. Disadvantages of using CREE system

There are some of disadvantages to using CREE prefabricated elements that should be mentioned and considered in this comparative analysis between the traditional and CREE structure.

- Transportation: The distance between the factory and the construction site is a factor that must be taken into account, as the higher the distance, the higher the cost of transportation.
- Handling: Prefabricated elements need to be handled with proper care and precaution. Prefabricated components are typically huge and heavy. The CREE components are often handled by portable or tower cranes.
- Modification: Prefabricated constructions have the disadvantage that it is challenging to change the structure. For instance, removing a structural wall will affect the building's overall stability.
- The Sensitive Connection: To ensure that connections between several structural parts behave as planned, supervision and good installation are required. In addition to this, bad connections might cause insulation failure and water leaks.

3.5. Proposed 4D framework

Figure 36 describes the proposed workflow which is explained in detail in the following sections.

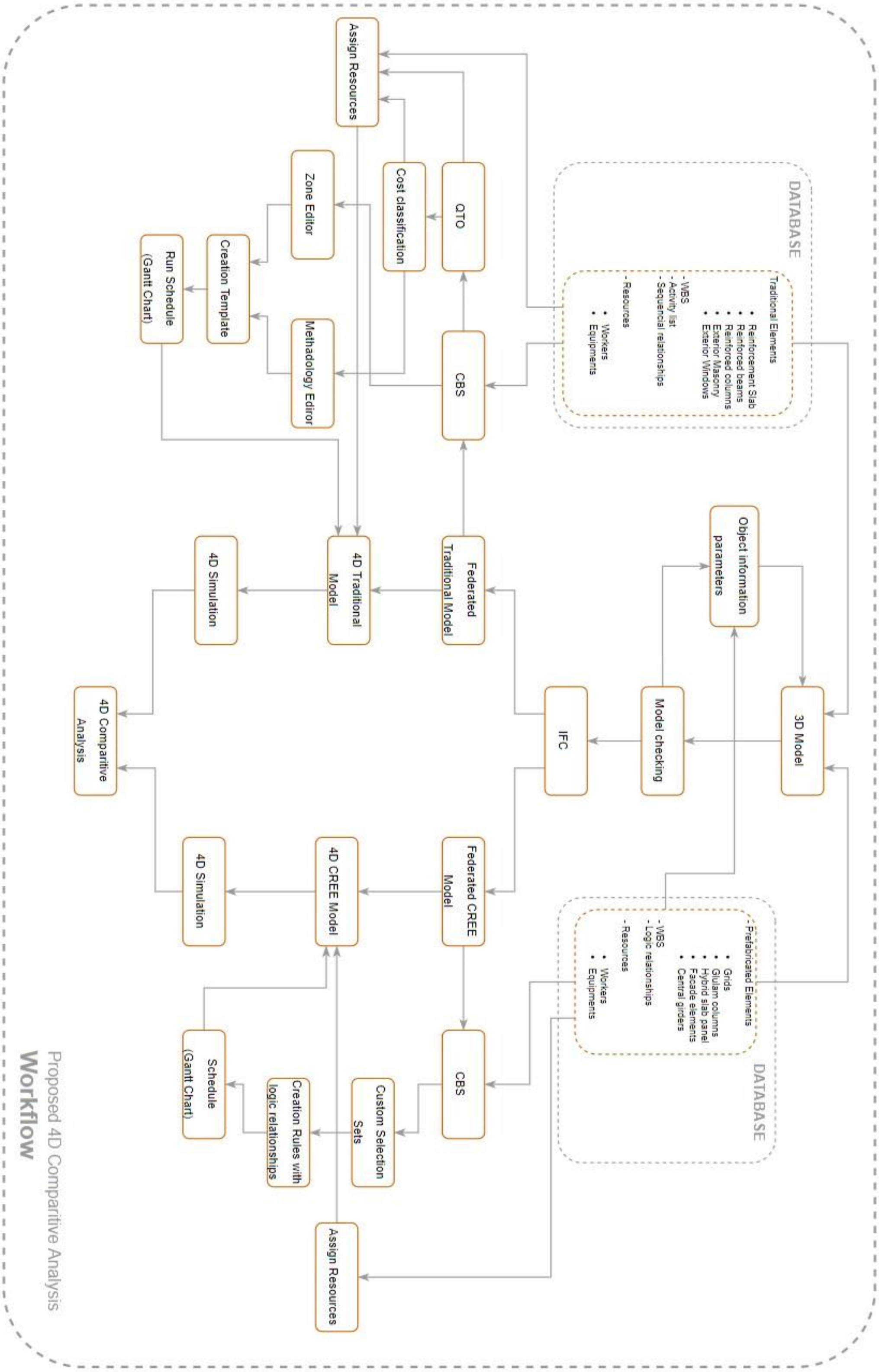


Figure 36 – Proposed 4D comparative Analysis.

3.5.1. 3D BIM model

This research was developed with Autodesk Revit as the 3D modeling software and BEXEL Manager as the 4D modelling software.

3.5.1.1. Create the 3D model

The modeling stage can start once all the necessary data has been gathered. By reviewing the 3D model and the schedule created by the project management team, the modeler or any team member working on this stage should double-check all the information acquired to create a detailed model that respects the level of information and details needed for the purpose of creating the 4D model.

3.5.1.2. Review the 3D model

The model should be reviewed and updated. Since the 4D modeler will be in charge of monitoring and coordinating the 3D modeler and making the updates to the 4D model, it is essential to add the missing information to the 3D model to facilitate the 4D process. Updates and modifications should be made as often as necessary. The review should make sure that:

- the modeling is simple to understand;
- the modeling can be utilized to create a 4D model afterwards ;
- the level of detail is correct;
- the level of information needed is provided;
- the model comprises all the necessary components of the project schedule.

3.5.1.3. 3D modelling for 4D analysis

It is important to have a 3D model layering scheme that supports the 4D modelling activities. This research addresses the traditional model, which is based on reinforced elements such as slabs, beams, and columns, and on the exterior envelop that is composed of masonry works and exterior windows. All building elements should be assigned to the created WBS level parameters in Revit. This WBS will make it easier for the 4D modeler to generate the 4D model by assigning the building components to the schedule. The WBS levels created in the 3D model in Revit file is shown in Figure 37.

Therefore, it is easy as for a 4D software such as BEXEL Manager, with a specialized way to automatically link the elements with the activities to support the accuracy of the 4D model. This can be implemented through the following process:

1. Specifying the layering standards in the 3D model;
2. Include additional building elements and activities that support visualization;
3. Allocate WBS levels to the building elements, according to the level of the actual planning.

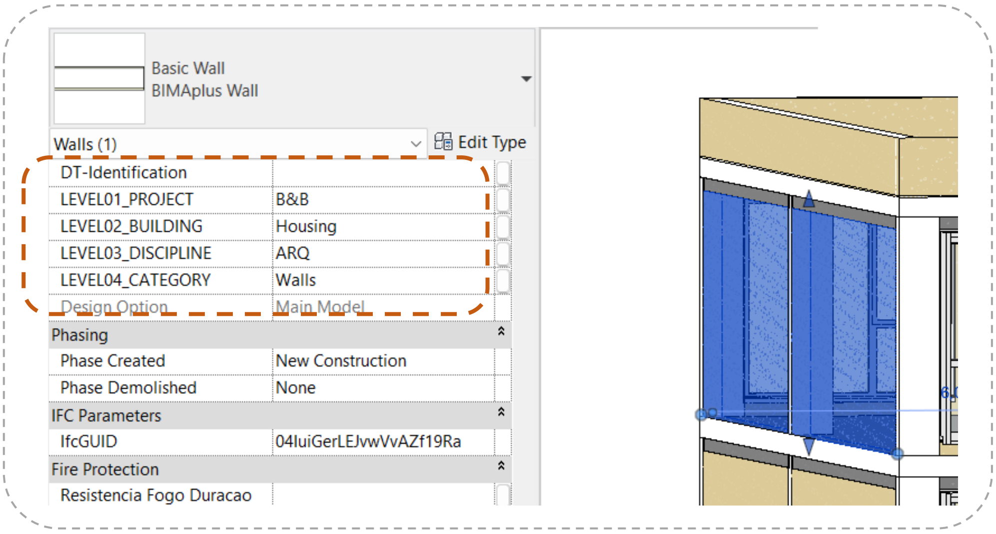


Figure 37 – WBS levels with element at Autodesk Revit.

3.5.2. Model checking and IFC

The Industry Foundation Classes (IFC) is an open framework for the exchange of building data models used in building design and construction across various software. It is utilized to exchange information within different disciplines along the project life stages (design, construction, maintenance, and operation.) The IFC file will be exported from the 3D model team in order to start the process of the 4D BIM integration model.

Before an IFC is published, the quality and accuracy of the IFC export must be verified. This is known as model checking. Afterward, the model can be checked in an IFC viewer (e.g., BIMCollab, BIMvision). Sometimes a setting is left unchecked, or the export is done from the wrong view (2D view rather than 3D views), which results in an incomplete IFC export.

Moreover, when everything has been exported, a quick check needs to be done, for instance, by making a few cuts and checking the geometry of the model in the IFC viewer and by navigating inside and outside of the model. Sometimes, specific objects may be wrongly exported to IFC. The best option in this situation is to erase the object and model it once more in the modeling software. Then you can make a new export.

To make sure that the level of information need is ready to be provided in the IFC file, it is possible to define it as an export user defined property set. Export user defined property sets is an additional method for exporting chosen parameters by specifying the export parameters in a text file. Everything between < > is replaced and defined by the user according to the specific parameters needs, as shown in Figure 38.

Basic structure:

```
# Format:
#    PropertySet:   <Pset Name> I[nstance]/T[ype]   <element list separated by ','>
#   <Property Name 1>   <Data type> <[opt] Revit parameter name, if different from IFC>
#   <Property Name 2>   <Data type> <[opt] Revit parameter name, if different from IFC>
```

Figure 38 – The text file has the replaced parameters by the user. (Revit IFC Manual 2.0)

3.5.3. 4D BIM model

Using BEXEL Manager as a software to generate the 4D BIM model. The first step is to import the IFC exported file from Revit. There are many features to do in BEXEL Manager before demonstrating the 4D model. The process in BEXEL Manager is starting with creating a custom breakdown structure (CBS) according to the created WBS in REVIT. These CBS will help the user to have a BIM model according to the selected attributes - in this manner it will be the WBS properties – which will help the user in the 4D BIM process and to know how many elements of the BIM model have within these selected attributes.

Furthermore, creating the custom selection sets (CSS) is the next step . The CSS is a user defined selection for group of elements which will help the user to select certain elements for the purpose of generating the 4D model. The process in BEXEL is sequential and it might be dependent on other factors. For instance, it is better to start generating the CBS first and create the CSS based on a selected CBS based on the creation wizard feature in BEXEL.

To generate a 4D integrated model in BEXEL Manager, it should start with creating cost classification and cost version using the auto-assign process before creating the automated schedule by defining the zone editor levels (spatial distribution), methodology levels (order of the work execution), and creating a template based on the zone and methodology levels which will be explained later in the case study, as shown in Figure 39.

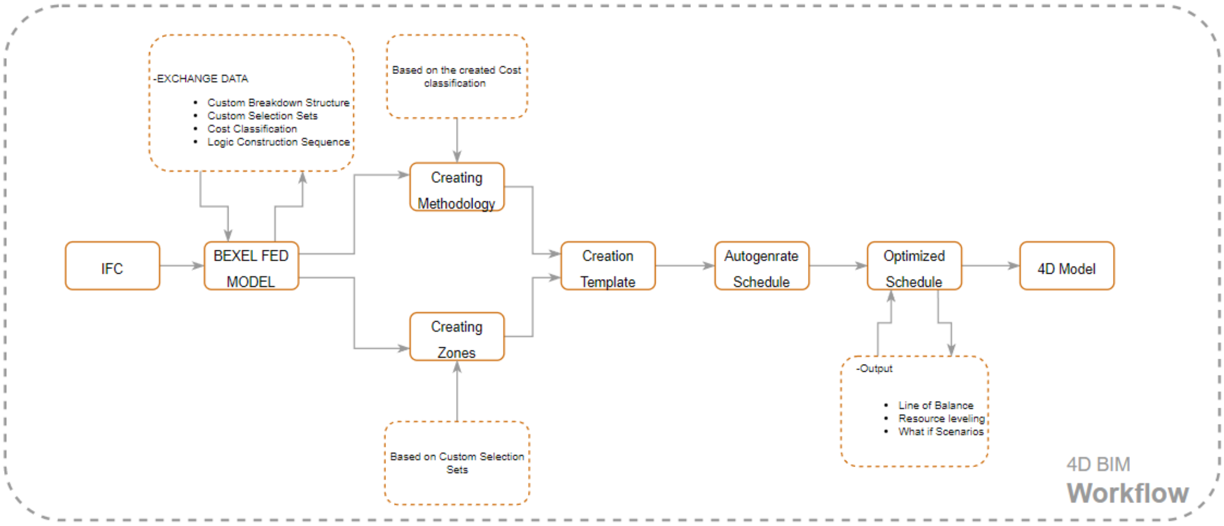


Figure 39 – The 4D BIM workflow in BEXEL. (‘BEXEL_Manager_Handbook-ENG’, 2020)

3.5.3.1. Custom breakdown structure

After the IFC model is inserted into BEXEL Manager, the first thing to do is to make a custom break down structure for the elements, depending on the criteria needed to start the 4D modelling process. This created breakdown could be used for reviewing the elements if they are under the certain defined attributes as well as it used for creating a smart custom selection sets CSS) which will be explained in the next part. The CBS displays the breakdown structure which is just created for two rules. The first one is the building levels and the second one is the categories as shown in Figure 40. The total model elements are given as 3497 elements that are divided into defined attributes. Each group can be disabled and made invisible in the viewport within the created breakdown.

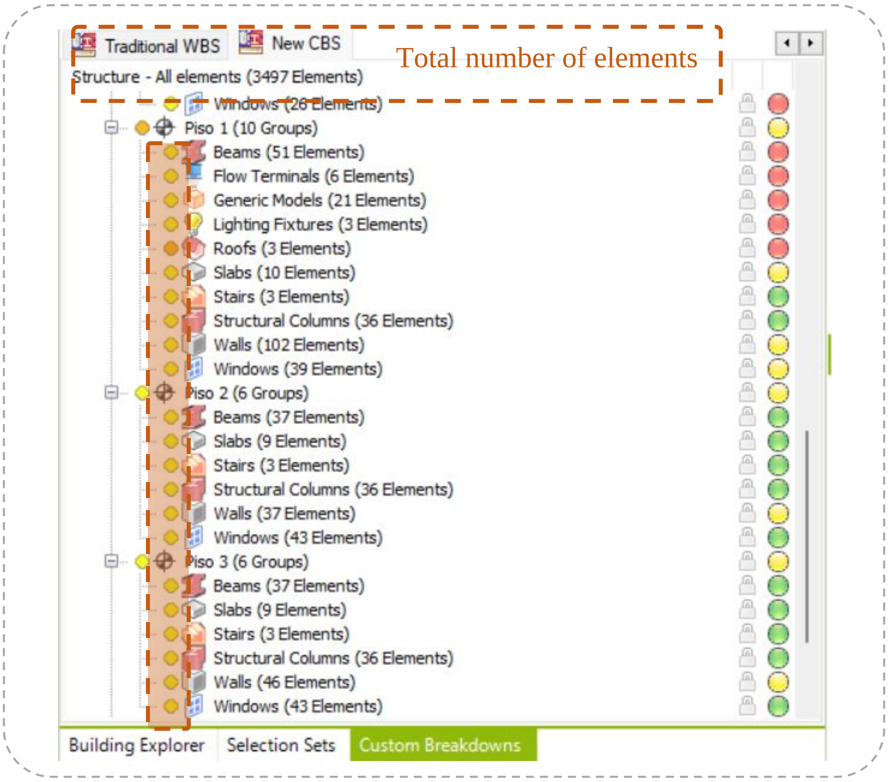


Figure 40 – An example of created Custom Breakdown Structure in BEXEL Manager.

3.5.3.2. Custom selection sets (CSS)

Creating smart custom selection sets is a smart and important tool in BEXEL Manager which is used in every single stage of the 4D BIM process. Beside creating the selection sets manually, there are smart selection sets that are created with predefined rules based on which elements are included in the selection sets. For instance, the Figure 41 describes the CSS for one building only which is selected by a rule defined with a building name.

The CSS has several uses such as when constructing a 4D BIM model. When linking the schedule to the BIM model, the selection sets can be assigned to a single task or to a group of tasks in the schedule.

In addition, the user can create CSS from previously created CBS. It could happen by with using smart feature creation wizard in BEXEL Manager as shown in Figure 42.

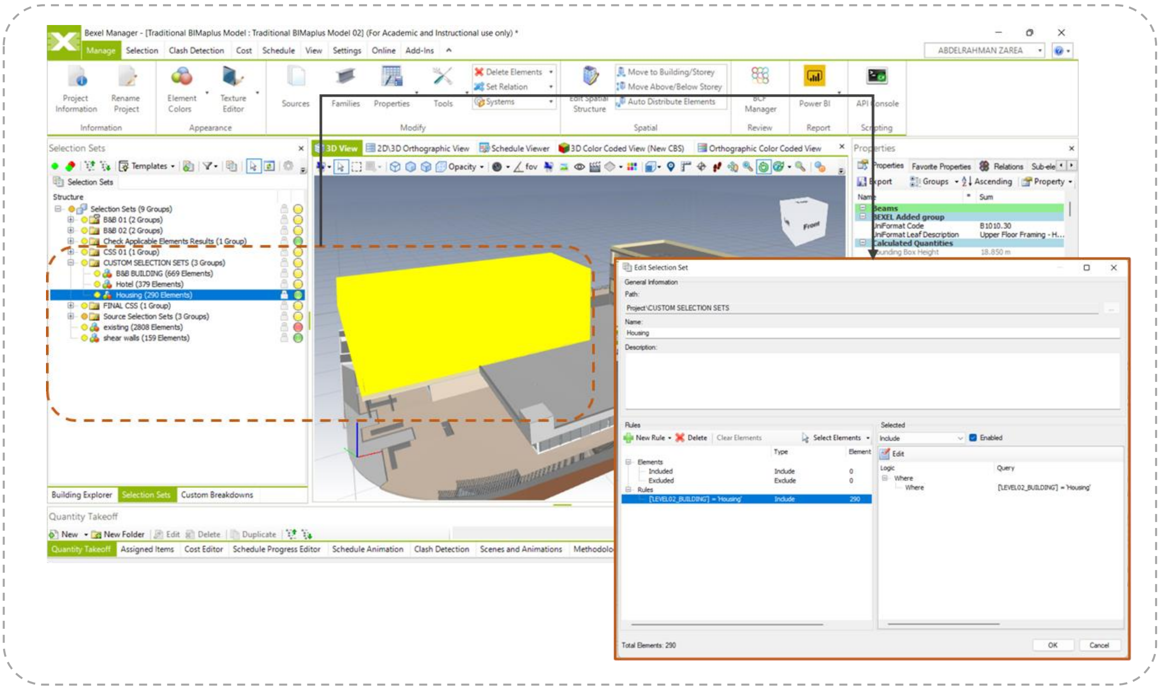


Figure 41 – Example of created Custom Selection Set based on rule in BEXEL Manager.

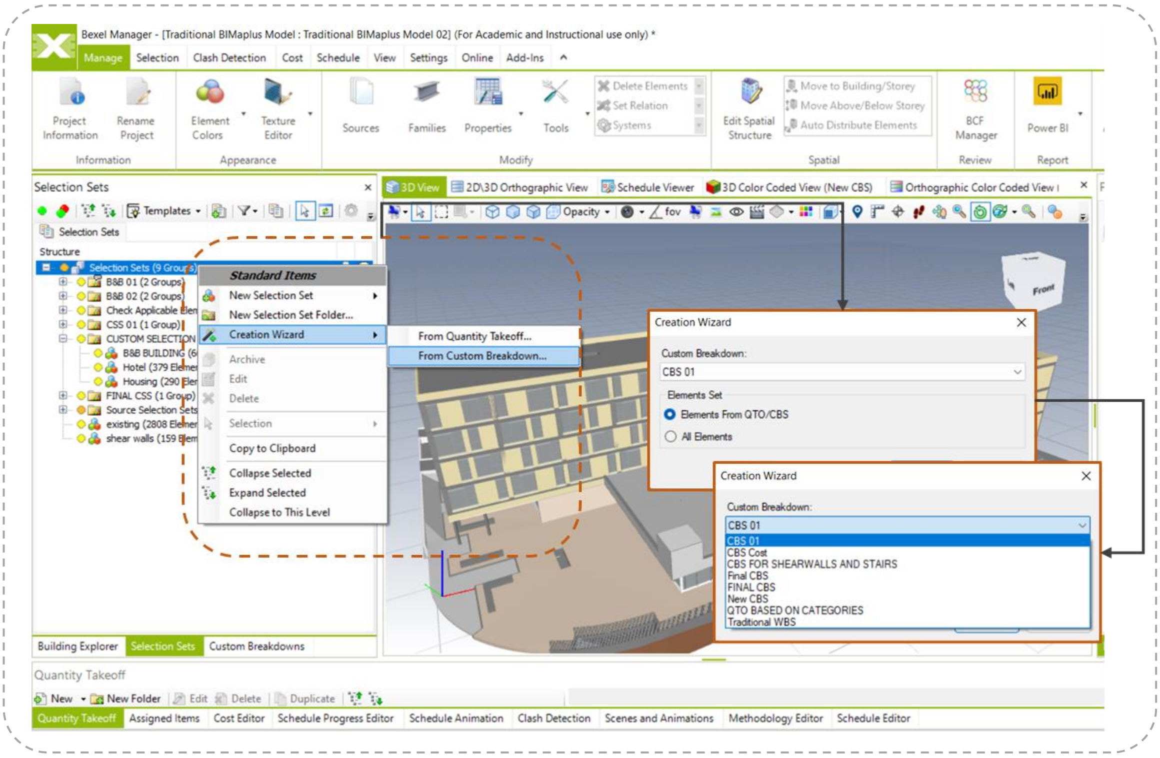


Figure 42 – Example of creating Custom Selection set based on created Custom Breakdown Structure in BEXEL Manager.

3.5.3.3. Intelligent scheduling

Planners and schedulers usually start the scheduling process in traditional way by creating schedules containing several tasks down to the level of each individual work task. After that start with linking and creating the sequential logical relationships among those tasks as well as allocating the resources individually, and manually for each task.

However, BEXEL Manager`s scheduling engine uses advanced scheduling algorithms that were created to make it possible to create fully automated schedules and reduce the painful process of doing that manually like any other solutions to create a 4D schedule where the user needs to create it manually or semi-automated.

Intelligent scheduling engine enables the creation schedule based on construction methodology (the defining order of works execution) in the way the planners think about the execution process. Therefore, methodologies in BEXEL Manager gives the planer that way of thinking to represent the way of construction in methodologies levels as well as create relationships and dependencies between theses activity groups, which act as methodologies in BEXEL Manager. The intelligent scheduling workflow for any project is shown in Figure 43.

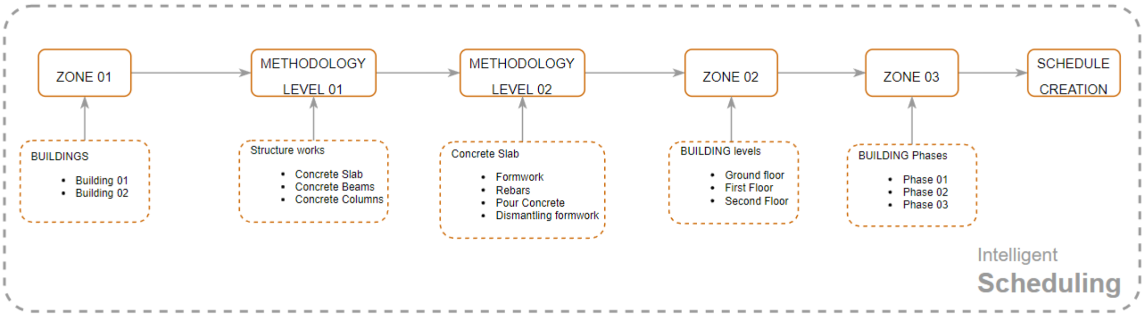


Figure 43 – Intelligent Scheduling workflow in BEXEL Manager. (‘BEXEL_Manager_Handbook-ENG’, 2020)

- Creating Zones

The spatial distribution of construction processes has to be properly scheduled on every project. Most of construction projects have different buildings in the same project, building storeys, and construction phases. All of them are considered as construction zones in this process. Therefore, the first zone level created should be the different buildings. Therefore, the zones (spatial project distribution) could be defined as a horizontal for the defined building and vertical for the building storeys as shown in the Figure 44.

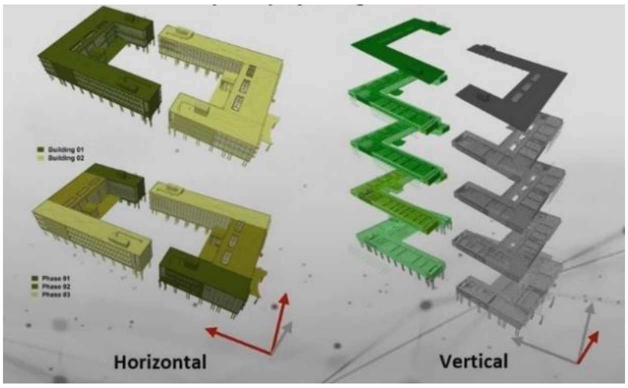


Figure 44 – An example for Zones Spatial project Organization provided by BEXEL. (Education and Webinars - BEXEL Manager, 2020)

- Creating the Methodology

The advanced way of creating the intelligent scheduling depends mainly on the created methodologies (the defining order of works execution) which represents the sequence in which are performed. The sequence of construction works and the relationships between various types of work can be defined by the user using methodologies. For instance, user specifies that the foundation works are performed after the excavation is completed. And the superstructure is completed after foundation completion. So, it is basically common construction logic that every scheduler uses.

Creating methodology is based on a certain classification which can be used for different similar projects. There are probably two main level of methodologies. At level one of methodology, the user can define the work packages and the relationships between them using logical sequential relationships. The user can enter one or more work packages at the second level of methodology and define the individual works and the relationships between each individual work that belongs to that work package.

For instance, structural work has been starting with column, beams, and slab. For the second level of methodology, user is able to define and enter every individual work in each group according to the construction logic sequence. For instance, in column work package, the work starts with the following sequence: assembly of formwork, rebars, pouring concrete and dismantling the formwork.

Another example of the first and second methodologies provided by BEXEL is shown in Figure 45 and Figure 46.

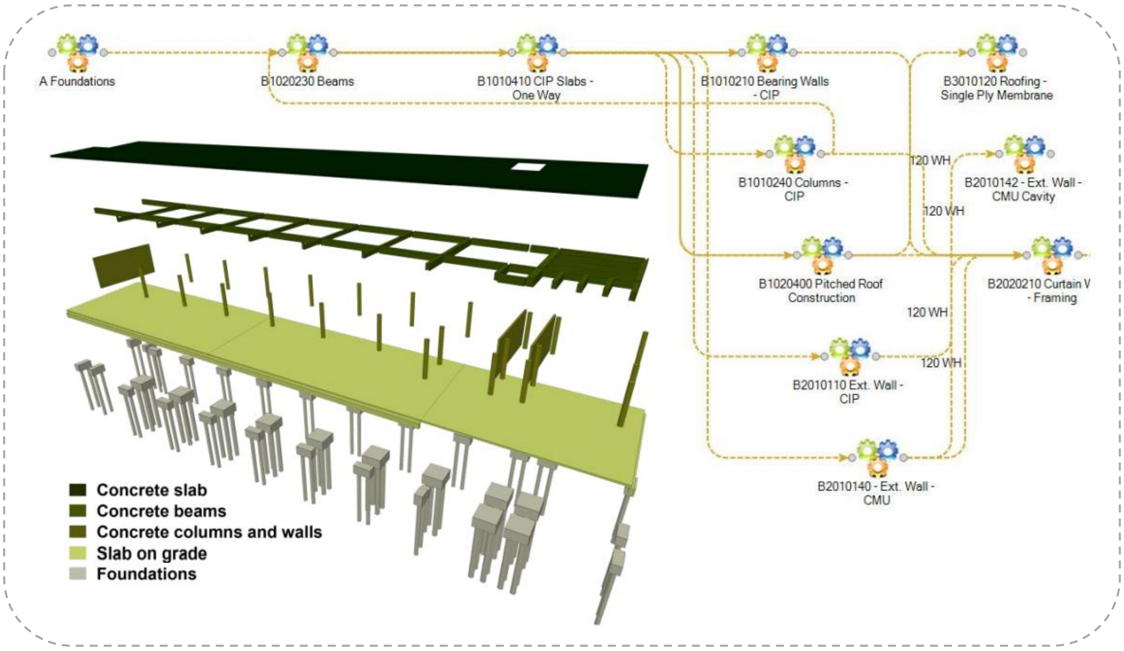


Figure 45 - Example of the first level of methodologies in BEXEL. ('BEXEL_Manager_Handbook-ENG', 2020)

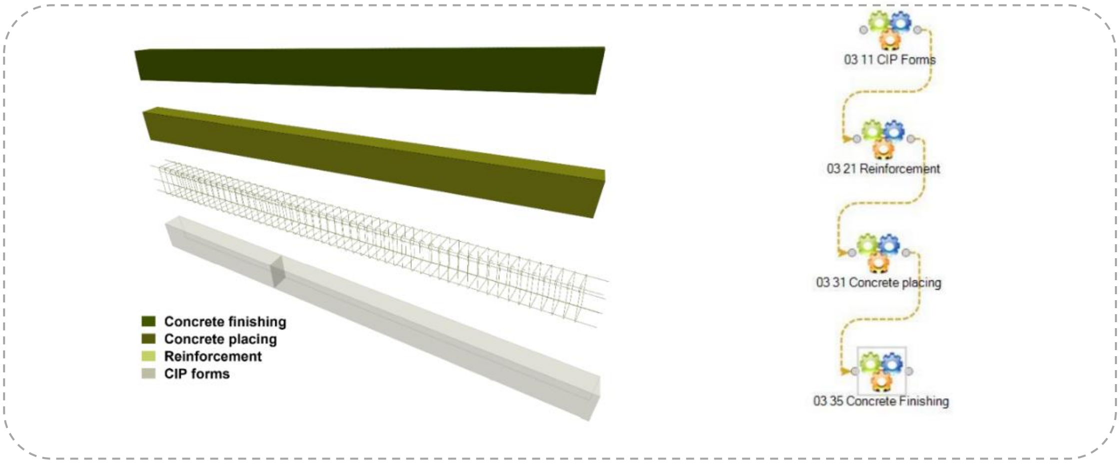


Figure 46 – Example of the second level of methodologies by BEXEL. ('BEXEL_Manager_Handbook-ENG', 2020)

- Creating Template

The schedule is generated through the creation templates. The template is a combination of the created construction methodologies and created zones which have been defined by the user before. The intelligent scheduling engine creates tasks and relationships automatically based on the created template.

Therefore, the first step in creating a template is the zone distribution by buildings if the project has more than one building. The next step is the created methodologies, starting with the level one of methodology. Methodology level two comes after. The next step is to define spatial zones which is already defined as zones. The building stories is defined as the vertical spatial distribution. The the construction sequence, which is represented in phases is defined as the horizontal spatial distribution. The user only has to put zones and methodologies in the right order and the schedule engine will automatically integrate all the rules defined by the user. The Figure 47 describes the integration between zones and methodologies.

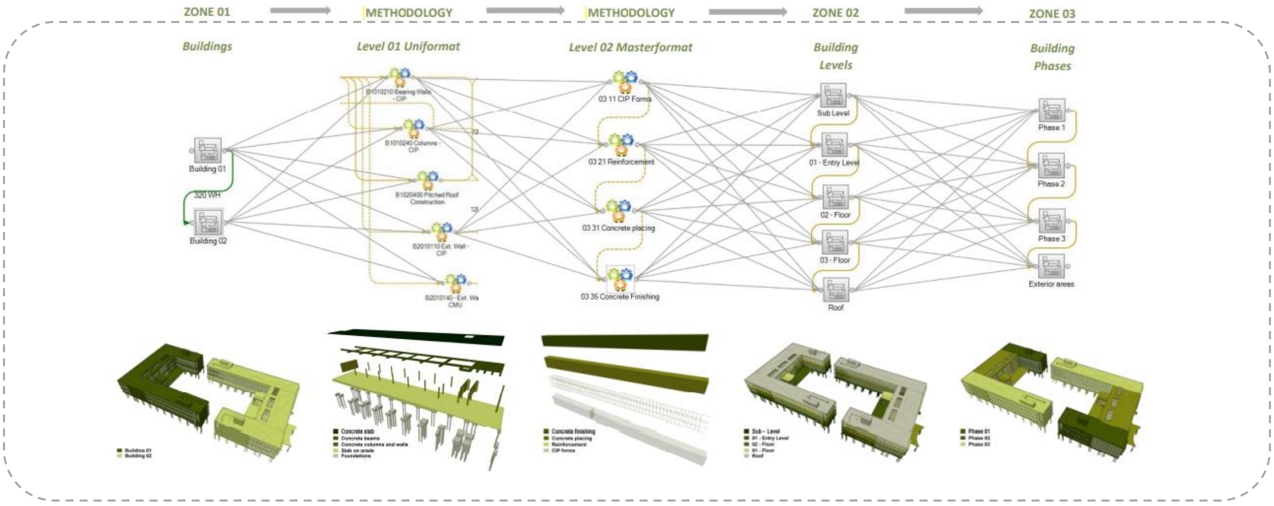


Figure 47 – The integration between the created zones and methodologies in BEXEL Manager.
('BEXEL_Manager_Handbook-ENG', 2020)

- Running the Schedule

After creating the template, the schedule could be created based on the created templates as explained before, as well as the user can optimize the schedule regarding to a needed scenario. The Gantt chart and line of balance will be provided according to the schedule. This process will be explained in detail with an example at creation template for the traditional model.

3.5.3.4. Assigning resources

Each activity needs a resource allocation to be carried out. The resources required to complete each component of the model will be assigned by the user. In BEXEL, resources must be assigned based on their cost classification. This will be explained in detail in the case study.

3.5.4. 4D comparative analysis

A 4D comparative analysis will be created once the proposed workflow has been used to create the 4D models for both the traditional model and the CREE model. This comparison will give the answer to the query of how long it will take to finish the structural work in the two types of construction, and how many work hours will be needed. The analysis will be done in accordance with the resource allocation to emphasize the amount of time it takes to finish the project and the benefits of using the CREE structure over the traditional method.

4. CASE STUDY

A specific case study will be used to apply the developed framework. This case study will be built using prefabricated CREE system. The key idea here is to consider the scenario in which this building is constructed conventionally and then quantify the advantages of using the CREE system over the conventional construction, as that the two ways of construction were previously discussed in Chapter 3. This case study was proposed by CASAIS, a construction company based in Portugal. CASAIS is the main consultant and contractor for this project.

4.1. Case study overview

Guimarães will have a hotel built in modules, called B&B Guimarães. It is combined with hotel and housing apartments. The project has a base level or podium that uses reinforcement concrete structural elements and two main buildings with 4-storey conceived with the CREE system. One of them is a hotel (brown in Figure 48) and the second one comprises housing apartments as shown in Figure 48, in green color.

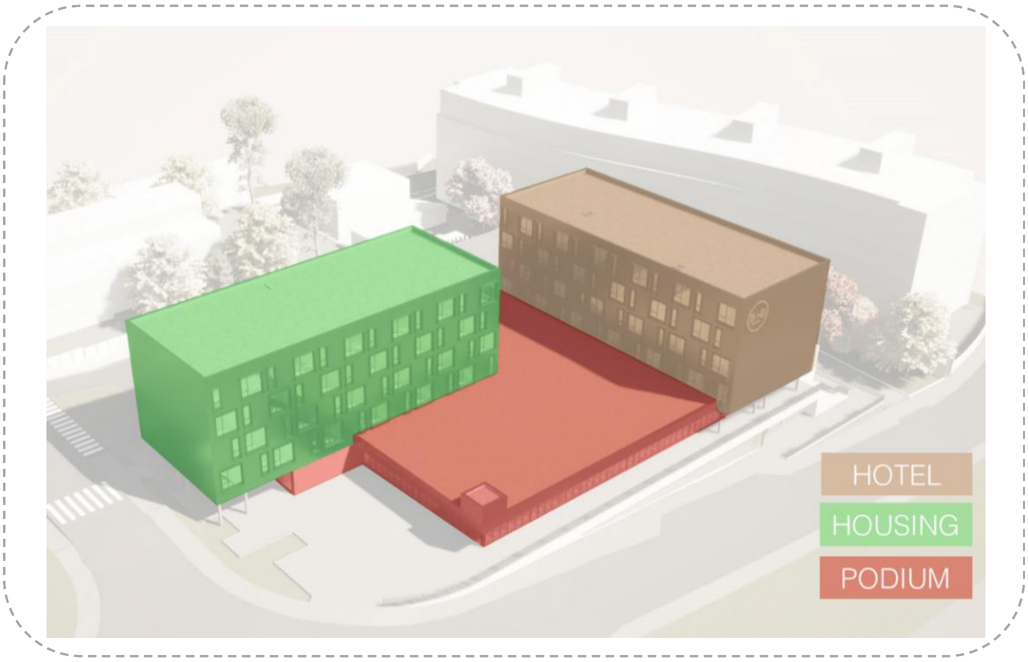


Figure 48 – The main zoning of the suggested case study.

The following general facts for the case study are the following:

-Contractor/Consultant: CASAIS Group

-Client: B&B Hotels

-Location: Guimarães, Portugal

-GFA: 8.300 m^2

-Height: 20 m

-Total floor area: 7.200 m^2

-CREE system area: 4.100 m^2

4.2. The scope of work

The two 4-storey buildings are the main scope of work at the superstructure stage only, focusing only on the structural skeleton of the two building and their exterior envelop. By using CREE elements, this building is being prefabricated in real life. For comparison purposes, the method of construction is changed so that the buildings are built with reinforcement concrete slabs, columns, and beams with a similar disposition to that of the CREE elements. The framework will be applied in these two ways of construction. Figure 49 highlights the scope of work (buildings in brown).

Figure 49 – The scope of work of the case study.

Therefore, the company proposes this case study to apply a 4D analysis on it. The 3D model for the CREE system is proposed by CASAIS. The traditional model must be developed before applying the 4D framework to it.

The objective is to measure the advantages of utilizing one method over the other in the scope of the 4D analysis. The traditional model is used first, followed by the CREE model. By implementing the same two related models, a 4D comparison analysis is performed as the conclusion to compare using conventional construction methods on site against using CREE elements in terms of time and resources use.

4.3. Traditional way case study

4.3.1. 3D BIM MODEL

The traditional model is created using Autodesk Revit, by using reinforcement concrete elements for the superstructure elements such as reinforced slabs, columns, and beams. The 3D model is created so that a 4D model can be associated afterwards. Therefore, deciding the level of information need is crucial to start the process of 4D modelling. Assigning the Work Breakdown Structure (WBS) for the elements is the first step after creating the 3D model.

Four levels of WBS were created. The first level is the project name, in case there are different projects; the second level is the building, if there is more than one building; the third level is the discipline, such as structure, architecture or others, in which the element belongs; the fourth level is the category of the element created. For instance, if we consider the exterior wall represented in Figure 50, level one is B&B project, level two is Hotel as this wall is in the hotel building, level three is ARQ, as it is an exterior wall, and level four, in this case, is Walls.

Figure 50 – Level of information need for the exterior wall on the case study, in Autedesk Revit.

All elements in the two buildings should be correctly assigned to this WBS classification. This WBS levels will help the 4D scheduler in creating an intelligent Custom Breakdown Structure (CBS) and any Custom Selection Sets (CSS) with queries regarding to these WBS levels as it was explained before in Chapter 3.

The way of assigning these parameters is defined as the following and is also shown in Figure 51:

- Create the shared parameters file with levels of WBS to be used in different projects.
- From project parameters, create a project parameter by using the shared parameters.

- Choose LEVEL01_PROJECT and select the categories that need to be assigned to that parameter.
- Repeat this process with other levels of WBS with determined categories.

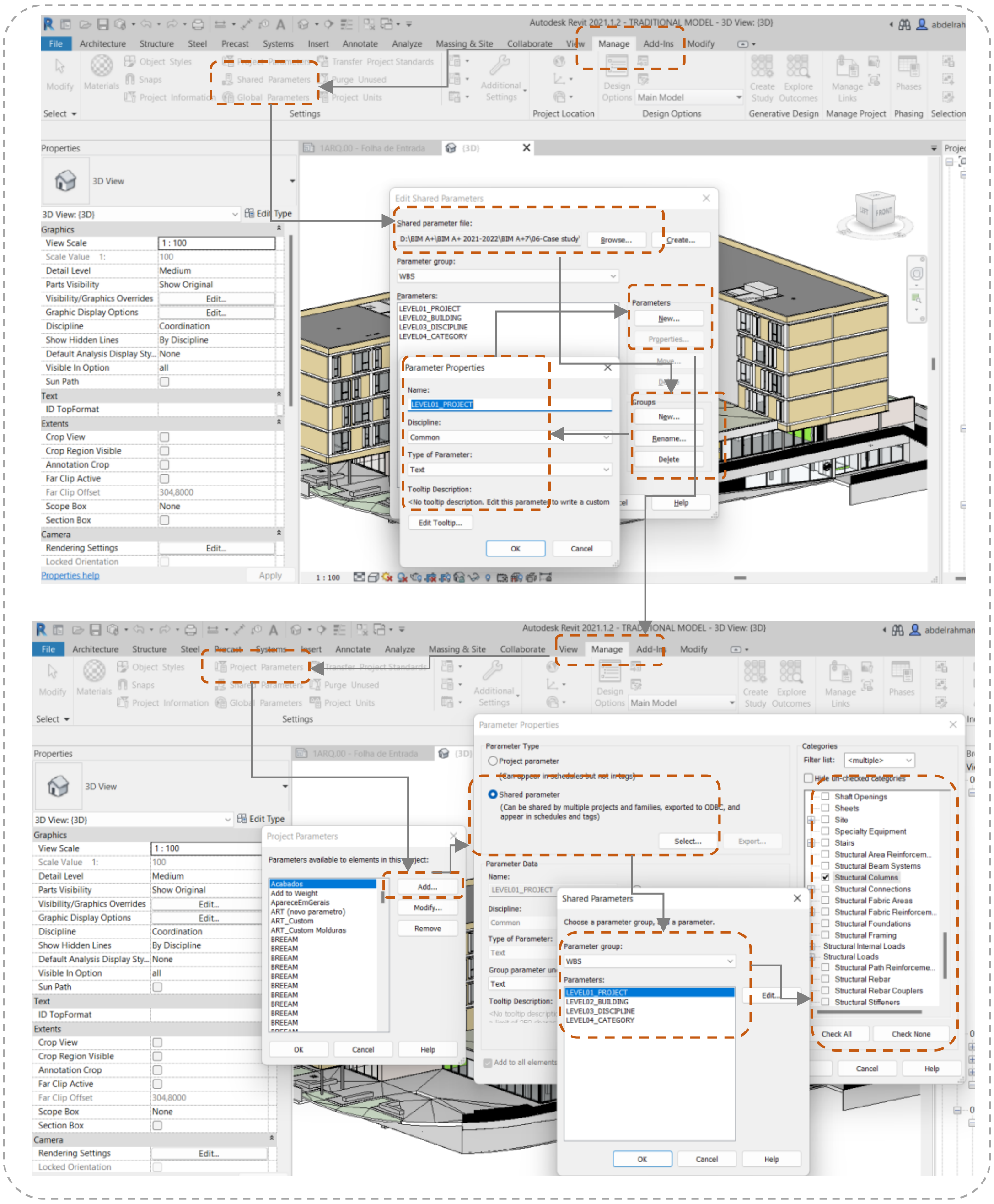


Figure 51 – The workflow for adding the WBS parameters to the elements.

4.3.2. Model checking and IFC

Model checking is the next step, to review and guarantee that all elements have been assigned to the WBS levels and that the level of information need has been defined. Then, exporting the IFC file with defined export settings and the user-defined property sets, to ensure that the added parameters are defined as a Pset_WBS in any IFC viewer, such as the software used for 4D modelling and simulation, BEXEL Manager. This part was explained before in section 3.5.2. By using the text file, the property names as displayed in Revit are on the left side and the property set names that need to be inserted by the user as displayed in the IFC property set, are on the right side. Between them, is the data type, which is Text in this case, as shown in Figure 52. The IFC is exported with the chosen parameters by specifying the export parameters in a text file as a user-defined property set, as is shown in Figure 53Figure 52.

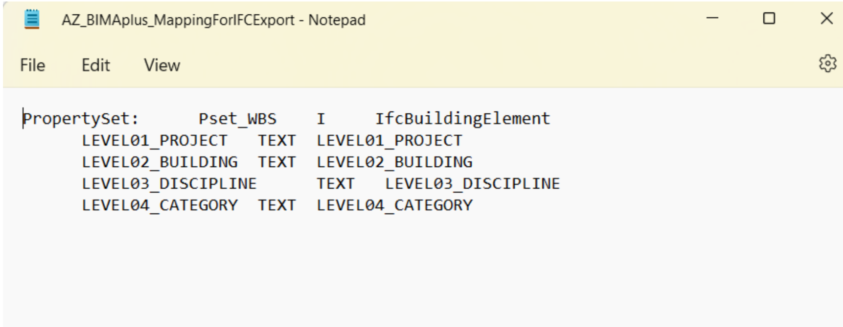


Figure 52 – The text file used for the user defined property set for the traditional model, in Autodesk Revit.

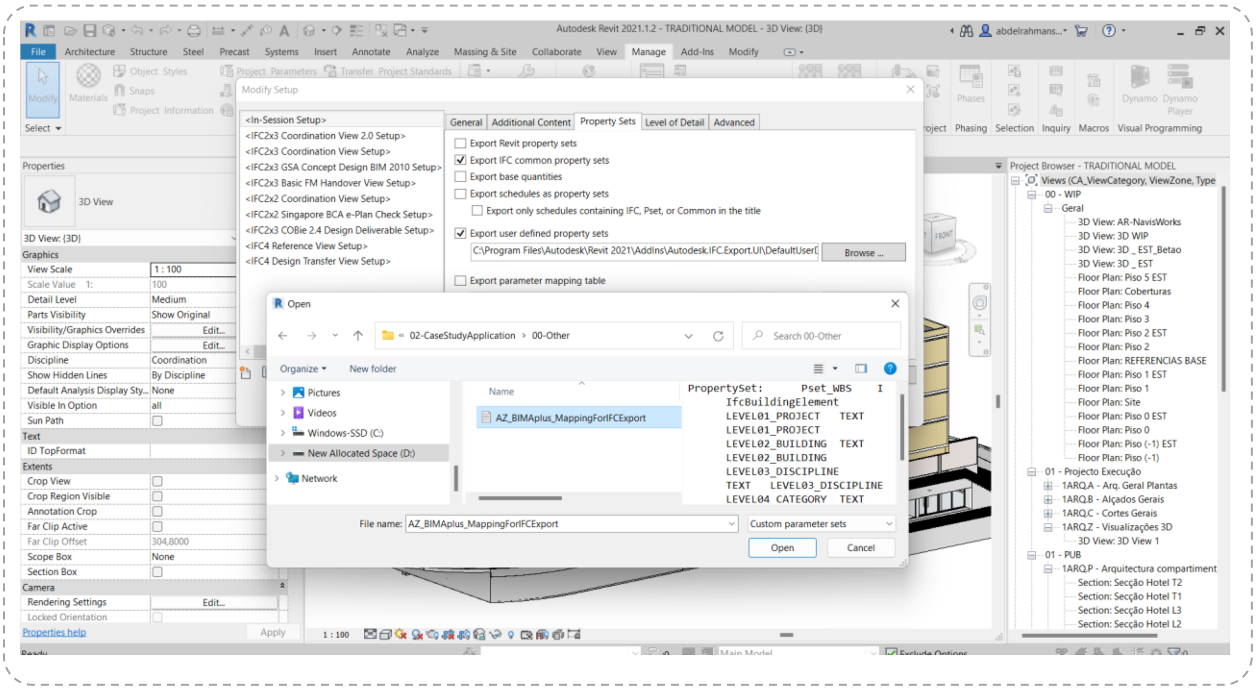


Figure 53 – The IFC export using the user defined property sets text file.

4.3.3. 4D BIM model

BEXEL Manager is an IFC-certified BIM software solution for construction project management that combines the most important 3D/4D/5D BIM uses into a single software interface and allows the user to optimise digital workflows. Therefore, this case study is set in BEXEL in order to get the advantages of using this software and take the best possible decisions regarding the obtained 4D analysis from applying the framework on both ways of construction, the traditional construction and the CREE system as prefabrication construction.

Firstly, import the IFC file of the traditional model to start the 4D modelling process. It starts with making CBS based on the defined WBS property sets defined in the Revit file. Secondly, the user can create some custom selection sets in a smart way. These CSS will assist the modeller in creating automated schedules for defining the spatial distribution zones, by using the intelligent scheduling, which generates sequential tasks linked to the BIM elements. Figure 54, shows a selection for the hotel building, that will help the modeller in creating spatial distribution and the sequence of work, at the intelligent scheduling phase. It is created from a defined query by using the property of LEVEL02_BUILDING to be equal Hotel.

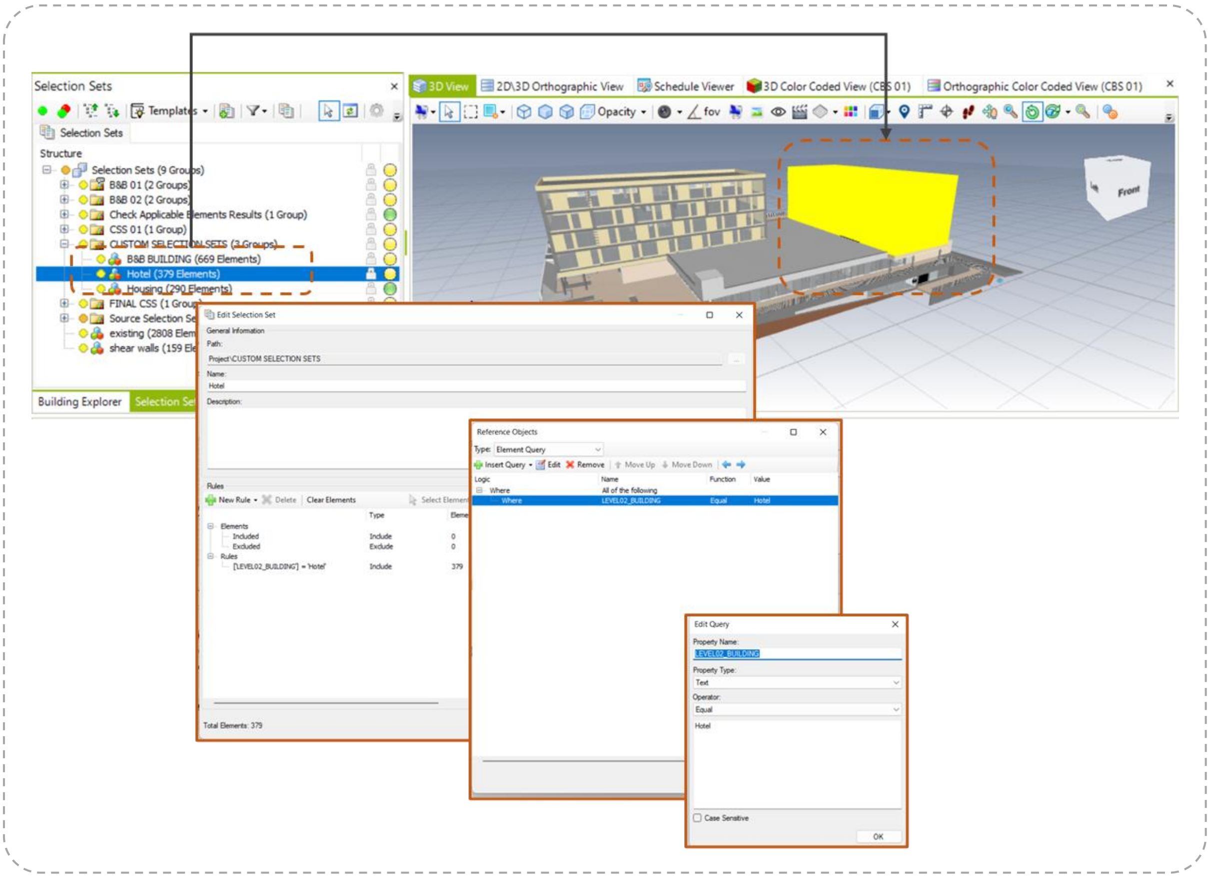


Figure 54 – Selection set created for the hotel building.

Meanwhile, the user should check the level of information needed in BEXEL Manager, as an IFC viewer. The user can click on any element in the model, such as, for example, the structural wall shown in Figure 55, and verify that the Pset_WBS is imported, readable, and attached to that element. Figure 55

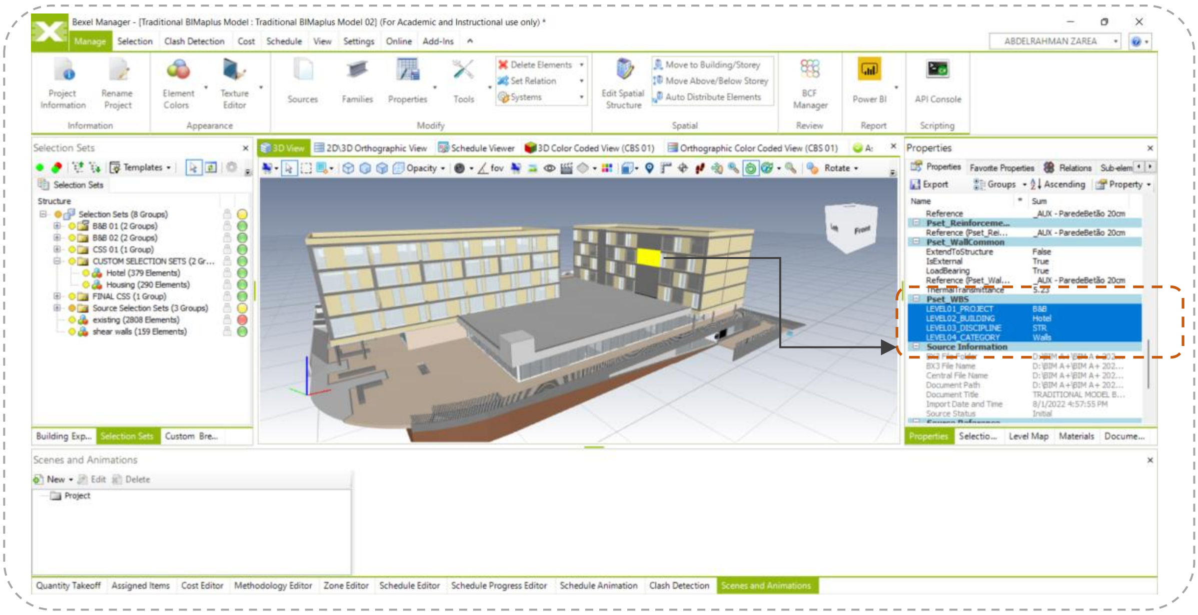


Figure 55 – The level of information need displayed in BEXEL Manager.

4.3.3.1. Custom Breakdown Structure CBS

The first significant step in BEXEL Manager is to create a Custom Breakdown Structure (CBS). The CBS should be sorted from level one to level four, starting with the B&B project and moving down to the categories and families' levels. By going to the custom breakdowns in the interface, a new CBS is created, select the building, and start to put defined property rules starting with the property name LEVEL01, LEVEL03, LEVEL04, and then add another defined rule that has a shortcut "family" as shown in Figure 57. LEVEL 02 will be used to define the spatial distribution through the creation of zones at the intelligent scheduling stage in order to create the sequence of work between the two buildings.

However, using BEXEL Manager has the advantage of adding any new properties under any group of property sets if the modeller needs any additional properties that are missing for the model. That could happen as shown in Figure 56.

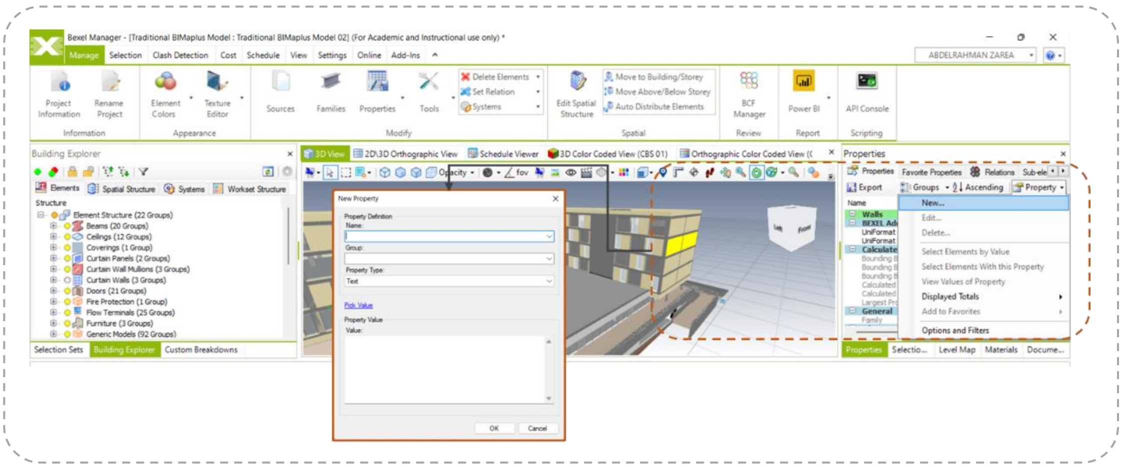


Figure 56 – Adding new properties to element in BEXEL Manager.

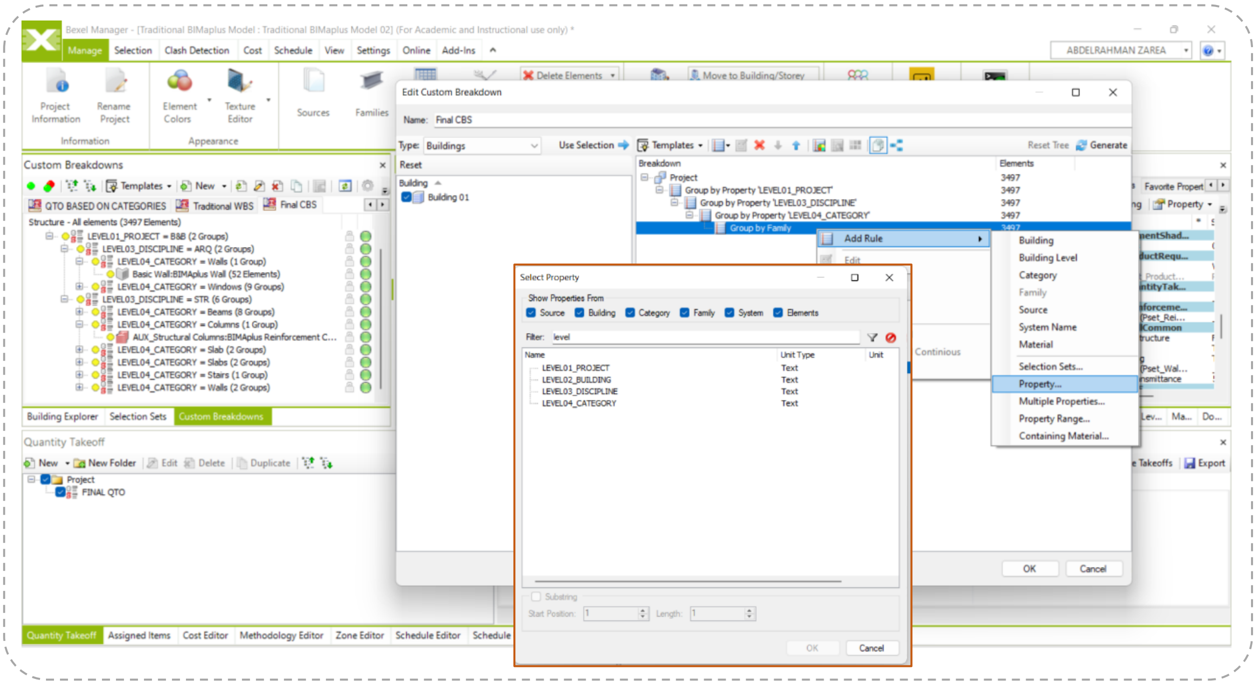


Figure 57 – The way of creating a custom breakdown structure with adding rules, in BEXEL Manager.

The purpose of creating a CBS is to categorize and sort the elements according to the created WBS levels. For instance, it is possible to select all structural building elements, such as slabs, columns, and beams. As well as the user can select elements that are sorted and created from the CBS by the defined properties, such as selecting all slabs or columns, as shown in Figure 58. The same is true for architectural elements like exterior walls and windows. The created CBS is shown in Figure 59 with colour coding for each discipline.

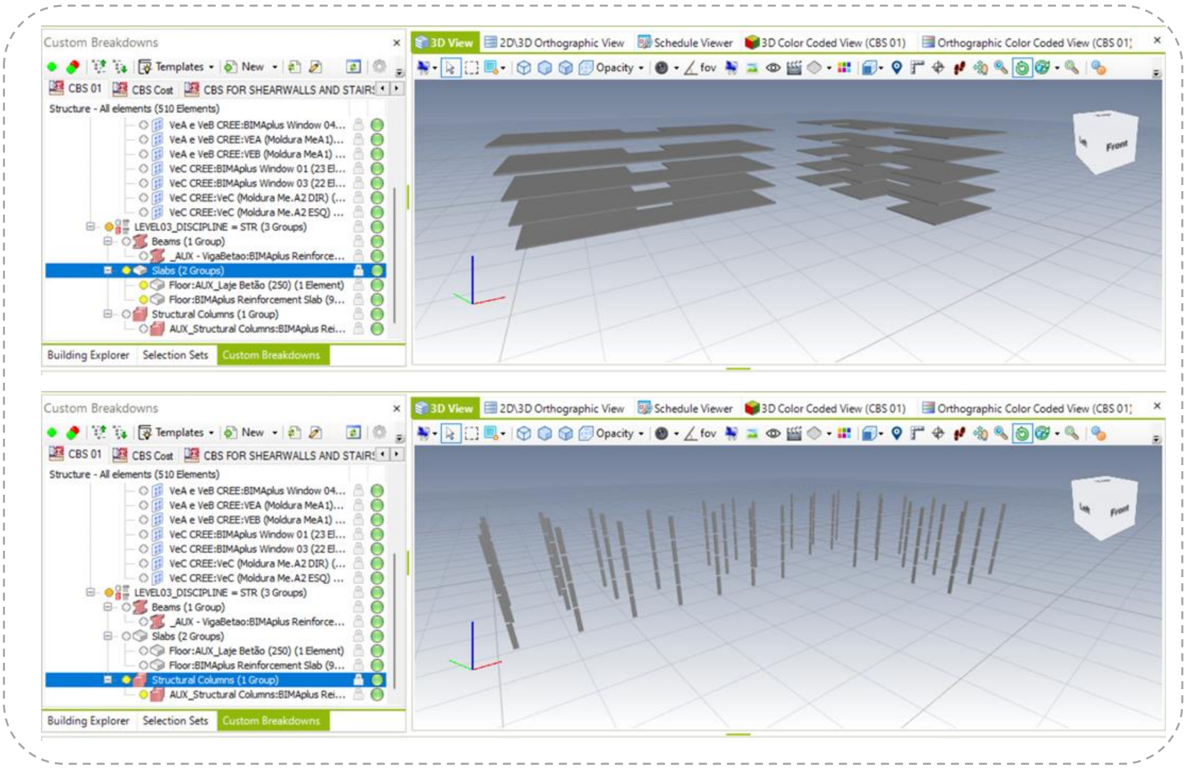


Figure 58 – Selecting the structural slabs only or columns from the created CBS.

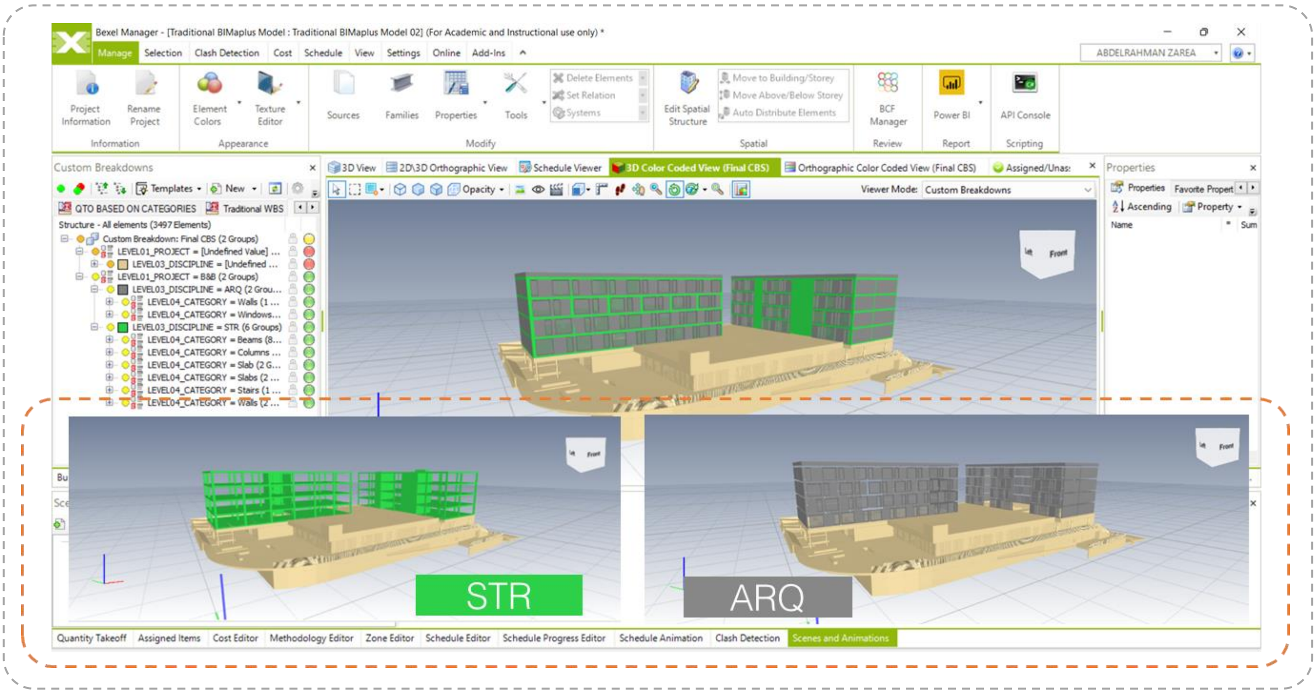


Figure 59 – The color coding for the created custom breakdown structure, in BEXEL Manager.

4.3.3.2. CSS, QTO, and Cost Classification

The purpose is to create an automated schedule by using the intelligent scheduling engine provided by BEXEL. Before starting the process of intelligent scheduling, some smart custom selection sets, the quantity taking off (QTO) and cost classification should be defined.

- To create CSS

From the building explorer, a selection set is created for the hotel building and for the housing building. The creation wizard is used to establish a new CSS from custom breakdown, and selecting the created CBS, as shown in Figure 60.

- To create the QTO

From the QTO editor, a new QTO is established, based on the previously created CSS, and adding the quantity units in accordance with the quantification's units for elements like volume, area, and count, as shown in Figure 61.

- To create the Cost Classification

From the cost classification editor, a new cost classification is established based on the previously created QTO, and making checks on the cost of items that are linked to the model elements, since they are created from the QTO, which is already linked with the BIM model. The cost classification created from the QTO is shown in Figure 62.

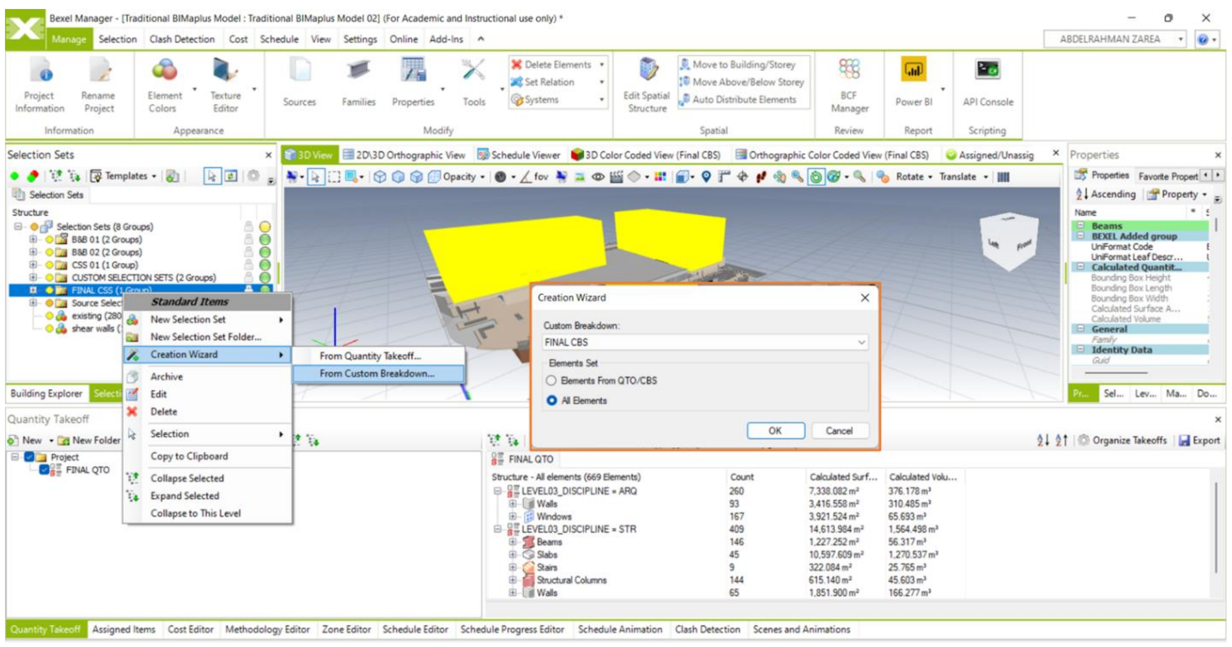


Figure 60 – Creating custom selection sets from created custom breakdown structure, in BEXEL Manager.

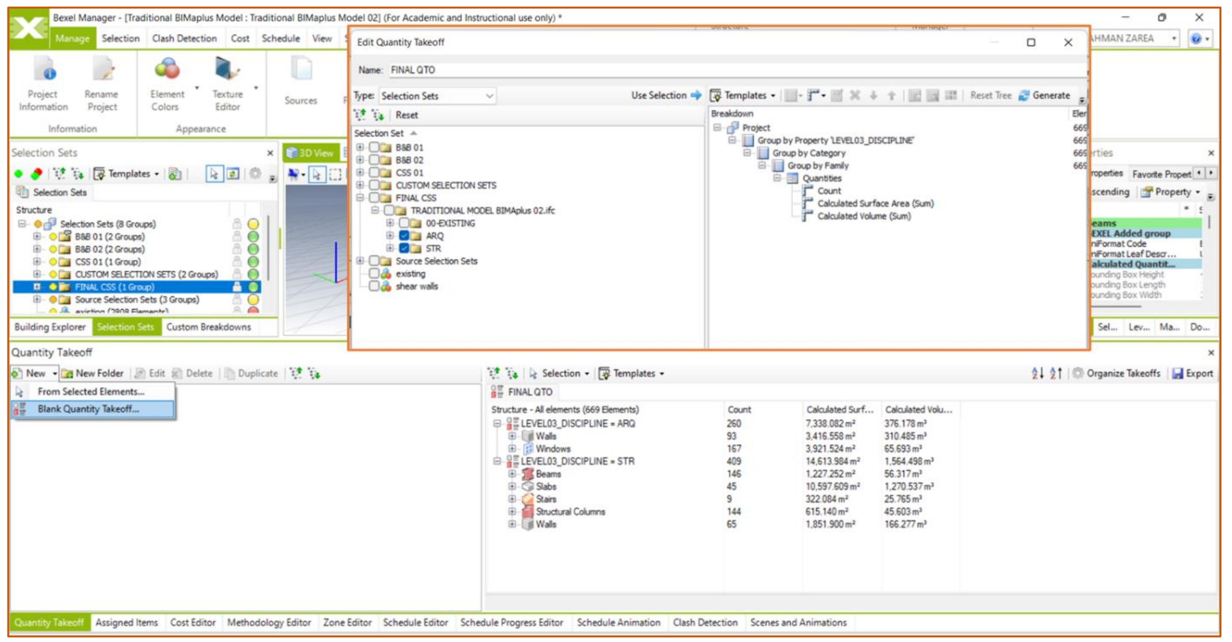


Figure 61 – Creating quantity taking off based on the created custom selection sets, in BEXEL Manager.

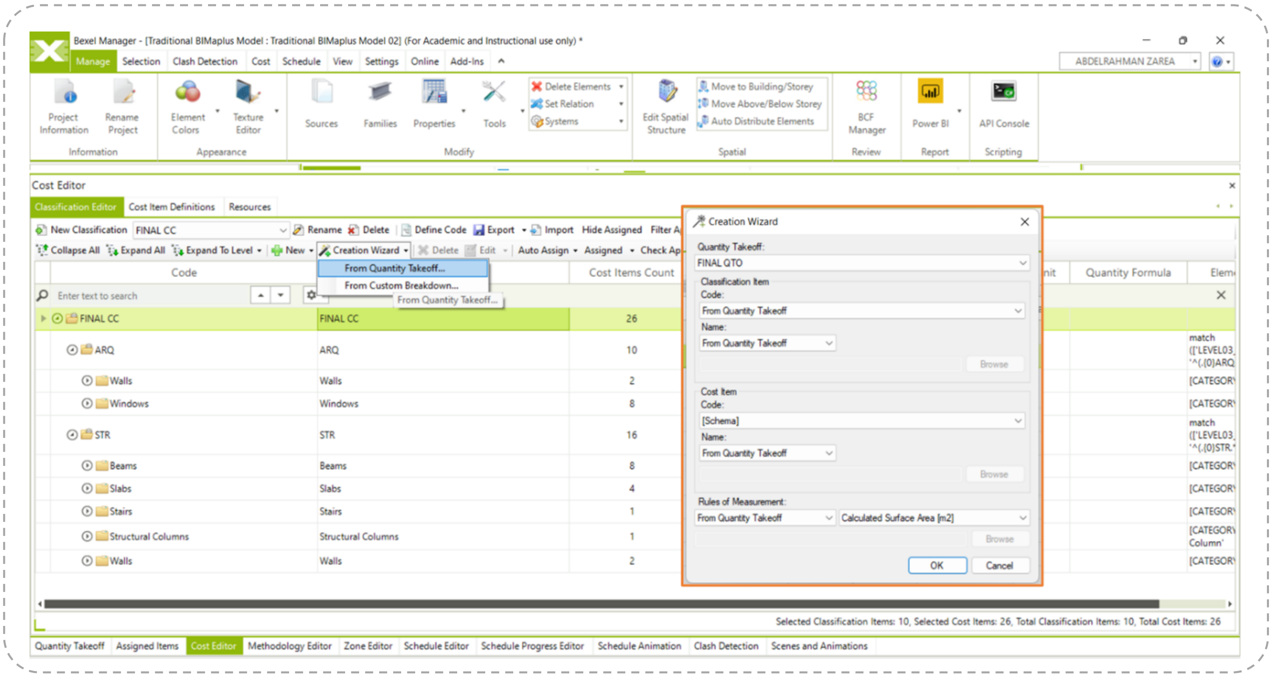


Figure 62 – Creating new cost classification from quantity takeoff, in BEXEL Manager.

4.3.3.3. Intelligent scheduling

As explained before, in section 3.5.3.3, the intelligent schedule engine needs to create the spatial zones, methodology levels, and the template before running the new schedule. The scope of work will be limited to the structural works of the two 4-storey buildings, hotel and housing, and the respective exterior envelop.

- Creating zones

By specifying spatial zones and relationships between the elements, the vertical spatial distribution is for the building stories and the horizontal spatial distribution is for the building construction sequence. The distribution and the sequence of work will consider these created zones.

Through the zone editor in BEXEL manager software, new zones are created based on the building's stories and the relationship specified between each one, beginning with the ground level and moving through the first floor, second floor, third floor, fourth floor, and roof floor. as shown in Figure 63.

According to the predefined construction sequence, a second zone needs to be created. A smart selection set must be made before this stage for the two buildings, hotel and housing. It is created from a defined query regarding the properties that the elements have. With the property of LEVEL02 BUILDING, the two CCS from that query will be defined, one for the hotel and the other for the housing. The next step in the zone editor is to establish a new zone for the phases, choose these selection sets, and specify the relationship between them, as shown in Figure 64.

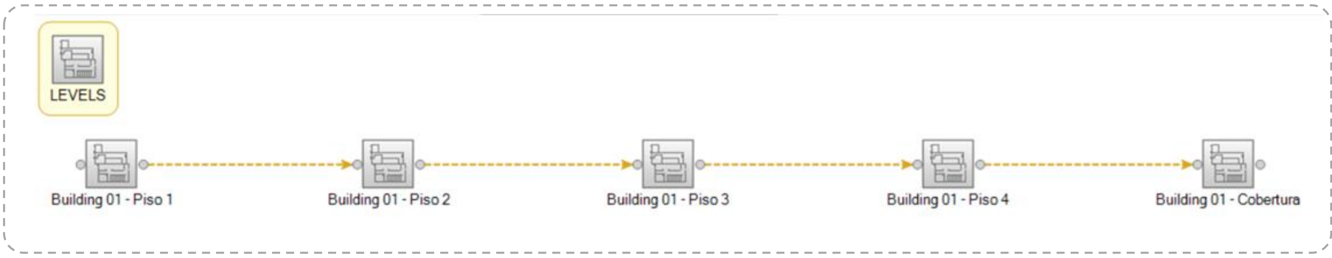


Figure 63 – The zones created for the Building Stories, in BEXEL Manager.

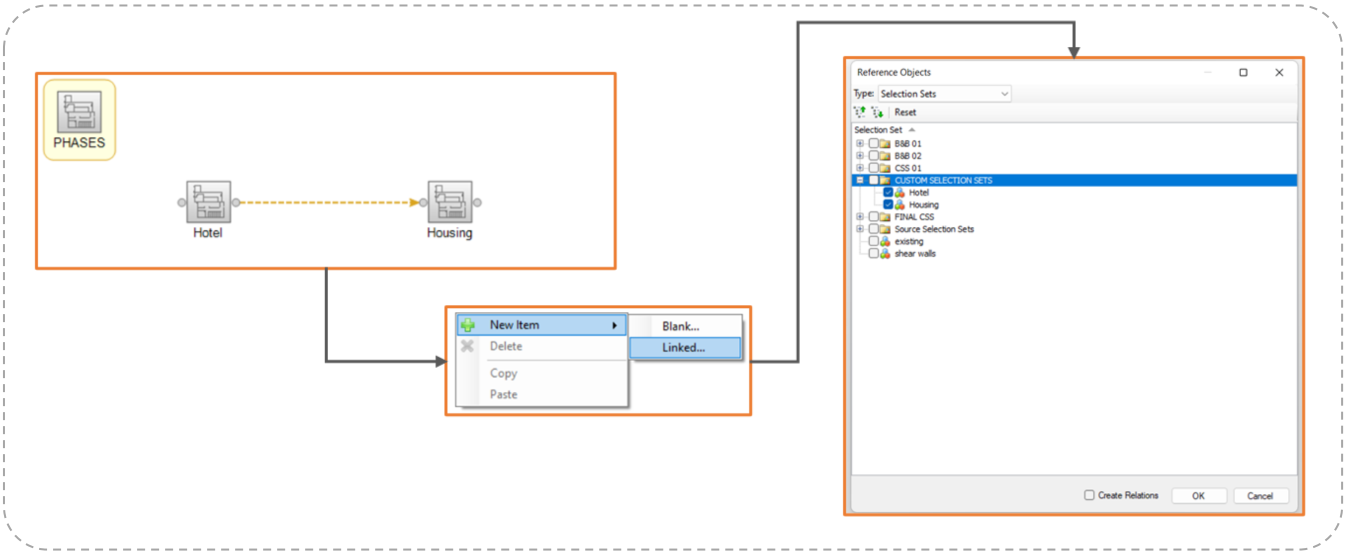


Figure 64 – The zones created for the construction sequence, in BEXEL Manager.

- Creating the methodology

Regarding the case study, there are three levels of organizing the construction elements for creating the order of execution. Level one divides the set of works between structural and architectural. The architectural works come after the structural ones, as shown in Figure 65. The second level is defined by grouping structural activities and assigning logical relationships among them, based on the logical sequence of construction. For instance, in the case study, the structural group of work consists of the execution of reinforced concrete slabs, beams, columns, shear walls, stairs, and the user needs to add logical relationships between them, as shown in Figure 66. Level three of the methodology is the relationship between the individual works inside the group works, such as shown in Figure 67, which describes level three for each group work in the level two.

Furthermore, the user must define the relationships between cost items and elements. The intelligent engine considers the relationships between tasks to create a certain schedule. If there are any gaps between two tasks, they must be defined as well, or the intelligent schedule will ignore them. For instance, to execute the concrete columns on site, it is necessary to wait seven days after casting for curing the slab. Therefore, the user needs to put in a five-day lag considering the work calendar with two days off per week. The relationships between structural works with time lag is highlighted, as shown in Figure 66.

Figure 65 – Level one of the methodology, in BEXEL Manager.

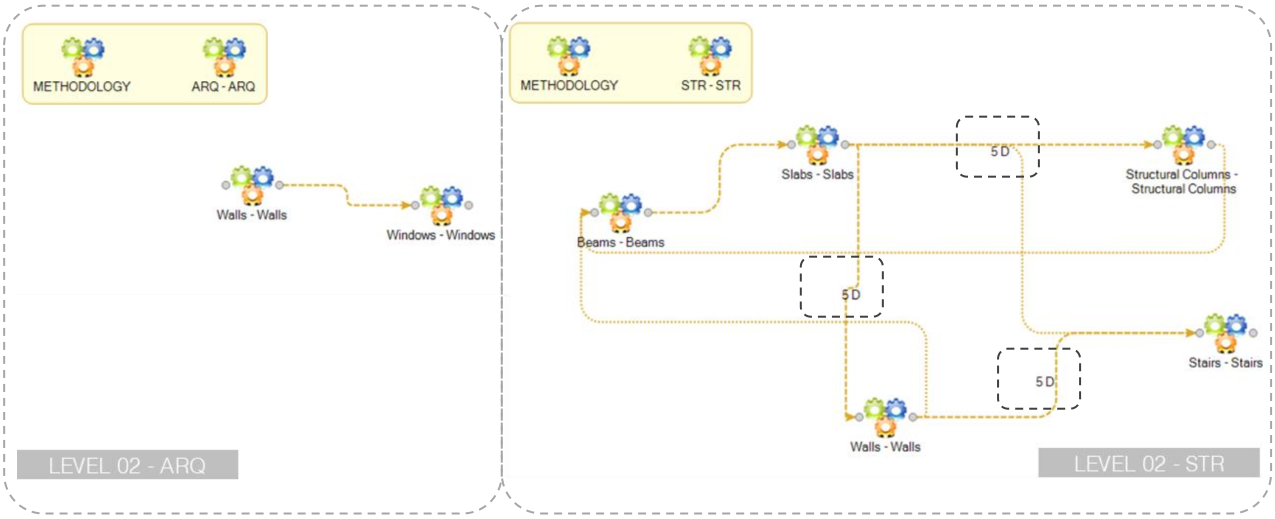


Figure 66 – Level two of methodology for group works, in BEXEL Manager.

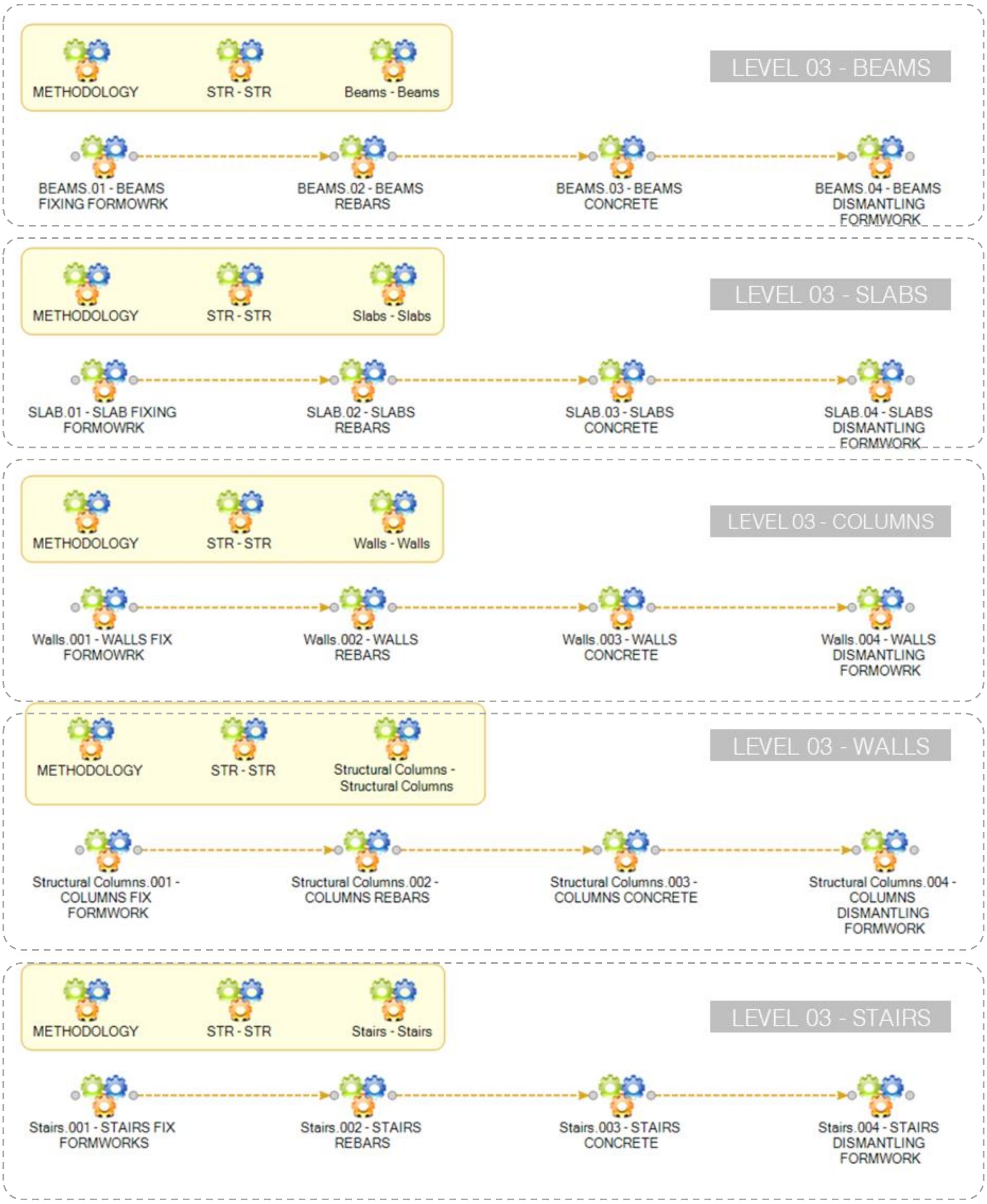


Figure 67 - Level three for each group work defined in level two, in BEXEL Manager.

- Creating the template

This is the final step before running the schedule. From the schedule toolbar, the user can create the template. From new, by selecting the created zones and methodologies, the template can be created. Figure 68 shows how the created zones are inserted into the template. Meanwhile, Figure 69 shows how the created methodologies are selected in the template.

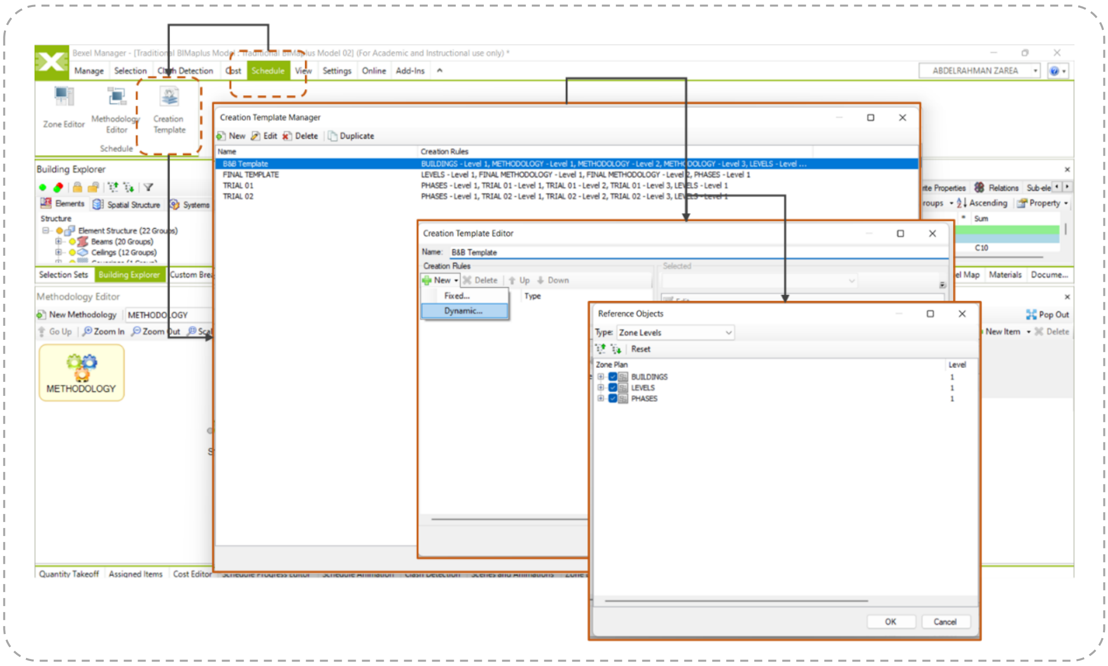


Figure 68 – Workflow to insert the created zone in the template, in BEXEL Manager.

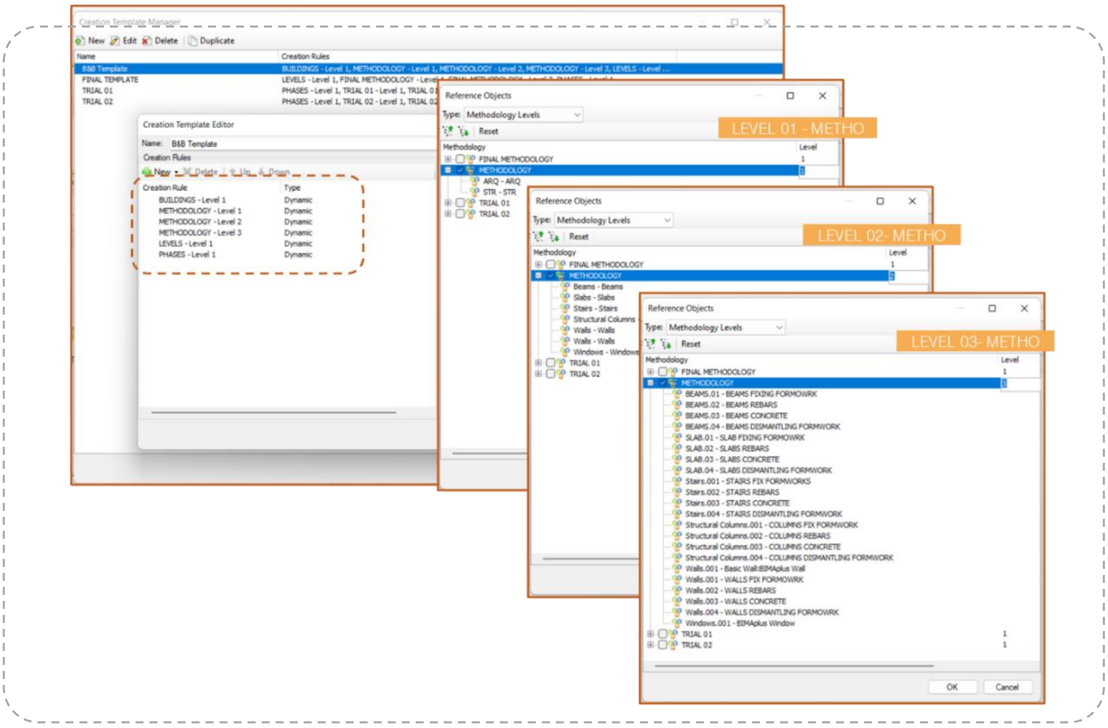


Figure 69 - Workflow to insert the methodologies in the template, in BEXEL Manager.

- Running the schedule

Through the schedule editor, the first step is to create a new schedule, then name this schedule and assign it to the active cost version. With the creation wizard, the schedule can be generated through the pre-created template. Figure 70 describes the sequence of creating the schedule based on the template created by the user.

The Gantt chart and the line of balance show the sequential relationships between tasks that are generated according to the relationships between methodologies. The user has to check if the sequential tasks are in an appropriate sequence by using the schedule simulation. If there are any errors in the sequence of work, the user needs to check again the relationships between the methodology items. Figure 71 shows the sequential relationships, the successors and predecessors, for one selected task.

Moreover, the user can have a Gantt chart and LOB for the created schedule. The Gantt chart and a LOB are displayed as shown in Figure 72 and Figure 73 respectively.

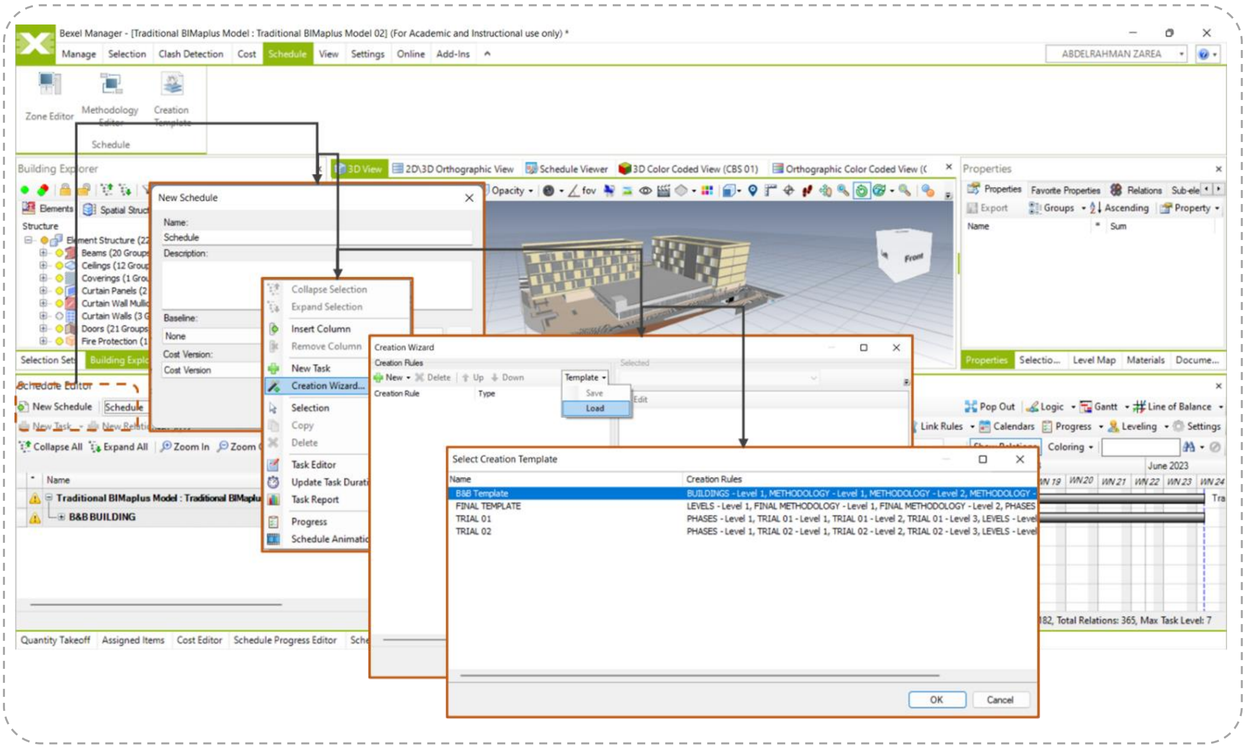


Figure 70 - The sequence of creating the schedule based on the template defined by the user, in BEXEL Manager.

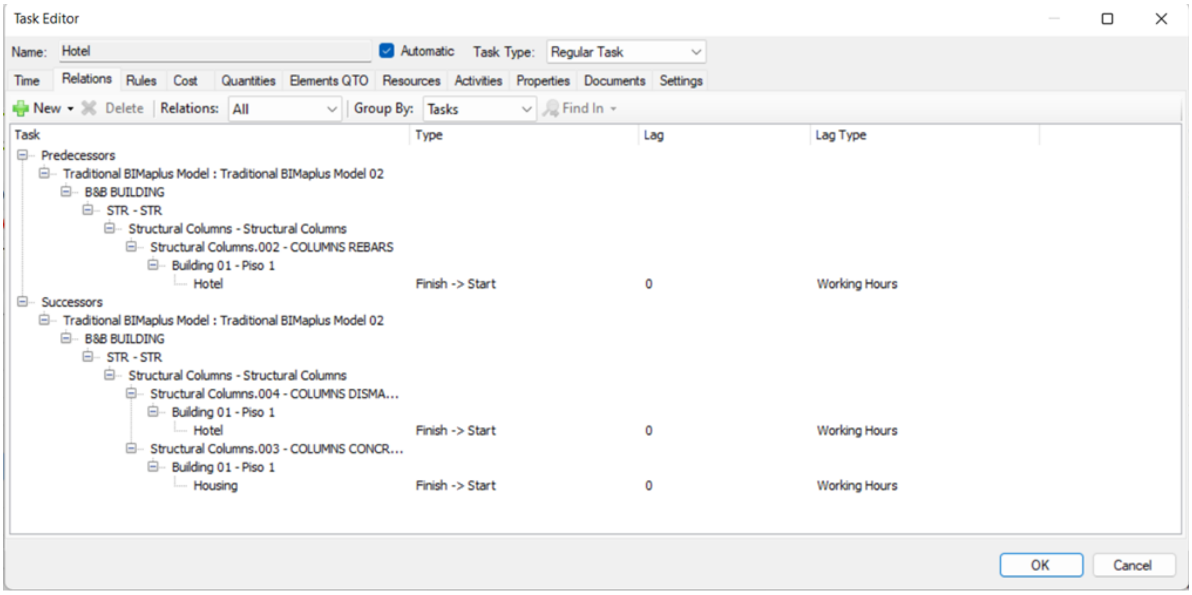


Figure 71 – Automatic sequential relationships, the successors and predecessor, for one selected task, in BEXEL Manager.

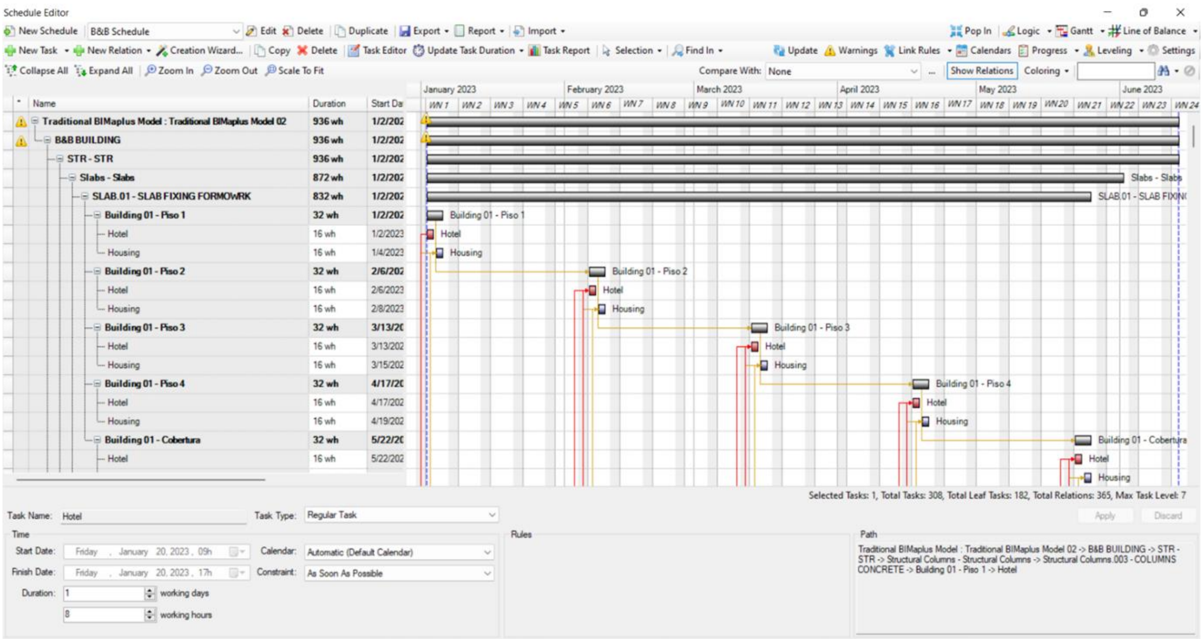


Figure 72 – Automated schedule and Gantt Chart, in BEXEL Manager.

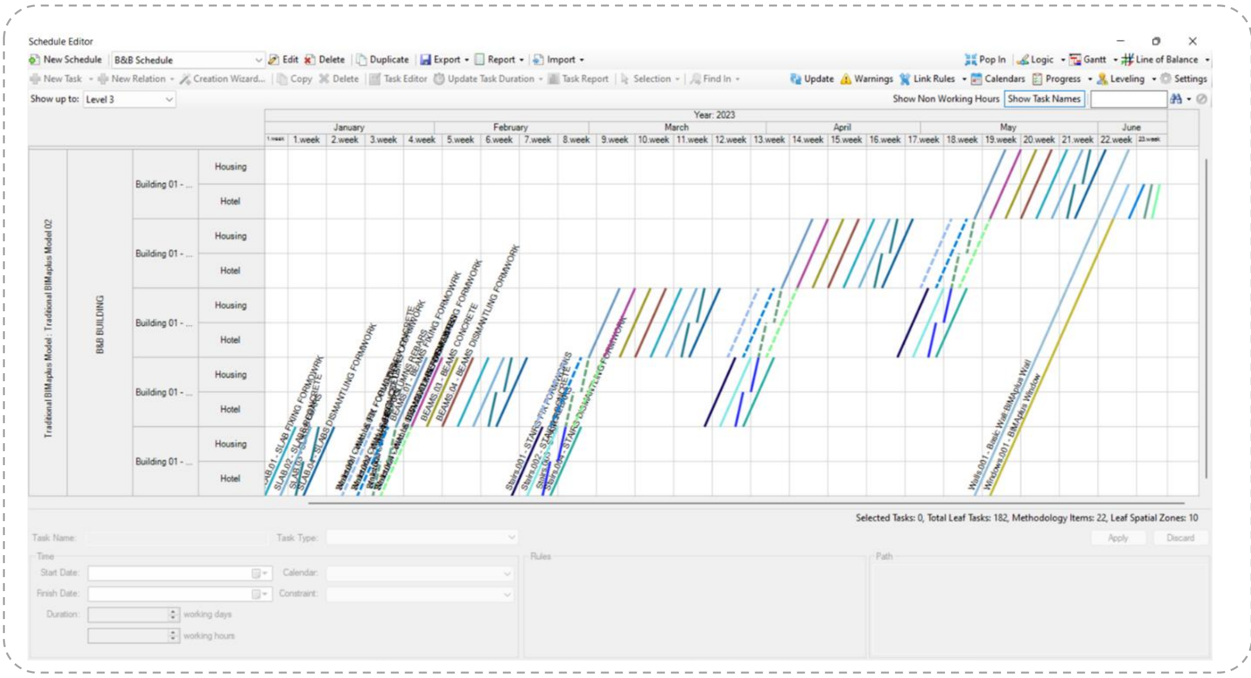


Figure 73 –Line of Balance for the created schedule, in BEXEL Manager.

4.3.3.4. Assigning resources and what if scenario

The project tasks need resources to be carried out on site. These resources depend on specific aspects of each task. The "what if" scenario needs to be considered. The resources that will be used for the Hotel building will be the same resources of equipment and crews for the housing building as well. The scenario is that the hotel will be constructed first, and the housing building will come after.

In BEXEL Manager, the resources need to be defined first by the user. The user will insert each resource need while defining the resource type, either if it is labour or equipment. For example, the quantity type and the quantity unit. To add one resource in BEXEL Manager, from the cost editor, by resources, add a new resource, and define the type of resource and its description. Figure 74 and Figure 75 show, respectively, the way of creating new resources in BEXEL Manager and the list of resources created for the traditional BIM model developed in the case study.

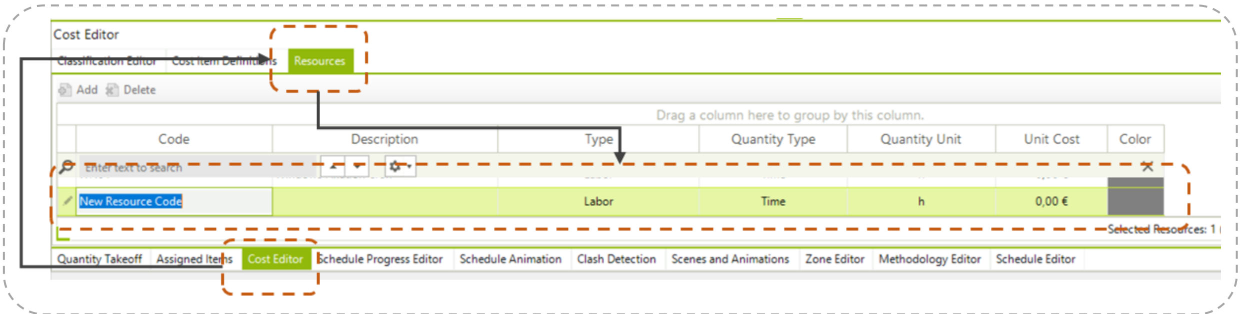


Figure 74 – The workflow to create a certain resource in BEXEL Manager.

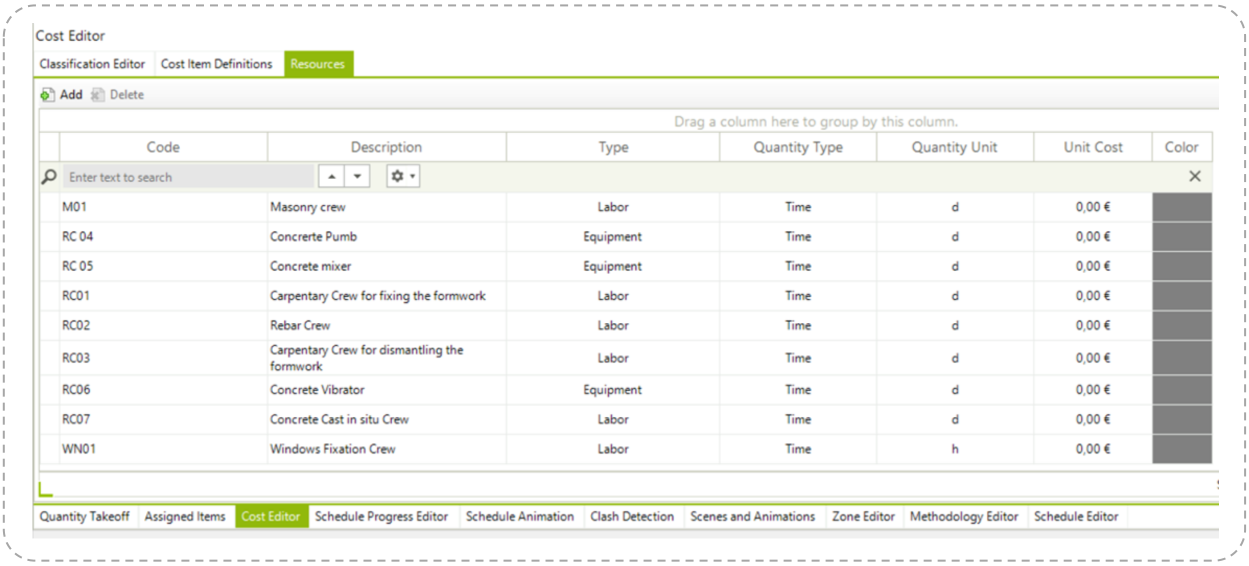


Figure 75 – List of resources defined by the user for the case study, in BEXEL Manager.

However, when the resources are created by the user, they are not assigned to the tasks yet and the next step is to allocate them to the task. That will happen by going to the cost items through the cost classification in BEXEL Manager which will allocate each cost item to its resources, as shown in Figure 76. The result is that the resources will be allocated automatically to the tasks by updating the schedule, since the schedule is created through the intelligent engine.

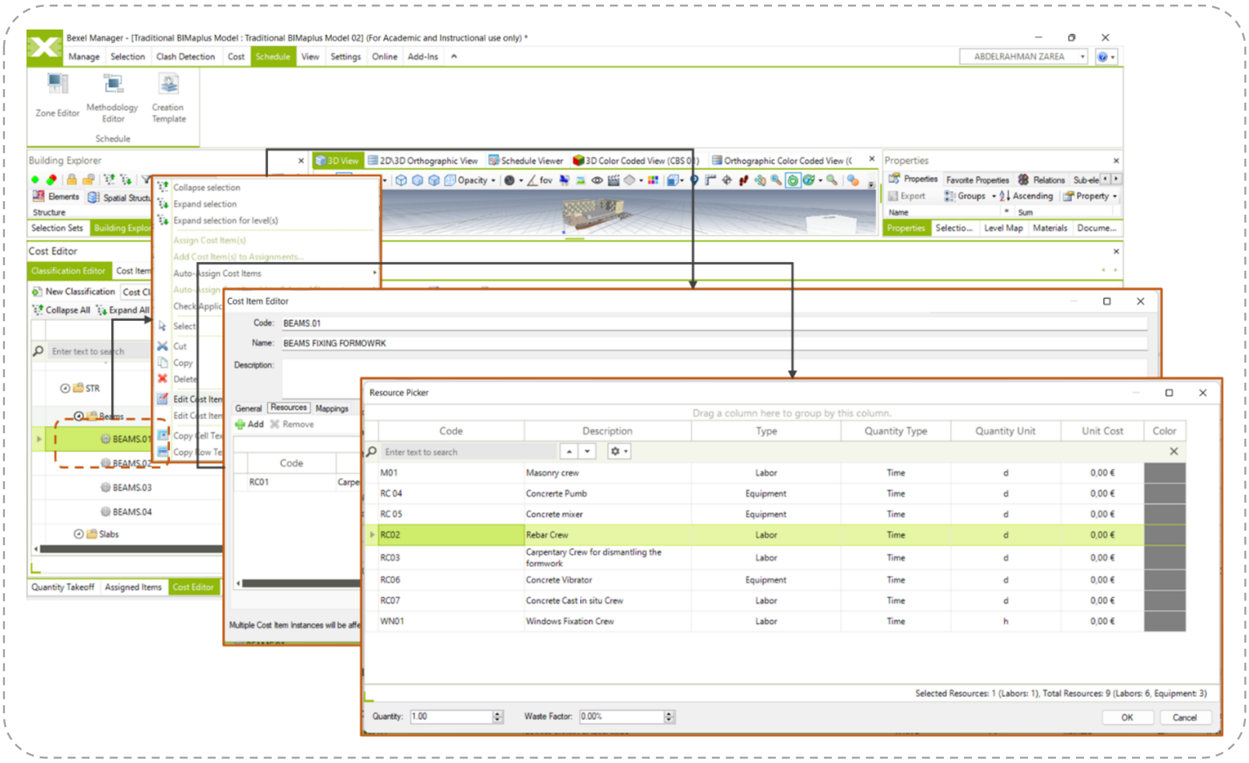


Figure 76 – Allocating the resources to the defined cost items, in BEXEL Manager.

4.3.3.5. 4D Simulation

The stage of 4D simulation comes next. In this step, the user can check and review the sequence for creating the traditional BIM model. The animation represents the created schedule based on zones and methodology, as shown in Figure 77.

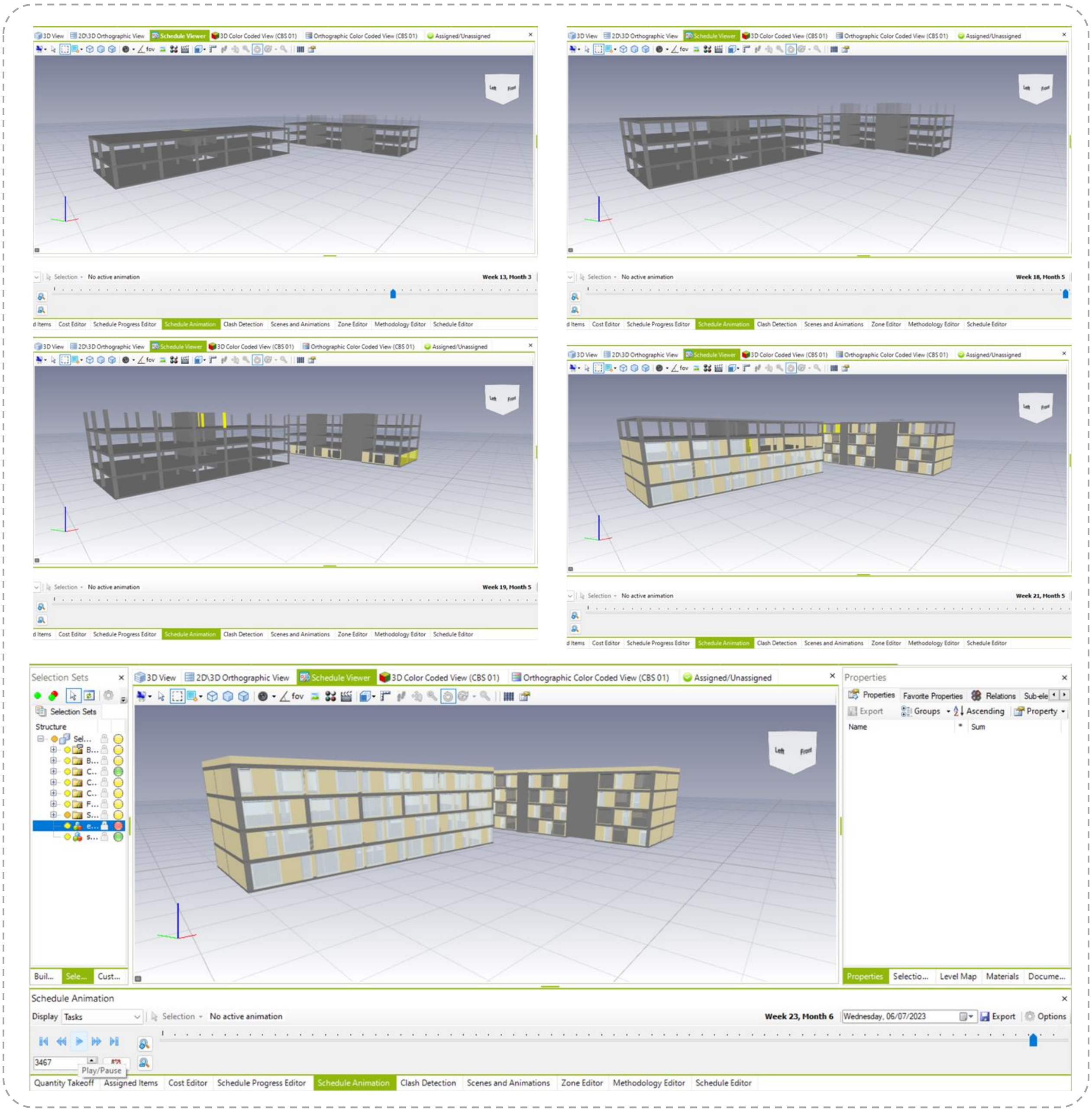


Figure 77 – 4D simulation for the traditional BIM model, in BEXEL Manager.

4.4. CREE system – Case Study

The B&B will be constructed with CREE technology. This system includes prefabricated light frame façade panels, steel girders and columns, and hybrid floor slabs. The CREE floor panels used have 8.1 or 6.3 meters of length. These slabs stand on the metal girder on one end, and on the wall panel on the opposite end. To prevent any down stands, the girder is flush with the floor system.

All the structural elements are prefabricated in the factory and transported to the site before the assembly process begins. This system allows a quick construction.

4.4.1. 3D BIM Model

The CREE 3D model was previously developed by CASAIS company. The scope of analysis in the development of the case study is restricted to the CREE elements, and the outer envelope of the building.

The typical CREE model is created using Autodesk Revit by using the CREE system elements such as panel slabs, wooden beams, columns, steel girders and façade panels. The 3D model is used to develop the 4D model afterwards. Therefore, deciding the level of information need is vital to start the process of 4D modelling. Assigning the WBS for the elements is the first step after creating the 3D model, in the same manner as was done before with the traditional model.

In the case of CREE, four levels of WBS were created. Level one is the project name, in case there are different projects; second level is the building, if there are more than one building; the third level is the building floors, such as the second floor; and the fourth level is the CREE element ID. For instance, by selecting one of the façade panels, CREE01_PROJECT is B&B, CREE02_BUILDING is the hotel, CREE03_LEVEL is Piso 4, and CREE04_ELEMENT is D23 as shown in Figure 78.

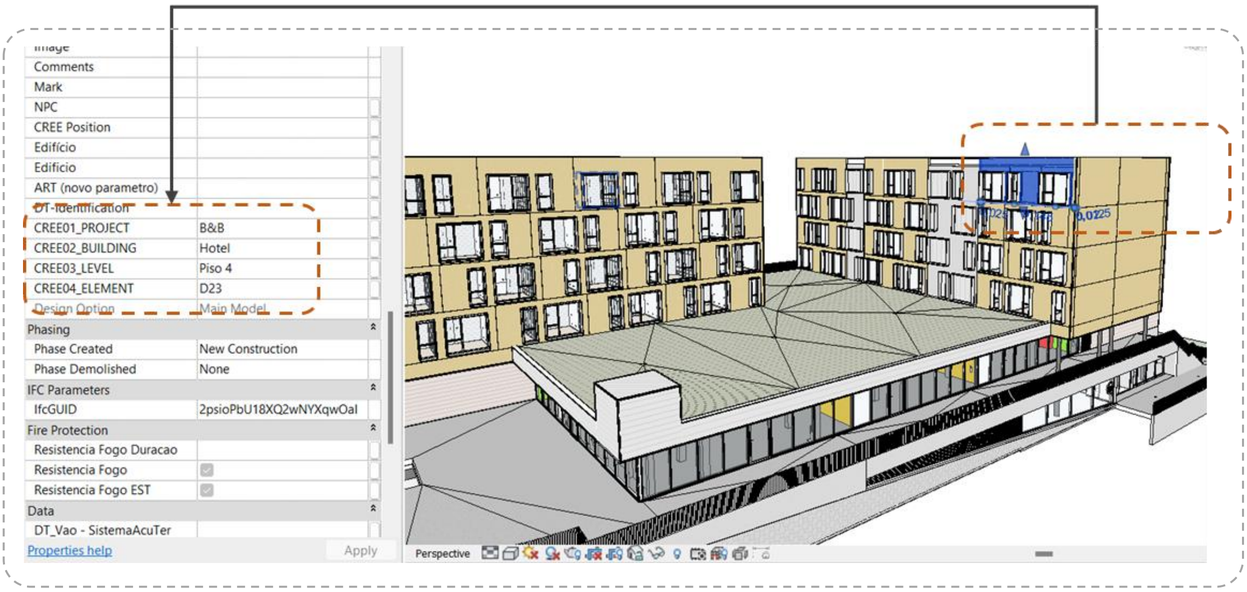


Figure 78 – The level of information need to the façade panel, in Autodesk Revit.

The way to add the level of information need is as same as was presented for the traditional model. Figure 79 shows the procedure to create the four levels of WBS.

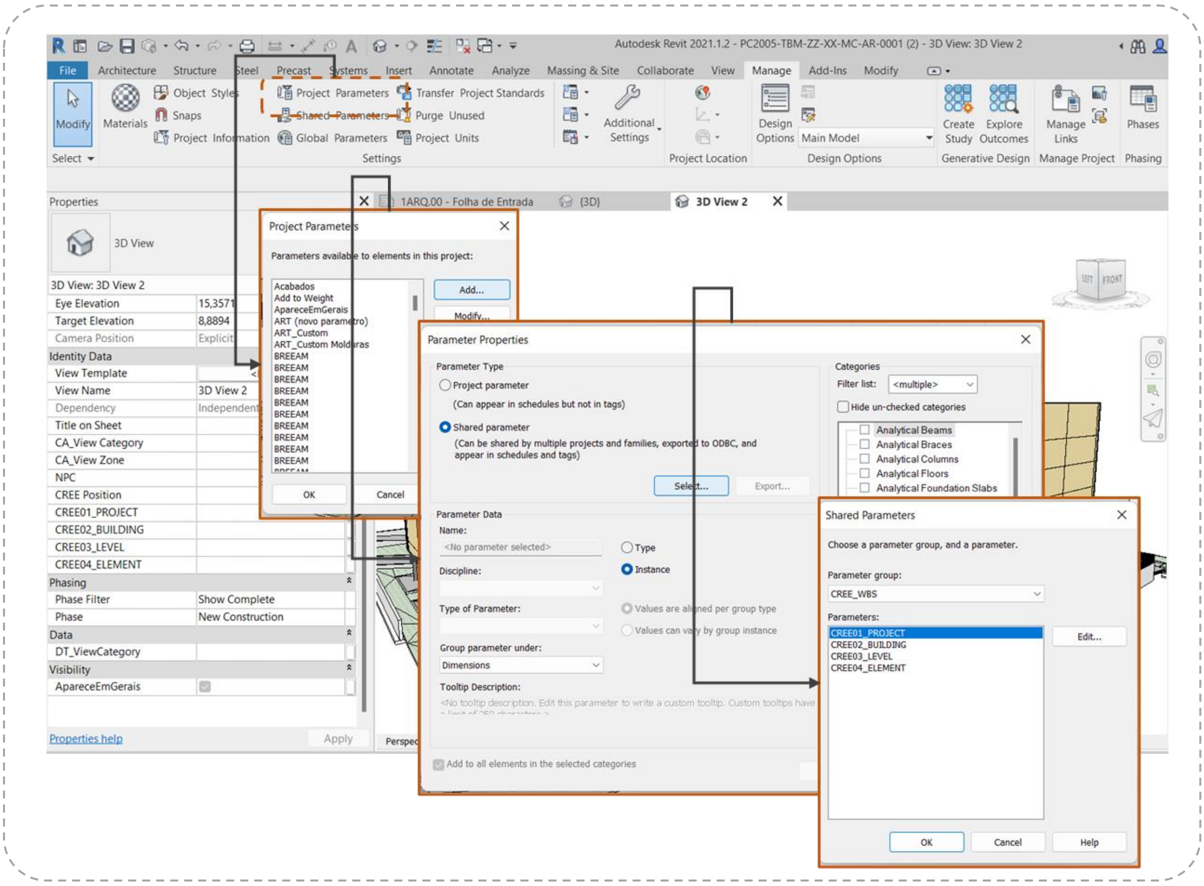
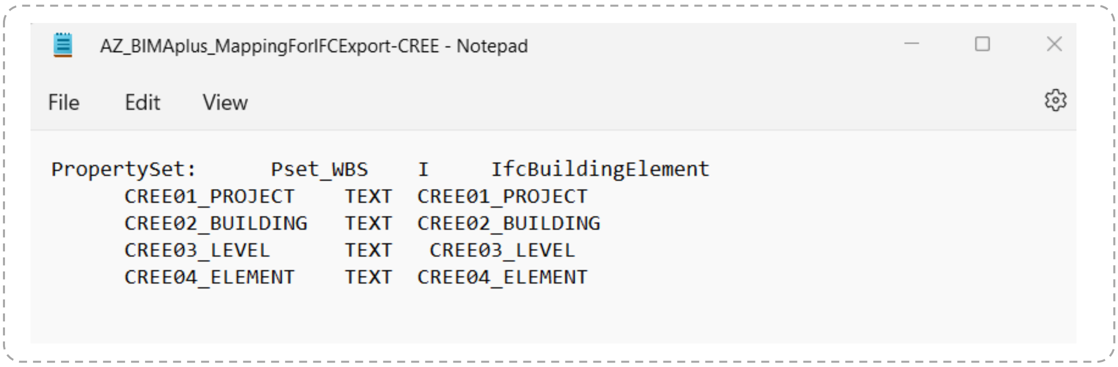


Figure 79 - The workflow for adding the WBS parameters to the elements, in Autodesk Revit.

4.4.2. Model checking and IFC

The same process that happened to the traditional BIM model is now applied to the CREE BIM model to review and check if all elements have been assigned to the created WBS levels. Then, exporting the IFC file with defined export settings and user-defined property sets needs the text files as was also explained before and is shown in Figure 80, to ensure that the added parameters are provided as a Pset_WBS in BEXEL Manager, which will allow to start the 4D modelling process.


AZ_BIMAplus_MappingForIFCExport-CREE - Notepad

File Edit View

```
PropertySet:      Pset_WBS    I     IfcBuildingElement
      CREE01_PROJECT     TEXT  CREE01_PROJECT
      CREE02_BUILDING    TEXT  CREE02_BUILDING
      CREE03_LEVEL       TEXT   CREE03_LEVEL
      CREE04_ELEMENT     TEXT  CREE04_ELEMENT
```

Figure 80 – Text file used for the user defined property in the CREE BIM model, developed in Autodesk Revit.

4.4.3. 4D Model

To start the phase of 4D modelling in BEXEL manager, it is necessary to have the IFC file for the CREE model ready and exported in the same way as done for the traditional model. The workflow for the CREE model is generally the same as the one defined for the traditional BIM model. Checking the IFC file that provides the added WBS levels to the elements is important to start the 4D modelling process for creating the CBS for the elements according to those levels.

For instance, one of the façade panels has a different categories of elements, such as, the vertical panel that acting as exterior wall, the Glulam columns that transmit the bearing loads as mentioned before, and windows. The level of information need is displayed as user defined properties in Pset_WBS. It has four levels of WBS for elements. The first level is for project, the second level is for the building, the third level is for floor level; and the fourth level is for a determined element, as shown in Figure 81.

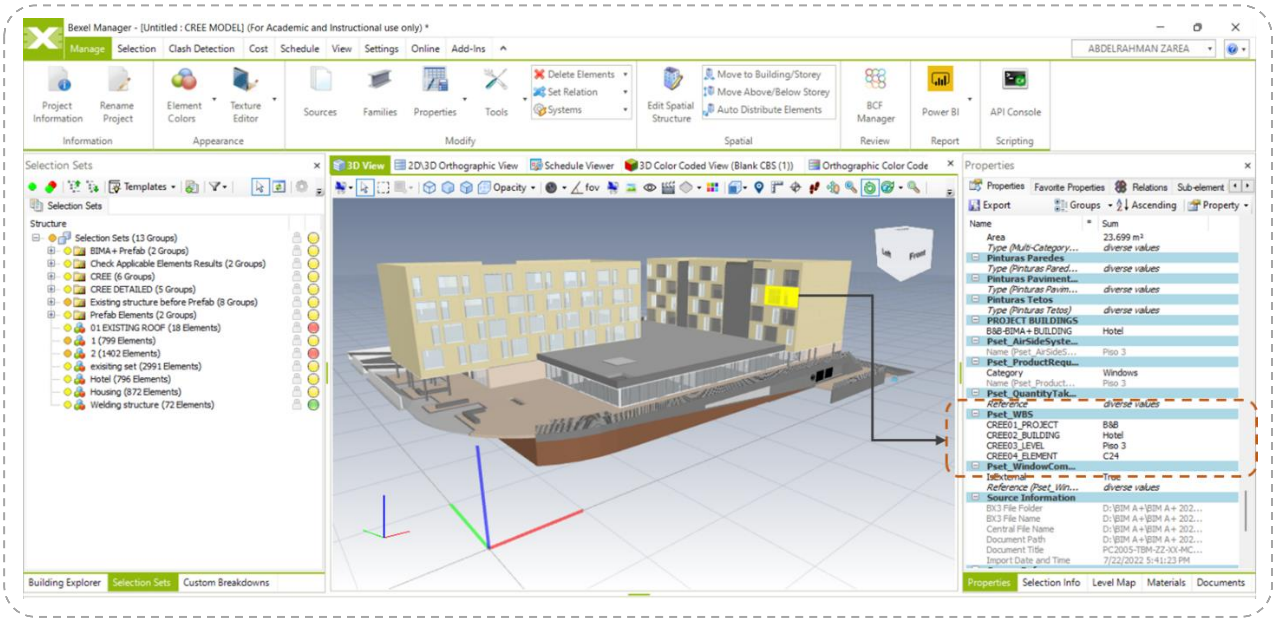


Figure 81 – The Pset_WBS has the created information need, in BEXEL Manager.

4.4.3.1. Custom Breakdown Structure

The custom breakdown structure for the CREE system is a bit different than the one defined for the traditional model. The CBS is created and sorted according to the defined WBS properties for CREE. The purpose of the CREE CBS is to reach the lowest level for elements that are used in the CREE system, which could be a vertical panel supported by columns or a horizontal panel supported with four beams.

To create a CBS for CREE, it is necessary to open the custom breakdown interface, create a new CBS, select the building, put defined property rules starting with the property name CREE01_PROJECT, CREE02_BUILDING, CREE03_LEVEL, and at the end, CREE04_ELEMENT. Therefore, the CREE CBS will be sorted according to the properties defined , and afterwards the user can reach the lowest level of elements easily. Figure 82 shows the way of creating the CREE CBS.

The user may choose any element from the resulting list after the CREE CBS has been created, as shown in Figure 83. After that, it is easier for the modeller to choose any CREE CBS level or element with just one click. In order to use it in the 4D process, a CSS can also be produced from these specific options.

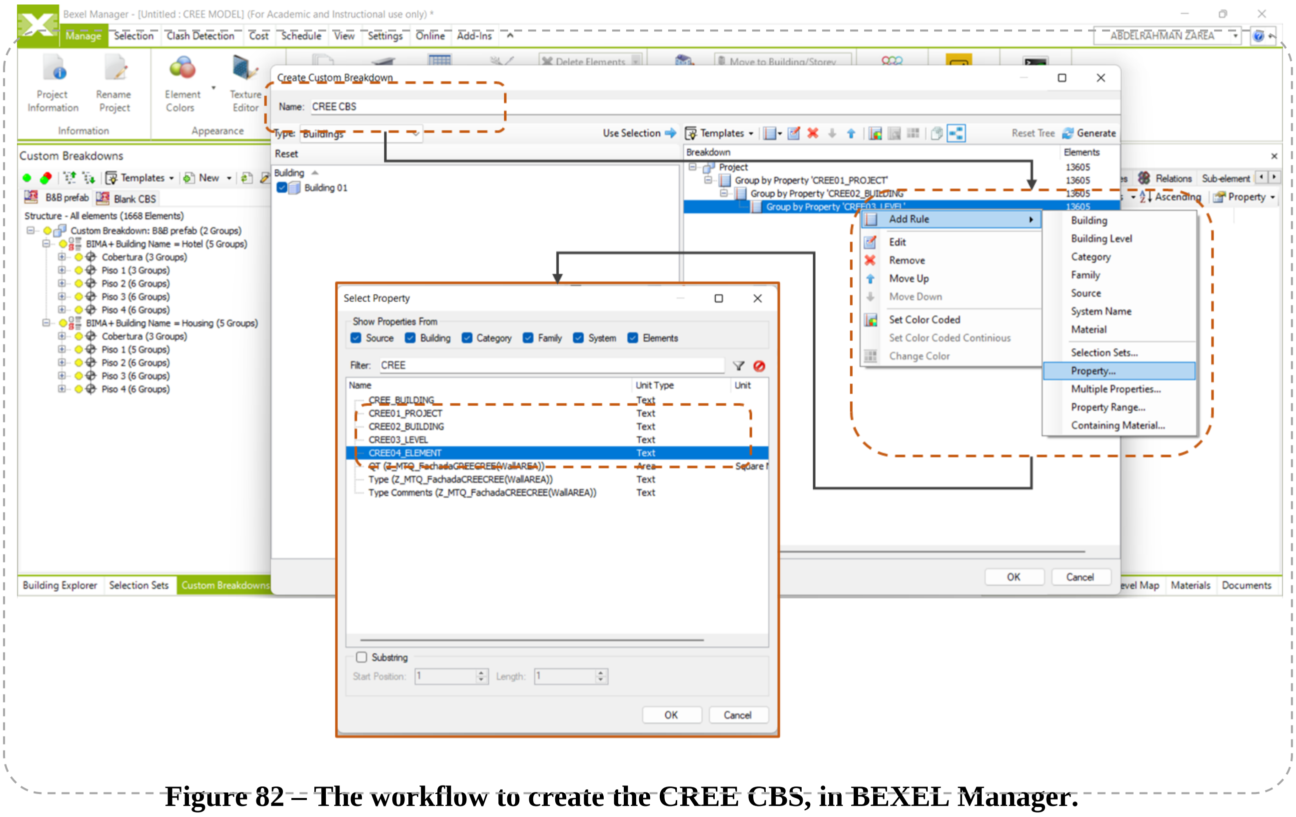


Figure 82 – The workflow to create the CREE CBS, in BEXEL Manager.

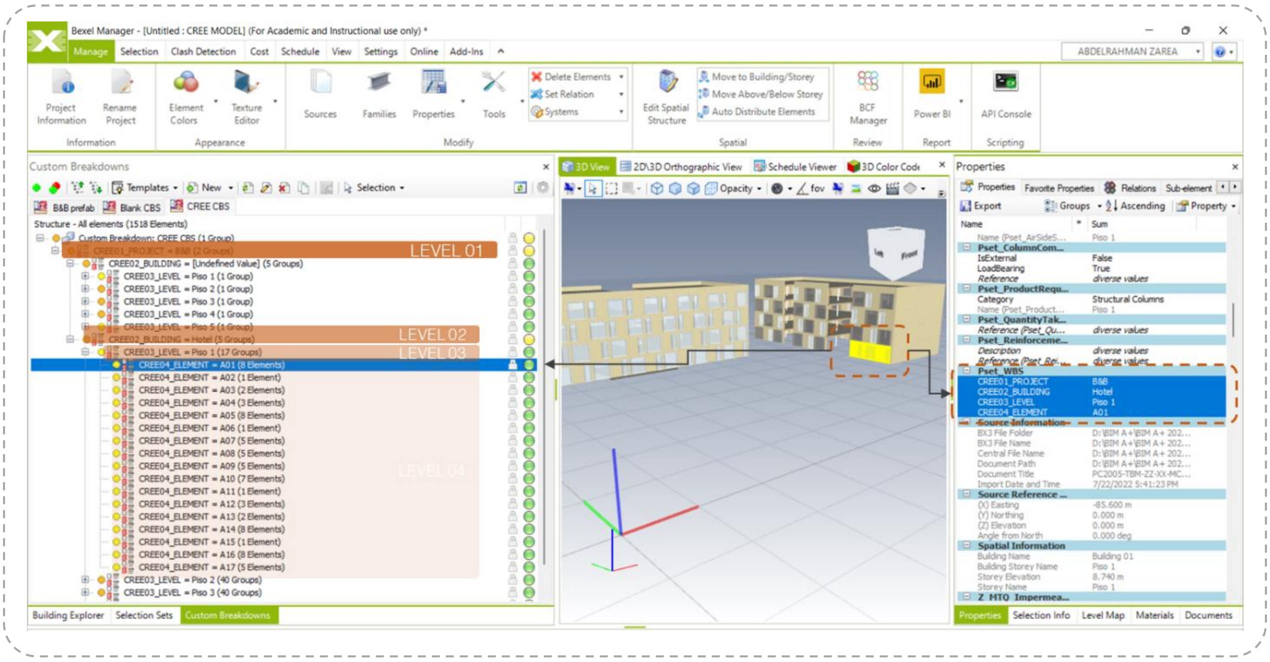


Figure 83 – The created CREE CBS, in BEXEL Manager.

4.4.3.2. CREE Custom selection sets - CREE CSS

The process used in the traditional construction system to create smart selection sets is also used for the CREE model. The purpose of creating CSS is to help the user demonstrate the schedule with the logical relationships between the selected sets. The CREE CSS is created as shown in Figure 84 by using the creation wizard available in BEXEL manager, from Custom Breakdown, selecting the created CREE CBS and pressing all elements.

Therefore, at the interface of selection sets, CREE CSS is displayed, and the user can keep selection with any of the created CSS lists. For instance, the first CREE floor of the hotel could be kept in selection by clicking on it in the selection sets interface as shown in Figure 85. In addition, it is easier for the user to select a specific CREE element, such as the vertical panel, or horizontal panel that will be constructed onsite as shown in Figure 86.

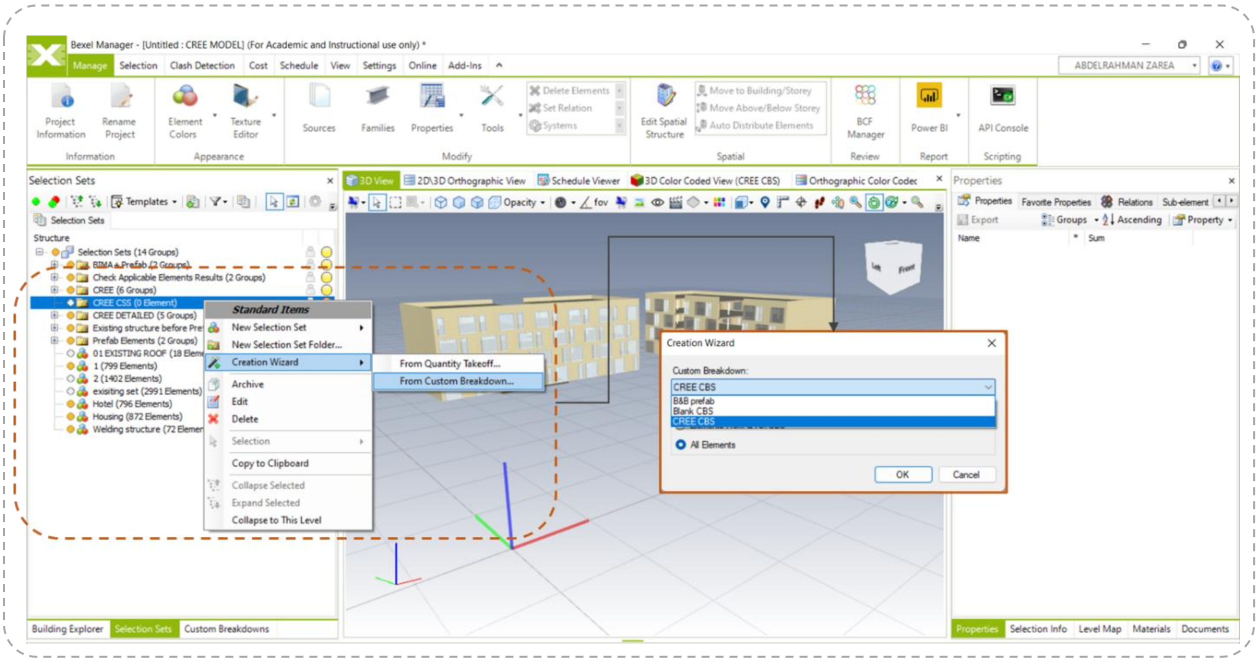


Figure 84 – Creating a CSS obtained from the previous CBS, in BEXEL Manager.

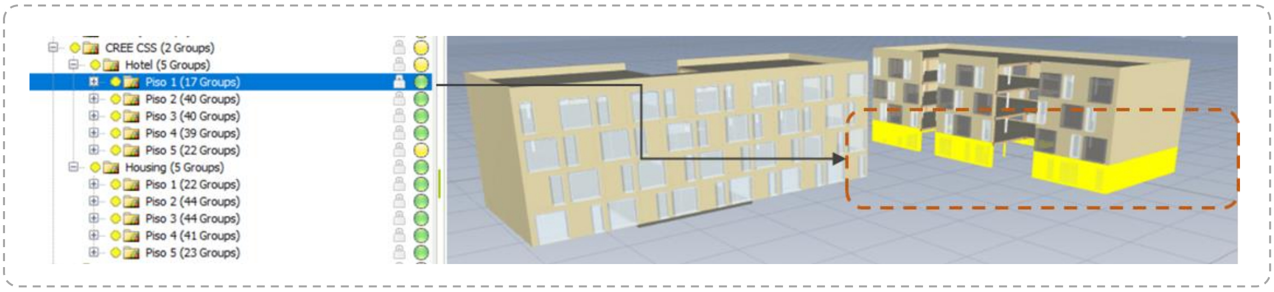


Figure 85 – Selection set for the first floor of the Hotel Building, in BEXEL Manager.

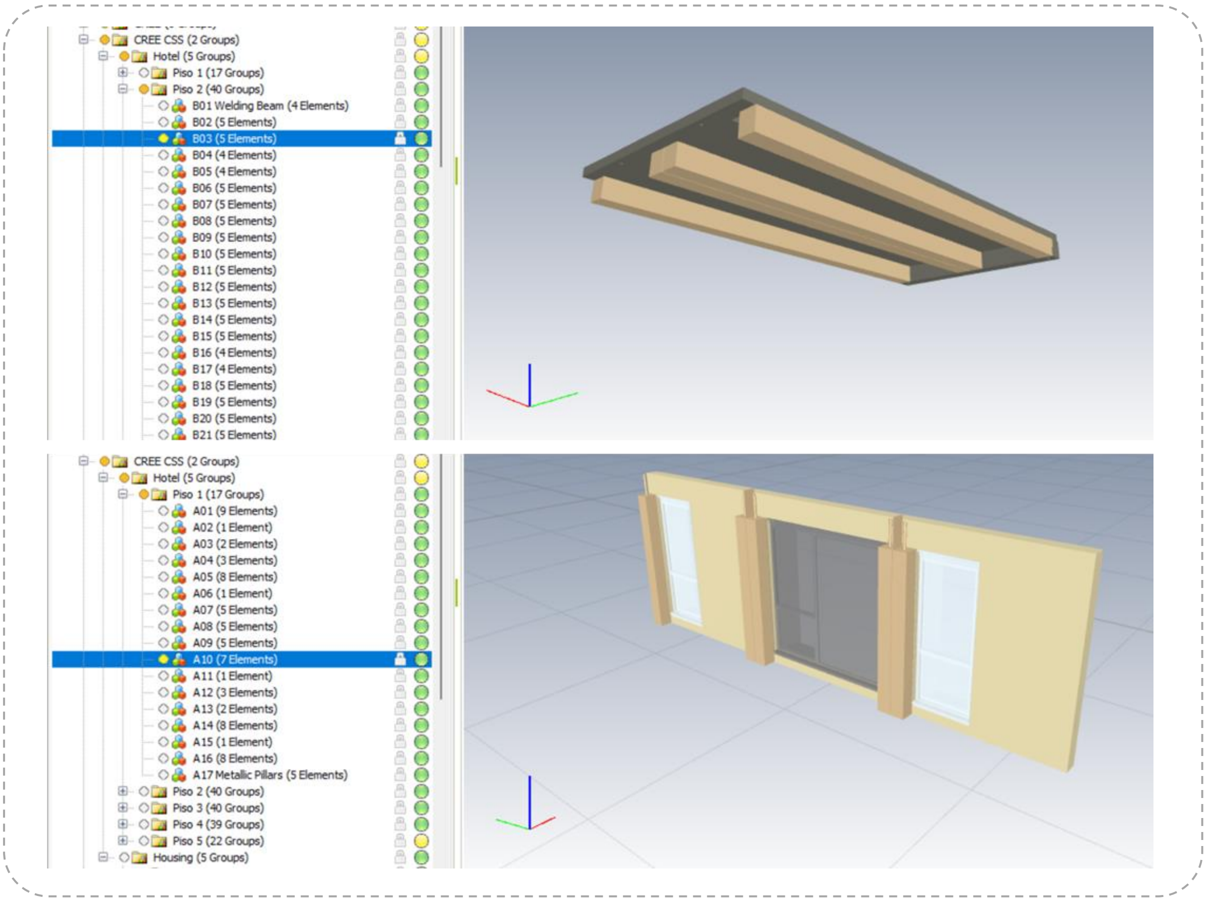


Figure 86 – Selecting vertical or horizontal CREE elements, in BEXEL Manager.

4.4.3.3. Creating Rules with logic relationships

The way of creating the schedule for CREE is a bit different than what was done in the traditional model with a semi-intelligent engine process. The 4D modeller in this case is able to automatically create a schedule already linked with elements based on predefined selection sets with defined easy logic relationships between them, since the majority of CREE elements are in a sequential finish-to-start relationships.

To create the schedule using the developed CSS, by following these steps, as shown in Figure 87 and Figure 88, respectively:

- Go to the schedule editor and create a new schedule;
- From the logic schedule interface, select new task;
- From the dynamic creation rules, select the parent tasks;
- Repeat this process till it reaches the children`s tasks;
- Set the relationships between parents and children`s tasks.

Following these steps, the Gantt Chart is built with elements that are already linked as shown in Figure 89, and the LOB is shown in Figure 90. The 4D modeller can update the schedule and begin the simulation, so that the schedule can check the logical sequence of the constructed elements.

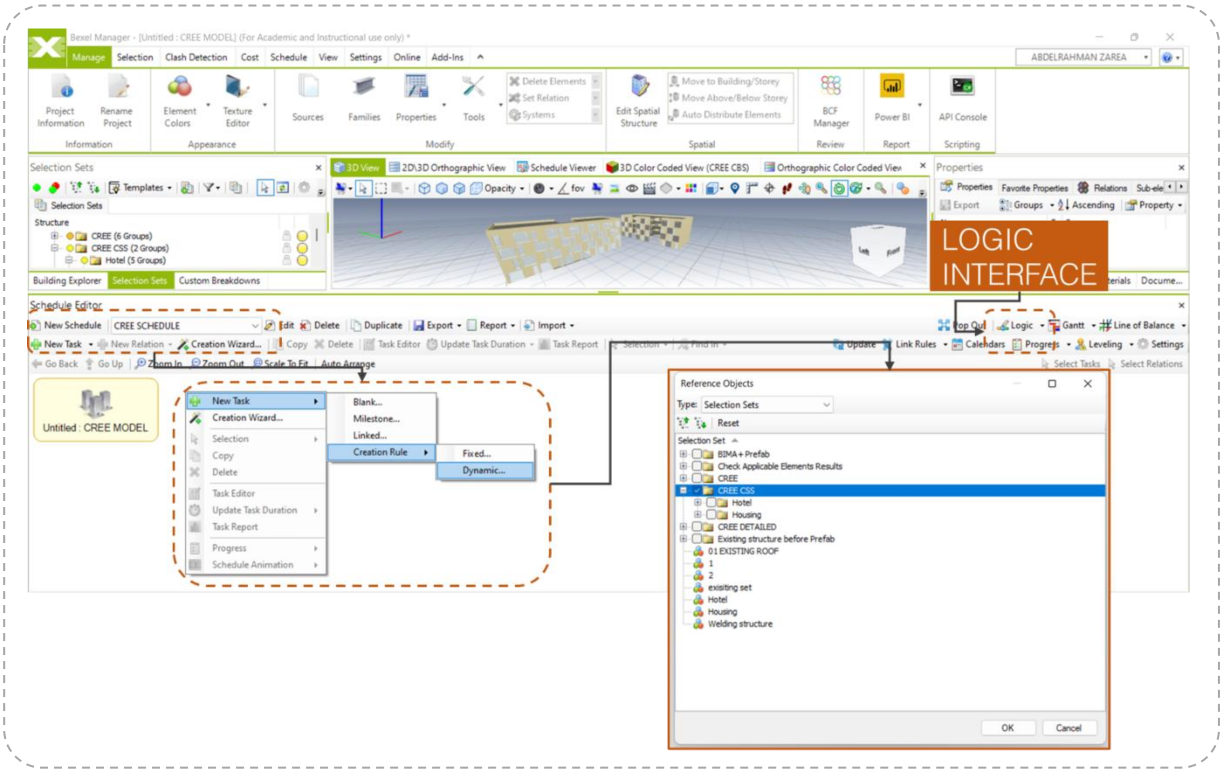


Figure 87 – Creating a schedule based on rules and selection sets, in BEXEL Manager.

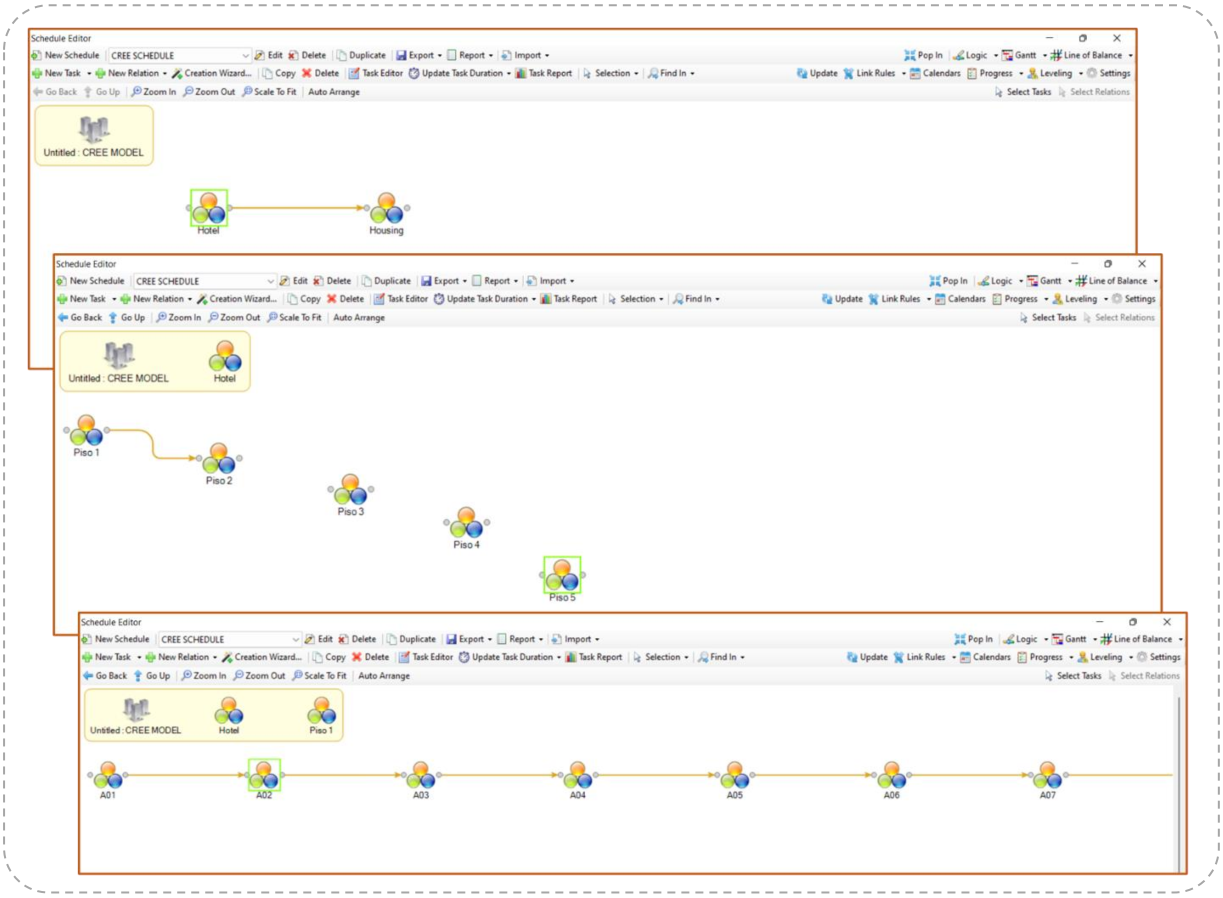


Figure 88 - Creating a schedule based on rules and selection sets, in BEXEL Manager.

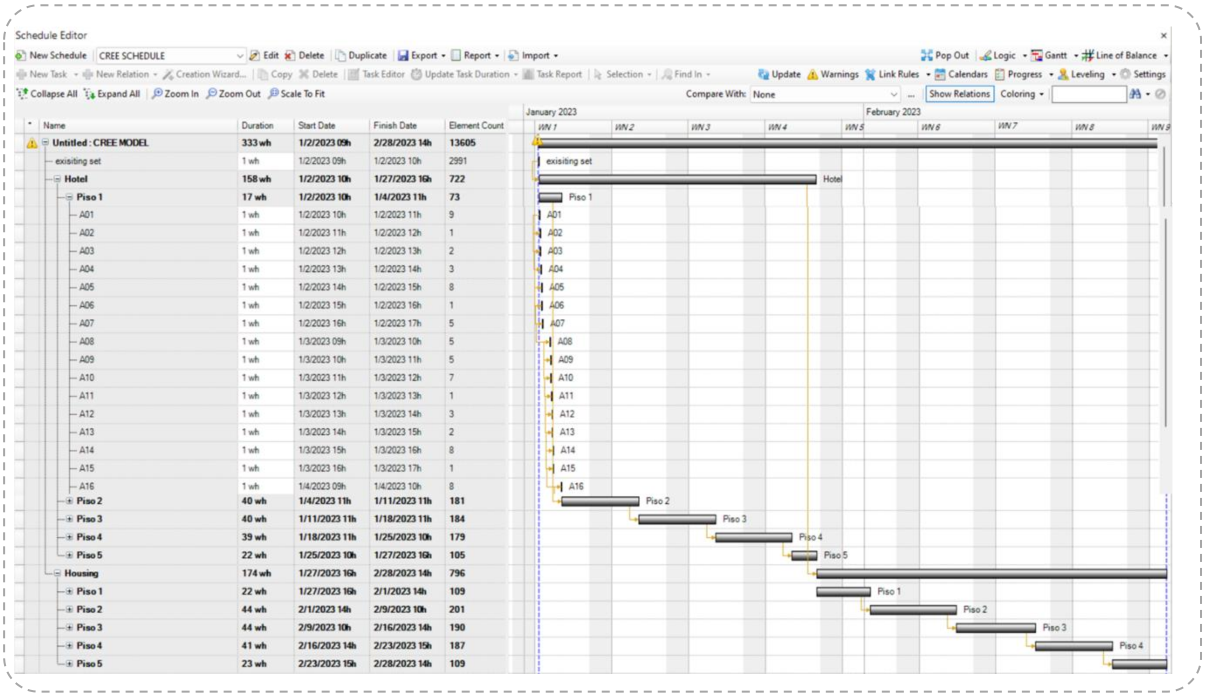


Figure 89 – The Gantt chart for the CREE model, in BEXEL Manager.

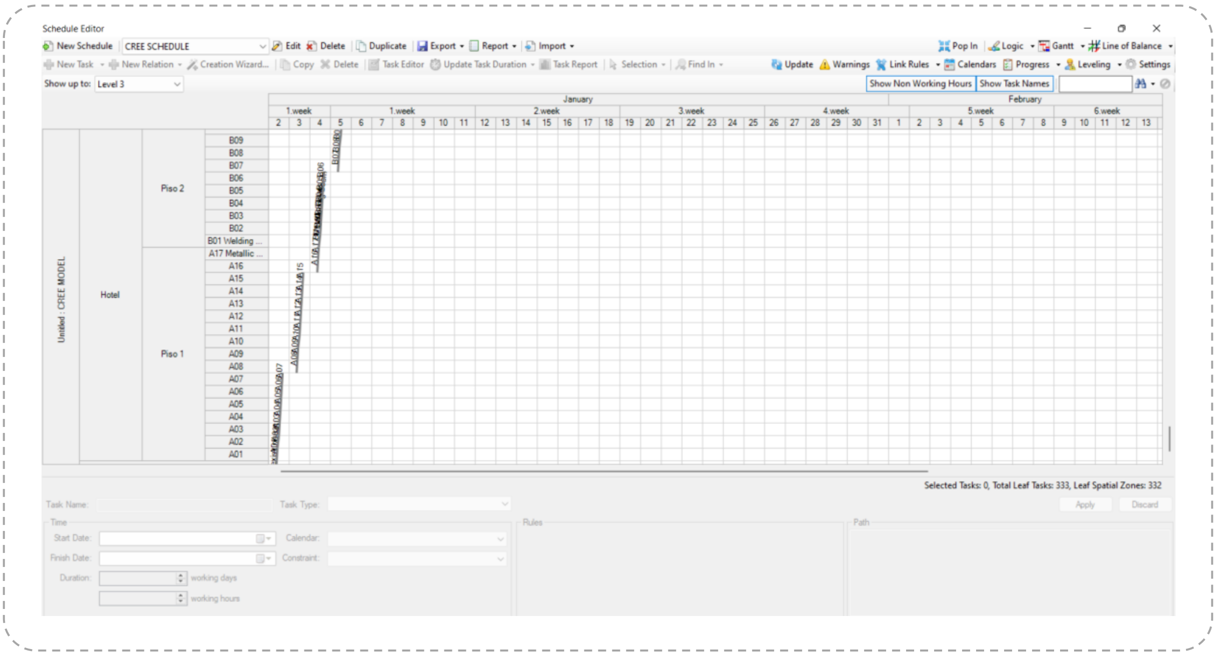


Figure 90 – Line of Balance for the CREE model, in BEXEL Manager.

4.4.3.4. Assigning resources and what if scenarios

The aim is to use the same resources to construct the hotel building and the housing building. The housing building follows the hotel building in all activities.

The needed resources in this case are just one portable crane and one tower crane to load the elements to their location, as shown in Figure 91. There is a trained crew of six people for the assembly process, who are there to connect the elements together with the assistance of the cranes.

In BEXEL manager, the user defines the resources needed in the current project and assigns them to each cost item that is created in the cost editor. This creation can be done in two ways: the first one is obtained with the creation wizard based on the QTO created from the selection sets, and the second one is collected from the created CBS, which has selections for each element. Since the CREE system is a sequential process, it uses the same crew and equipment resources along the assembly process.

Figure 91 – Using a portable crane and a tower crane with the trained crew in the assembly process.

In BEXEL Manager, the user should follow these steps to define resource, it is described in Figure 92:

- Define the needed resources;
- Select the needed resources from the cost editor window;
- Assign the resources needed to complete the task, using the created cost items editor.

This process needs to be applied to all cost items. If the task needs the same resources, the user can select all the tasks that need the same resources and assign the resources at once. If not, the user needs to assign the resources to each cost item.

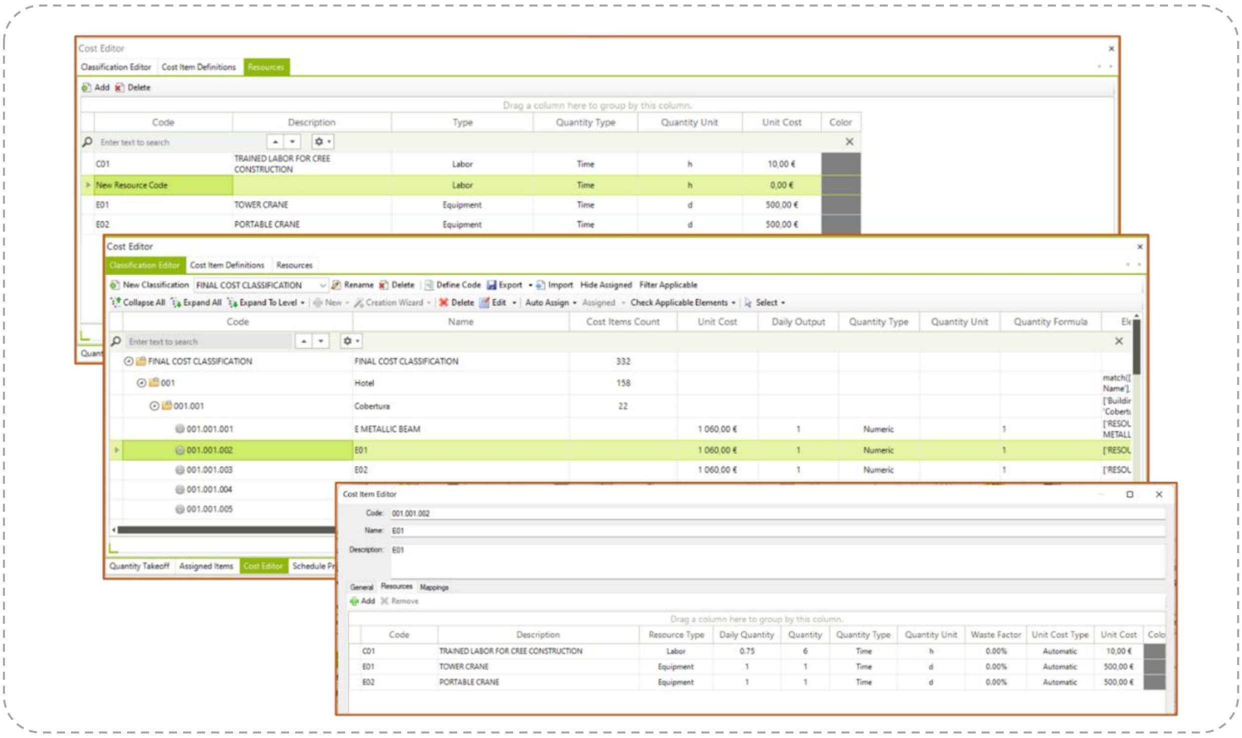


Figure 92 - Workflow to define the needed resources in CREE system, in BEXEL Manager.

4.4.3.5. 4D Simulation

In this step, the user can check and review the sequence for creating the 4D CREE BIM model. The animation represents the created schedule-based model that is based on creation rules and selection sets, as shown in Figure 93.

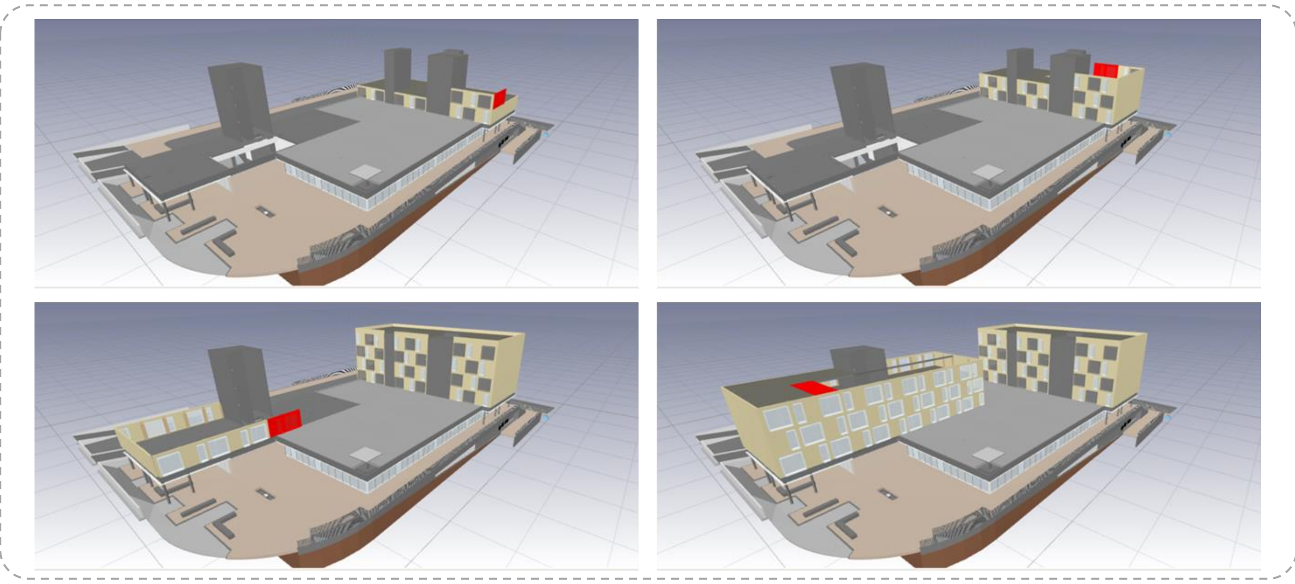


Figure 93 - 4D simulation for the CREE BIM model, in BEXEL Manager.

4.5. 4D Comparative Analysis

The aim of using two approaches of construction, such as the traditional one and the totally prefabricated CREE system, is to establish a comparison between the two systems, through a 4D BIM analysis.

The 4D analysis is focused on the project time, which is the time needed to complete the project, which in this case it will be the scope of the work. The analysis also includes the resources used to complete the work and the quantification of how many work hours are needed for both ways of construction.

Furthermore, BEXEL Manager is used as a 4D modeling tool to create the schedule for both ways of construction - traditional construction and CREE system. The user can use the reports provided by BEXEL Manager, but the schedule, the relationships between tasks and the assigned resources can also be exported to Excel or MS Project.

4.5.1. Time

The two 4D model have the same calendar. In this calendar, it is assumed that the project starting date is the first workday of the next year. Therefore, the project starts on the 2nd Jan 2023 for both 4D model. The results regarding the project time for the two 4-storey buildings that will be constructed in traditional way needs 107 days. On the other hand, if it is constructed using the CREE system as total prefabrication, it will take only 16 days. Figure 94 shows the gap between the time needed to complete the scope of the work for the case study in case it is applied in traditional way or using CREE system as prefabrication construction.

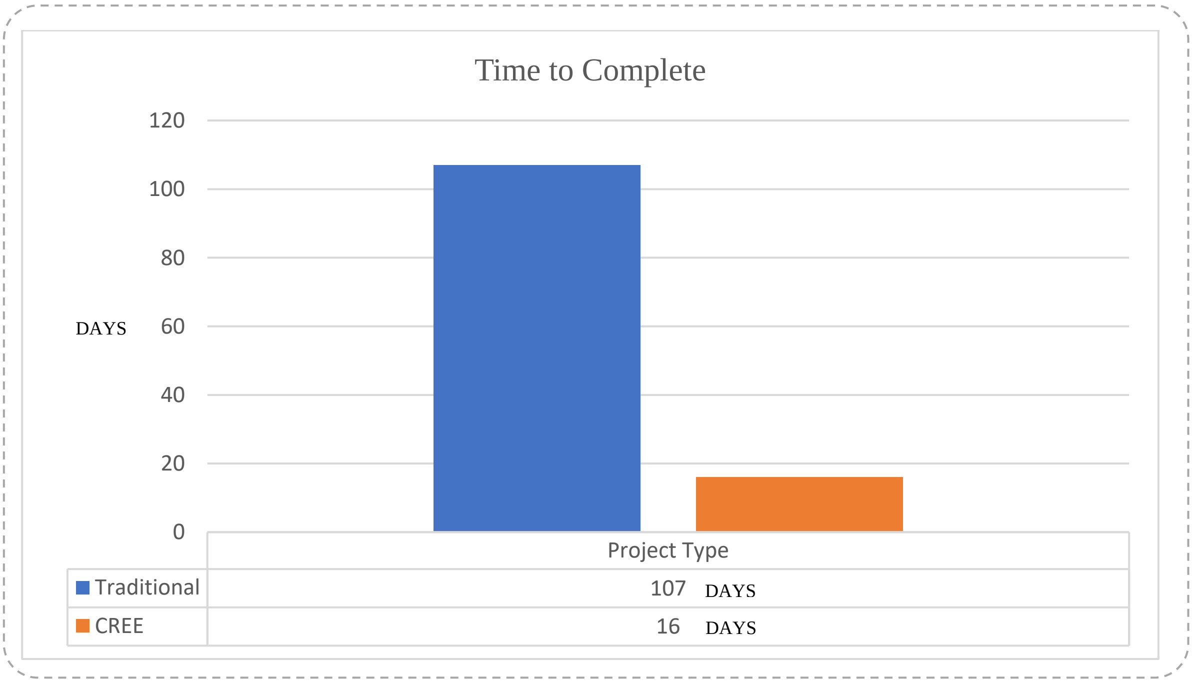


Figure 94 – Time needed to complete the scope of work for the case study with traditional construction and with the CREE system.

4.5.2. Resources

The project needs resources to be carried out and the two approaches use different ways to be constructed. Therefore, the point is to quantify the work hours needed to complete the work. The work hours are the work time needed for all resources to carry out the needed tasks.

In the traditional way, there are more resources needed to do the work than using CREE system. The traditional construction needs 36,160 work hours divided between the carpentry crew, the rebar crew, the concrete cast in situ crew, the masonry crew, the window fixation crew, concrete mixer, concrete pump, and concrete vibrator, as shown in Figure 95. Table 5 shows the start date and the finish date for each resource, as well as the work hours needed for each resource.

On the other hand, by using the CREE system as the prefabrication option, only 5,414 work hours are necessary. It is much less than in traditional construction. The CREE system needs only an extra portable crane, a crane tower and an assembly crew, including six trained labors, as shown in Figure 96. Table 6 shows the start date and the finish date for each resource in case of using CREE system as the construction solution.

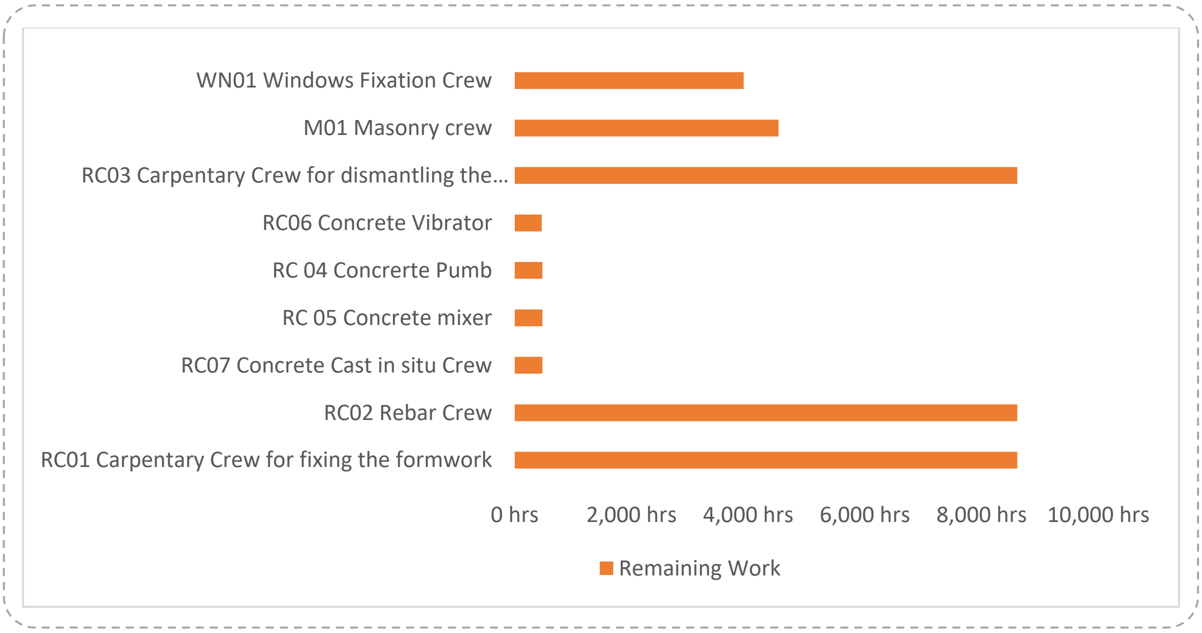


Figure 95 – The work resources stats for the Traditional 4D Model.

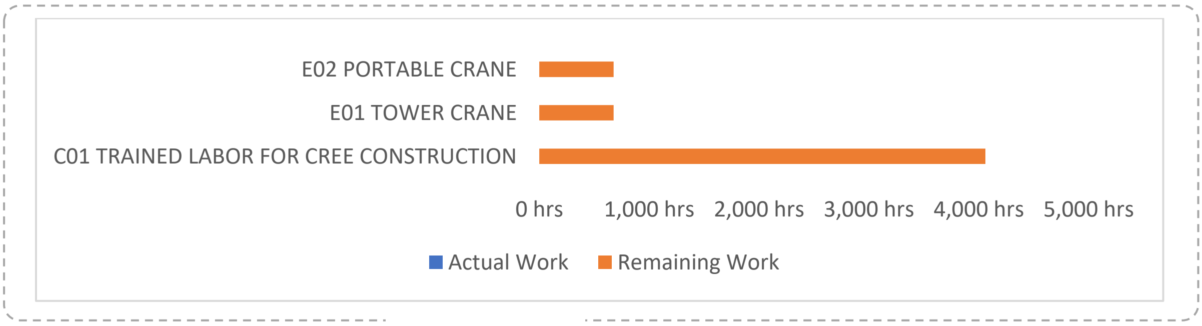


Figure 96 – The work resources stats for the CREE 4D Model.

Table 5 – Work hours for all work resources in the 4D Traditional Model.

Name	Start date	Finish date	Work (hours)
RC01 Carpentry Crew fixing formwork	Mon 1/2/23	Thu 5/11/23	8.610,25
RC02 Rebar Crew	Wed 1/4/23	Mon 5/15/23	8.610,25
RC07 Concrete Crew	Fri 1/6/23	Tue 5/16/23	474,81
RC 05 Concrete mixer	Fri 1/6/23	Tue 5/16/23	474,81
RC 04 Concrete Pump	Fri 1/6/23	Tue 5/16/23	474,81
RC06 Concrete Vibrator	Fri 1/6/23	Tue 5/16/23	463,13
RC03 Carpentry Crew dismantling formwork	Mon 1/9/23	Thu 5/18/23	8.610,25
M01 Masonry crew	Thu 4/20/23	Tue 5/30/23	4.520,77
WN01 Windows Fixation Crew	Tue 4/25/23	Fri 5/26/23	3.921,52
			36.160,00

Table 6 – Work hours for all work resources in the 4D CREE Model.

Name	Start date	Finish date	Remaining Work (hours).
C01 trained CREE construction crew	Mon 1/2/23	Mon 1/23/23	4,060
E01 tower crane	Mon 1/2/23	Mon 1/23/23	677
E02 portable crane	Mon 1/2/23	Mon 1/23/23	677
			5,414

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5. CONCLUSION

5.1. Theoretical and practical conclusion

The construction industry can greatly benefit from prefabrication. In the construction business, offsite construction does not capture the desired attention in comparison to traditional construction. Developers, consultants, and even contractors are not well aware of the advantages of employing total prefabrication systems in the building sector. This study focuses on these advantages, such as improving work efficiency, using less manpower, producing less waste, cutting the cost of building services, and significantly reducing the amount of time spent on the various tasks required.

Nevertheless, offsite construction is a good potential solution for many housing and commercial projects, especially when it is important to reduce the construction time. Therefore, this research focuses on developing a 4D BIM analysis considering the traditional construction system and the total prefabrication CREE system.

The study focuses on evaluating how the time factor plays a crucial part in adopting prefabrication building technologies from a time-saving perspective. Which method of construction requires the completion of the full design engineering stage before proceeding with the onsite construction, and which method integrates the fabrication industry during the design and engineering stage?

The CASAIS company decided to use the CREE system for total prefabrication on the construction of the B&B Guimaraes Hotel. The compound is nearly finished and was chosen as case study for this work. The two systems and the elements needed to create the 3D model are both provided and explained. Additionally, their benefits and drawbacks are discussed.

By using BEXEL Manager as a 4D modelling software, a 4D comparison analysis of the two 3D BIM models — the traditional model and the CREE model — will be shown. To achieve the goal of the research, a framework with two workflows — one for the conventional model and the other for the CREE model — is proposed. The purpose of both 4D models is achieved by using an advanced intelligent engine and the advantages of the BEXEL Manager. The modeller uses intelligent scheduling as a cutting-edge tool that is directly associated with the 3D BIM model.

The traditional model is more recognizable and friendly to the majority of planners; the schedule may be easily created by using the spatial distribution zones and work methodologies. On the other hand, prefabrication construction must reach the lowest number of elements that will be built, since each façade panel in the CREE system needs 40 minutes, as well as, 20 minutes for the CREE slab, to be erected on site. That demonstrates how the CREE system requires additional minute's preparation and selection sets to properly match the elements with the schedule, despite BEXEL Manager the minimum task`s duration is only one hour, the user needs to export the schedule to another scheduling software such as MS project to change the durations` units of the tasks into minutes to get the right calculations.

As a result, using CREE system guarantees a great time saving when compared to the traditional construction. The CREE system depends on very sequential procedures to perform the assembly process while traditional construction needs time for curing concrete and adding loads for the vertical spatial distribution. The B&B Guimaraes needs only 16 days to be finished with the CREE system, when the two 4-storey buildings are considered. If these two buildings are erected with the traditional method, they need 107 days of work. Regarding the work hours, the CREE system needs 5,414 work hours of different resources to be carried out and the traditional system needs 36,160 work hours.

The following table shows the advantage of using CREE system as one type of total prefabrication and quantifies the 4D analysis based on the suggested B&B Guimaraes Hotel case study.

	B&B in Traditional way	**B&B using CREE System**
Start Date	2-Jan-23	2-Jan-23
Finish Date	30-May-23	23-Jan-23
Duration	107 days	16 days
Work hours	36,160 hours	5,414 hours

5.2. Further research and recommendations

Although the purpose of this study has been achieved, some recommendations are proposed, and further work is suggested:

- This study focuses on the impact in terms of time of using a total prefabrication system instead of the traditional construction. It is recommended to develop a 5D comparative analysis to evaluate the costs. How is the cost affected by using prefabricated construction instead of the traditional methods of construction?

- BIM can serve as a link between information throughout the prefabrication construction process. BIM is a platform that allows all stakeholders to develop, exchange, share, and manage building information. The prefabrication business may employ additional sensing technologies in addition to RFID technology for the building components in order to create a comprehensive construction management system, by integrating BIM with RFID technology.

- Total prefabrication asset management is defined as the asset management information hierarchy required to design, build, operate, and manage. Because this type of construction requires highly coordinated and organized data exchange among stakeholders, such as the designer, engineers, the factory, and the onsite assembly process.

- In total prefabrication construction, logistics management is essential to meet the project objectives on cost, time, and safety. By creating a logistic model using BIM and a 4D modeling as a tool for visualization the optimized logistic planning for the prefabricated building system and site assembly.

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LIST OF ACRONYMS AND ABBREVIATIONS

BIM	Building Information Modelling
INC	Incorporated
4D	3D + Time Dimension
5D	4D + Cost Dimension
AEC	Architectural, Engineering and Construction
CII	Construction Industry Institute
NIBS	National Institute of Building Sciences
IFC	International Foundation Class
WBS	Work Breakdown Structure
CBS	Custom Breakdown Structure
CSS	Custom Selection Sets
QTO	Quantity Take-Off
LOB	Line Of Balance