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THE USE OF BIM FOR DESIGN-BUILD-RELOCATE PROJECTS

UPORABA BIM ZA ZGRADBE TIPA NAČRTAJ-IZGRADI-PRESELI

European Master in
Building Information Modelling

Master thesis No.:

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Cosupervisor:
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Izvleček:

Projekti načrtaj-izgradi-preseli (*angl. Design-Build-Relocate - DBR*) obravnavajo arhitekturo, ki je pogojena s časom, to so stavbe, ki so projektiranje za razstavljanje, selitev, premestitev, ponovno uporabo. Stavbe, ki so od trenutka njihove zamisli zasnovane neposredno povezane z občutkom omejene življenjske dobe. Zato morajo biti zasnovani tako, da jih je mogoče dekonstruirati.

Razvoj in napredek v zgodovini arhitekture se kaže v eksperimentiranju oblikovanja začasnih stavb. V sodobni digitalni dobi, v kateri živimo, je tehnološki napredek idealen scenarij za inovacije in preizkušanje novih rešitev za projekte DBR. Te vrste zasnov morajo omogočati visoko stopnjo prilagodljivosti in vsestranskosti skozi napredne in avtomatizirane tehnološke odzive v svetu, kjer se morajo spremembe in inovacije močno osredotočiti na ekonomičnost virov, vitke koncepte ravnanja z odpadki ter načela ponovne uporabe in recikliranja.

Cilj diplomskega dela je preučiti nekatere digitalne tehnologije, ki temeljijo na informacijskem modeliranju zgradb (BIM) in procese, ki podpirajo ustvarjanje začasne ali premostljive arhitekture. Vprašanje ogrodja temelji na razumevanju in raziskovanju, kako lahko tehnologije BIM sodelujejo za izboljšanje procesov načrtovanja in gradnje premičnih stavb. V nalogi je predlagan delotok za avtomatizacijo pakiranja elementov stavb za transport v kontejnerjih. Avtomatizacija pakiranja je tudi demonstrirana na izbranem primeru, na osnovi katerega so podane tudi smernice za elemente BIM. Glavni prispevek k metodologiji načrtovanje je identifikacija potrebnih prilagoditev v zgodnjih fazah projektiranja, ki podpirajo načrtovanje tovrstnih mobilnih stavb z nižjimi stroški in porabo časa.

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BIBLIOGRAPHIC – DOKUMENTALISTIC INFORMATION AND ABSTRACT

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Abstract:

Design-Build-Relocate (DBR) projects refer to architecture that presents temporality in its existence. Buildings that are created to be dismantled, disassembled, moved, relocated, reused. Buildings that, from the moment of their concept idea, are designed directly connected to the sense of a limited useful lifetime. Therefore, they must be designed to be deconstructed.

Advances and progress in the History of Architecture are reflected in the experimentation of design for temporary buildings. In the contemporary digital era in which we live in, technological advances are an ideal scenario to innovate and experiment new solutions for DBR projects. These types of constructions must allow high levels of flexibility and versatility throughout advanced and automated technological responses, in a world where changes and innovations must have a strong focus on the economy of resources, lean concepts for waste management, and reuse and recycle principles.

This thesis work aims to study some digital tools based on Building Information Modelling (BIM) and processes that support the creation of temporary architecture. The frame question is based on understanding and researching how BIM technologies can collaborate to improve the design and construction processes for relocatable buildings. A workflow to automate the packing of building components for shipment was proposed. Packing automation was afterwards applied in a case study project, which also contributed to predetermine initial set of DBR guidelines to be followed by BIM elements. The main contribution is to be able to identify necessary modifications in early-stages of the design process, enhancing the planning of DBR buildings and avoiding over costs and waste of time.

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I would first like to express my sincere gratitude to my supervisor Prof. Tomo Cerovšek, for supporting me in the topic selection and for providing me with his insightful knowledge across the development of this Master's thesis.

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I thank my colleagues with whom I shared this experience. The constant and warm support between each other was essential as we were so far away from our home countries, even more in times of global pandemic. They definitely became my closest family.

Finally, my most special and deepest thanks go to my so-valuable family and friends, who had always supported me in every step I decided to take in my life, and believed in my path and dreams. Without their encouragement and support, I would not be where I am today. All my love goes to my parents, who taught me by their example and efforts to persist in life; and who motivate me to keep moving every day. They are and will always be that couple I will admire.

I feel fortunate and proud of having the opportunity to study an advanced education program in such distinguished European universities. I take not only sharper skills and deeper knowledge from this experience but valuable links in my professional life. Concluding a Master's thesis does not mean closing a chapter in life; it means opening up more paths to walk through and daring to pursue them.

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1 INTRODUCTION

Scope of the chapter: to outline the thesis methodology, content and structure; and to introduce the previous experiences which led the author to have a strong desire of developing this thesis topic, and how this background relates to the dissertation work.

1.1 Motivation

"La facilidad y la rapidez de transformar las ideas en realidades hace de las arquitecturas efímeras una plataforma ágil para el pensamiento, la experimentación y la investigación."[1]
Carmen Blasco, »Efimeras, alternativas habitables«

In her publication »Efimeras, alternativas habitables«, Carmen Blasco refers to the ephemeral architecture as an opportunity for innovation of the habitational spaces, saying that *"The ease and speed to transform ideas into reality make ephemeral architectures an agile platform for thinking, experimenting and researching."*[1]

I have always been motivated by the design process with dry-layered construction systems -or "dry architecture", as we usually call it in my country. Although I come from a place where people commonly build with bricks and concrete -because besides being typical in the region, it is related to the feel of security and perdurability-, my interest in design in dry materials like wood or steel started from the first years of my studies in Architecture.

At that time one of the first and most memorable tasks I had to do was to design a **thirty-sqm shelter** for a specific city in Argentina, with the appropriate construction system for the location, the weather conditions and the available resources in the region, following the techniques of the local architecture. The resulted projects varied significantly along with the different areas for which the shelters were designed. Mine was located in a cold and cloudy city in the South region of the country. It was designed in wood framing panels and roof and with local stones for the foundations and bases. That design process introduced me into the world and the logics of the layered architecture and the **sequencing in construction**, as well it was the first glance to **lean construction** concepts.

A **competition for post-disaster emergency** units took place in the third year of my studies, and that was an occasion where I applied concepts of **modularisation and high-ended solutions** for details and connectors for our design. It was the first time we opened our design-thinking towards the **temporary architecture, quick responses and easy transportability** of these buildings, and the **versatility to be adaptable** to different topography conditions within the providence of Córdoba, Argentina, where these modules were going to be allocated. This region is characterised for having seismic activity, because it is near to the Cordillera De Los Andes, one of the world's most extended mountain ranges. Therefore, the base and foundations were adaptable to a certain extend for different ground surfaces.

In the fifth year of my architecture studies, a project for an **interpretation centre** led me to explore the solutions for **transportable and transformable architecture**. The design contained **modular and foldable units**, which were self-supporting and allowed to build up big spaces in a short time, ideal technology as well for other types of functions like emergency architecture.

Also, in our **final year thesis project,** we worked for a competition developed in the frame of the ONU Habitat III -United Nations Conference on Housing and Sustainable Urban Development- that took place in 2016 in Quito, Ecuador. The challenge was to propose how to achieve more dense cities in Latin America, under the main concepts of **sustainability and innovation**, re-densifying and promoting the renovation and diversity of cities with the design of social housings. Our response to this was with **dry architecture** as well, creating public corridors functioning as connectors inside the blocks in the most disused neighbourhoods of our city. Besides the rest of the good design intentions, the main thing to highlight from this experience was the type of solution for the construction system: once more, **quick and clean construction resolution, high ended finished architecture**, which promotes the **reuse of the structural elements in a future**. For the first time, we were referring to a familiar approach in this dissertation: the concept of **Circular Economy**.

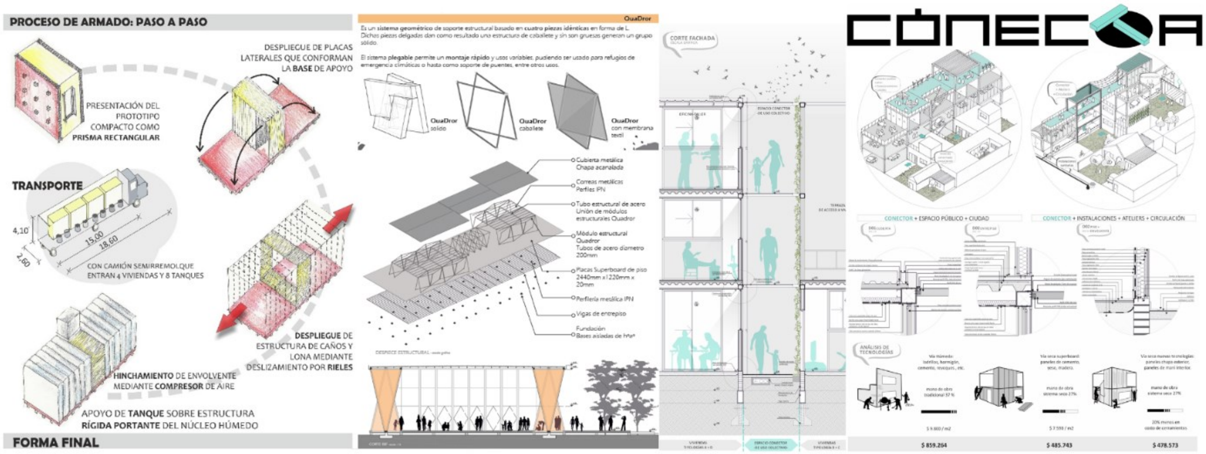


Figure 1.1: Author's background projects

All these projects I developed while doing my studies have led me to have a strong desire to work with a prefabricated and modular architecture, but in particular circumstances: with a social purpose and human commitment when there are states of emergency after disaster events, such as natural catastrophes -big floods, fires, earthquakes-, man-made calamities such as wars, or even special scenarios like a global pandemic, as it is currently happening while the developing of this work.

In these post-disaster situations, it is usually needed to construct emergency houses or specific buildings as hospitals, educational edifices, or places for care and health assistance for the affected people. The construction of these buildings required quick responses, precise and technical solutions and good planning for their build-up as well for their disassembly process if they are prepared to be relocatable or reused.

Although this work dissertation is limited by the time to develop it and to the case study worked in, my perspectives for the future are related to the development of the architectural responses for these emergency states mentioned, bringing BIM methodology to collaborate and ease the processes involved for the design and construction of temporary buildings for this scenarios, moreover through the whole lifecycle of these projects.

1.2 Objectives, goals and scope

GENERAL OBJECTIVE. The essential purpose of this study is to answer the question: **How can Building Information Modelling (BIM) support Design-Build-Relocate (DBR) building projects?**

METHODOLOGICAL OBJECTIVES. The following goals are aimed to be covered to answer the central question presented:

- Study and describe theoretical aspects of DBR (Design-Build-Relocate) projects;
- Research about temporary buildings and their purposes, design, construction and lifecycle;
- Study the main BIM aspects that relate to DBR projects;
- Analyse the potential BIM has for DBR;
- Analyse a case study under the aspects of BIM methodology for DBR project;
- Propose an improvement of one process in the case study;
- Apply demonstrations of BIM practises in a relocatable project used as a case study;
- Explore methods for the optimisation of the mentioned process;
- Extract conclusions and suggestions for further development.

SCOPE. The scope of this study will be limited to

- a relocatable project of a temporary exhibition typology;
- a BIM model of the structural discipline only;
- the process of redesign building parts within the procedure of **Fitting building parts into containers for their shipment and future relocation**

1.3 Methodology

After the completion of the Master's coursework, the thesis' author chose a topic to develop the dissertation work. It was provided to her a case study from a company to analyse it and apply practical knowledge acquired during the lessons. This project was closely related to the motivation and background experiences of the author; therefore, it was possible to explore the purposes of the research in the case study with certain freedom and pertinently aligned to the aspirations of the author.

ANALYSIS OF THE TOPIC. The analysis of the main topic -temporary architectures- had already been studied and developed in previous professional and academic experiences of the author of this work. It was completed and studied more in-depth during the period of the dissertation, reviewing key literature. The most relevant document consulted in this research is the book from R. E. Smith et al., *Prefab Architecture: A Guide to Modular Design and Construction*. 2011.

TYPES OF RESEARCH. A combination of several types of research was used:

- Documentary and historical research for the description of the central topic and its background
- Descriptive and explanatory research, for the description and analysis of the case study
- Case Study

GENERAL PROCEDURE. Regarding the procedure followed generally in the dissertation:

- The first phase was practical: to complete a commissioned work for the company with a BIM approach from which it was possible to explore the project, to understand it and to face issues that allowed to research for solutions and to learn from them;
- The second step followed was to decant the process done by writing down a step by step of the lessons learned. In this part, it was possible to understand more aspects to be included in the scope of the dissertation and to expand them even more. Also, the bibliography research was key in this section to confront the practical work with theory and to explore more which were the possibilities for applying BIM procedures to improve internal processes in the project. In this part, it was detected a process to be improved by applying practical procedures;
- The third state was to analyse the current workflow for a specific process in the company and the project, propose a better solution and verify it.

APPLIED PROCEDURES IN THE STUDY CASE. Particularly for the practical part, the case study was used for:

- Analysis of the current company's workflow for calculation of the transportation of the building parts;
- Evaluation of advantages for applying practical BIM procedure in that process detected;

- Proposal for an improved Process Scheme, applying BIM methodology procedures;
- Verification of the proposal's feasibility;
- Conclusion and lessons learned.

LIMITATIONS. From the classification of temporary architecture, the study case belongs to the Architecture for Events, and it relates to the lifecycle where the parts of the building need to be packed after dismantled, shipped and assembled again in a new allocation. The project is used as an example to apply some automation procedures to improve one process in the relocation of the building parts.

Even though the work done in this thesis narrows to the presented process, it is aimed to leave »doors opens« to further researches and developments in the field of BIM in relocatable buildings with additional functionalities of architecture, being of author's preference the emergency architecture for post-disaster events with humanitarian reasons.

1.4 Content structure

This thesis work is structured in six chapters, starting from the current Introduction part which aims to present an outline of the thesis content, its objectives and methodology as well as an overview of the author's motivation for working on the chosen topic.

The second chapter introduces the State of the Art of Design-Build-Relocate projects, outlining the history and classification of the temporary architecture, citing examples and presenting the main concepts that support relocatable buildings throughout research and review of the key literature.

The third section introduces the foundations of the Building Information Modelling methodology, relating this technology to prefabricated architecture and the potential that BIM has for this type of constructions.

The case study is fully addressed in chapter fourth. It describes the project and presents its context and general structure. It also reviews the project and the company’s internal organisation that led the project to be executed. Theoretical aspects of BIM are contrasted with the case study, pointing out a personal and critical appreciation form the thesis' author point of view.

The fifth chapter summarises the practical work applied in the case study. The focus is on a process selected to be improved by BIM procedures (automation of the process to fit the disassembled building into containers). Partial conclusions and discussions are opened here, besides possible solutions to avoid future shortcomings to face in this phase.

The final chapter corresponds to the conclusions based on the practical work done, lessons learned and future perspectives considered as a result of this study.

Each chapter begins with a short outline *"Scope of the chapter"*, which guides the reader to the main ideas covered in that section. Lists of Tables, List of Graphics and Abbreviations are at the beginning of the thesis, followed by the chapters previously described, and ending with References consulted along the thesis dissertation time.

2 STATE OF THE ART: DESIGN-BUILD-RELOCATE PROJECTS

Scope of the chapter: to introduce DBR concepts and present its different building typologies; to review concepts and criteria for prefabrication architecture used in DBR projects.

2.1 About Design-Build-Relocate buildings

The concept of Design-Build-Relocate (from now on referred to as DBR) projects refers to an architecture that presents temporality in its existence. Building projects that are designed and constructed to be transported and reused in a different construction site once they fulfil the purpose for which they were built. They are conceived since its design to be dismantled, disassembled, moved, relocated and reused. In fewer words, they are **designed to be deconstructed**.

For their limited use-time, temporary buildings require efficiency in their design concept form, flexibility in their use and functions, high precision in the technology solution adopted, lightweight of materials and speed in their construction.

The functions of relocatable buildings are diverse, from habitational, commercial, healthcare, educational or leisure applications, till security and military purposes. The range of building types resulted is wide: residences, high-rise buildings, sales-centres, cultural buildings -such as concerts or expositions halls-, schools, hospitals, military bases and more.

2.1.1 Origins & typologies

The temporary architecture -also known as ephemeral architecture- has existed since ancient times. Before humans began to settle down, their nomadic lifestyle led to the creation of temporary shelters for their survival until they needed to migrate and settle in a new site. These were the first vestiges of the ephemeral architecture that have existed in the History. After the human turned to a sedentary lifestyle, his need to gather in society, to carry out ceremonies or celebrations of different nature, led him to create meeting spaces, where it was necessary to create buildings constructed only for a limited period of time that comprised those events.

Despite the circumstantial character of the temporary architecture, it has been present throughout the whole History of the Architecture. Since ancient times, temporary buildings were commonly used for celebrations and specific events for which these structures were created and dismantled once the events were finished.

Beyond circumstances of survival and leisure, temporary architecture exists as a response to emergency situations where it is necessary to provide habitable spaces to people affected by disasters.

Although there is not a stiff classification for types of temporary buildings, based on their functionalities and context, it can be differentiated three types:[2]

- **Ephemeral Architecture of Events or Exhibitions**: created to gather people, celebrate events, host festivals or perform shows, all kind of events that last a limited time, so the structures are dismantled once the event is finished;
- **Ephemeral Architecture as a Dwelling (nomad conception):** an architecture merely of houses, that questions why humans should adapt to architecture and not the other way around. It interrogates and reviews the continuously changing human lifestyle in comparison to a millennial architecture of static conception, which is built to remain through the time;
- **Ephemeral Emergency Architecture**: an architecture of immediate response to situations of catastrophes where entire populations need assistance and shelters to survive.

After their lifespan is over, the destinies of temporary architectures are varied:

- To be dismantled and **discarded or recycled** (example of Sigheru Ban emergency architecture, Figure 2.6 to Figures 2.8, or ephemeral exhibitions -example in Figure 2.2);
- To be disassembled and reuse its parts for other purposes;
- To be dismantled, moved, and **reassembled again for next several uses** (temporary scenarios for seasonal events; or temporary exhibition structures, see Figure 2.1);
- To be disassembled, pack its parts, transport them and **reassembled in a new site for its permanence** (exhibition architecture; best examples are the temporary pavilions from World Expos).

The **Ephemeral Architecture of Exhibitions** is used for events such as expositions, scenography in streets, museums and more, and it is commonly designed as monumental architecture for their large scale. Universal expositions are as well good examples of this typology of buildings: architectures designed to expose technological and innovative advances of nations that are aimed to be dismantled once the fair is done. In chapter fourth, the building typology more typical for this type of event -the pavilions- are going to be explained in more detail, as the case study of this thesis belongs to the World Expo 2020. As another example of these cases, the project »Connected domes for events« -Figure 2.1 - are temporary structures designed to be assembled for short events and disassembled every time after events are done. The mechanisms to construct these buildings are specific for their easy packing, transportation and assembly process.

In this classification it is also included architectures for street exhibitions, that quickly appear and disappear in public spaces. They are usually considered as »Obsolescent Architecture« because their lifespan is planned intentionally short, and even though these buildings could still be used, they become obsolete after a time. They are closely compared with the contemporary trend of the high-speed goods replacement, driven by new technology and fashion launches or a programmed ended-lifespan of products. It is part of the mentality of an ever-changing society in which is a daily habit of throwing or discarding their assets that still work. Furthermore, these buildings aim to transmit messages or raise awareness of specific issues that the contemporary world faces. As an example, the Rainforest pavilion in London -Figure 2.2- was a temporary structure constructed to recreate a microclimate of a forest, raindrops and plants inspired in the Chilenial climate [3].

Figure 2.1 (Left) Connected domes for events. Baku, Azerbaijan[4]
Figure 2.2 (Right) Rainforest Pavilion, by Gun Architects. Photograph by Valerie Bennett [3]

The **Ephemeral Architecture as a Dwelling, -**also known as Portable or Nomad Architecture- is ephemeral due to its capacity of being moveable. It conceives the criteria that the architecture was born nomadic in the initial times of the human being history because it was precisely created by people who had a nomad lifestyle thousands of years ago.

Following that conception is that some decades ago it was brought back the concept of a nomad lifestyle, not only in architecture projects for buildings but also for cities, like in the ideas of the Archigram group in the ’60s with their utopic ideas for designing futuristic cities. One of them was the Plug-In-City, a megastructure with no building inside but a big frame where single and standardised service-capsules were able to be plugged, each of them with a limit lifespan depending on their function [1]. The Walking City (Figure 2.3), was another of their utopic designed cities; basically, they were enormous structures containing habitats inside, close to look like insects that could walk around searching for resources to be self-sufficient.

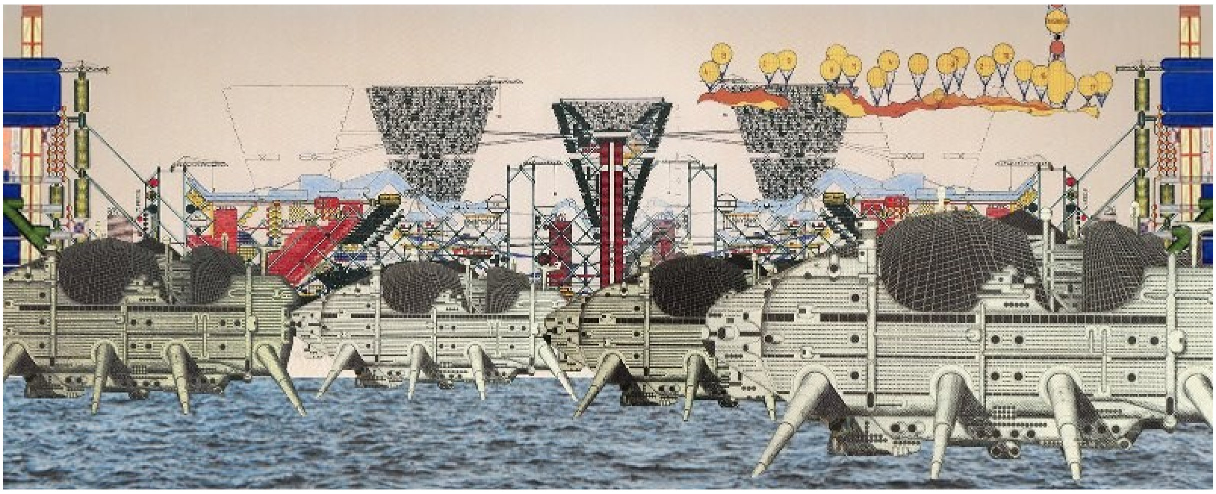


Figure 2.3 The Walking City, Archigram [5]

In a smaller scale, it is also contemplated in this classification designs for minimal units of habitability, which in most of the cases, the criteria reduce to the design of only the vital space for living. Sleeping capsules or small portable units are examples of design which people can take them as a backpack and carry out around the world.

The architect F. Marchet exposed this type of architecture in his theoretical project "the org", where he designed a mobile and independent modular system that offers minimal habitable spaces around the city, from dormitories till garden units, kitchens and work places[6]. These modules can be rented from a mobile app on the phones, similar conception to the current systems for renting shared vehicles, bikes or scooters in the cities.

Figures 2.4 & 2.5 Project »the org« by arch. Florian Marchet[6]

We are not far away from developing and using this type of architecture. Future challenges in the AEC industry are getting close to develop the technologies to support and develop these ideas, for a society and lifestyle that is demanding every time more alternative living spaces adjusted to their necessities.

Regarding the **Ephemeral Emergency Architecture**, it is one of the most common applications for relocatable buildings. More than their perdurability, the importance lies in their fast response to be constructed because they must solve particular necessities when catastrophes occur. They are characterised by a low-cost in their execution and the use of local resources and materials, available in the places where they are situated.

The most well-known and paradigmatic example of this architecture is the response to the Kobe earthquake in Japan in 1995. The architect Shigeru Ban designed temporary homes -Figure 2.6- and a church -Figure 2.7- for the victims of this catastrophe, with local recycled materials such as card-boards and paper tubes for the walls, beer crates loaded with sandbags as foundations and tenting material for the roof. The units were easily dismantled, and the materials easily disposed or recycled. [7]


Figure 2.6 (Left) Paper Log House Kobe, Japan, 1995. Image: Takanobu Sakuma [7] |
Figure 2.7 (Right) Paper Church, Japan, 1995. Image: Hiroyuki Hirai [7]


Figures 2.8 & 2.9 Cardboard Cathedral, New Zealand. Images: Stephen Goodenough [7]

As an emergency architecture, it should definitely be included the temporary buildings created in response to the global pandemic that outbroke the world by the end of 2019 and that, by the end of this dissertation work, it is still hitting every nation around the globe. Many questions will raise up on how to re-think the architecture, and which will be the requirements that will remain for the design of the future public spaces and buildings after the era of COVID-19.

Different approaches were addressed around the world in response to the necessities for spaces to host patients of COVID and for the treatment they need to follow. An example is the set of units as isolations wards with respiratory machines necessary for the patients built-up in record time in a hospital in Torino, North Italy -Figures 2.10&2.11-[8].

Figures 2.10 & 2.11 Carlo Ratti's First Intensive Care Pod Installed at a Temporary Hospital in Turin, Italy[8]

2.2 Related concepts for DBR

Buildings comply with a primary requirement to be relocatable: they are prefabricated. From this concept of prefabrication, more related terms are derived, which will be described below.

PREFABRICATION. Prefabricated construction is the process of building in a manufacturing site, or assembling the components part of a structure there and afterwards moving those parts to the destination site to assembly them and construct the complete building[9].

MODULARITY / MODULAR CONSTRUCTION. Buildings to be relocated are typically constructed off-site and commonly designed under Modular Construction processes. As Mark describes in his book "Design for modular construction", this concept refers to the use of three-dimensional prefabricated units that are essentially fully finished in factory conditions and that are afterwards assembled on-site to create complete buildings or major parts of them [10]. The benefits of modular construction concentrate in:

- speed of construction -shorter building times-,
- reduction in cost for the client, economy in the manufacture and production thanks to the repetition of modules,
- less disturbance in the building process,
- superior quality in the design and production process,
- less wastage of materials in comparison with traditional site construction,
- a decrease in its lightweight, and more reliability[10].

Modular construction also means a higher capacity to disassemble the building and reuse or recycle the materials and modules[10]. The most common materials used in modular construction are steel, concrete and wood.

CIRCULAR ECONOMY. This concept proposes a different economic model from the actual one, where it leads the idea of cycles instead of linear processes in business opportunities [11]. In other words, the objective of the circular economy is to allow products to be recycled or reused once the lifespan is over, and promotes a production model where leads methods of sustainable process and manufacture. It is the opposite concept to the linear economy, where the lifecycle of the products "has a clear beginning and a clear end"[11]. It is a close concept to the temporary architecture approach, where the buildings are designed to be disassembled and reused, and the goals of the design and production persues lean construction strategies.

LEAN CONSTRUCTION. It is a method which aims to produce less waste through the production cycle in the construction field or to reduce it as much as possible. Several principles are applied to be successful in its philosophy; among them, the main are:

- to reduce transport or unnecessary movement of materials;
- avoid extra inventories, prevent motion;
- non-productive waiting times;
- eliminate over processes and overproduction; and
- evade defects on the products which do not meet the expectations or specifications of the production [12].

AUTOMATION. To automate a process is to create a set of methods used to perform repetitive tasks on a computer. It aims to replace manual processes, accelerating the execution time of tasks and removing possible human errors that may be committed when working manually [13]. The automation of processes derives in the increase of the productivity of the overall process.

The next chapter addresses these concepts again, along with the introduction to the History of BIM in the field of relocatable buildings.

2.3 Prefabrication and relocatable buildings

2.3.1 Design for Assembly

Design for assembly necessarily requires a consideration of the construction sequence of assembly and disassembly the building. Organising the assembly process during design can have an enormous impact on projects' aesthetics. Without this information in the design process, may cause cost overruns and many more conflicts.

A useful way to think about the order of assembly is to evaluate first the designed assembled project and then start to dismantle it systematically. The technique of inverting the process may suggest a more effective assembly order. Integration of design, engineering and detail is of vital importance. Prefabricated modules, panels and components made into larger sub-assemblies allow a shift of work to the factory where product coordination can be better assimilated and integrated.

However, for logistical prefabrication matters, these are the assembly principles to consider [9]:

- Uncut units: dimensional and modular coordination between the subassemblies components to be assembled on-site, so that little or no cutting is required.
- Minimise elements: limit the number of elements to be shipped and assembled to reduce the possibility of joint failures.
- Easy to handle: avoid designing elements that are too large for manufacture, shipment or hoisting from a size or weight criteria.
- Repetition: the use of repetition in the construction sequence leads to reach higher quality and faster erection. In larger projects, it becomes more important because great reduced standardisation costs can be achieved
- Simulation and prototyping to foresee potential conflicts. The BIM thechologies has enabled much of this to happen through analysis in 4D and 5D (cost and time). Besides, the creation of prototypes and mock-ups allows early prefabrication errors to be resolved.
- Accessible mock-ups: Teams can place the prototypes on-site for the project assembly teams to observe. This can be especially important if several individuals are installing.
- Accessible connections: to facilitate installation, design assemblies so that on-site workers can reach the elements at an accessible height. Sequences that do not allow workers to access parts for screwing, bolting, sealing or nailing should be reviewed on-site (for example, connections behind columns, spandrel beams, corners, etc.), as well as connections that may need to be accessed for maintenance or dismantling processes
- Clearances: Although a structure can be designed and manufactured to fit perfectly, all details should have a bit extra space in addition to their actual dimension due to variations in the site

as a result of dimensional intolerance of erection or the simple manoeuvring of an element in its final space.

- Clash detection: commonly, cost overruns are due to changes in orders as a result of conflicting systems in a building. Clashes are typical between the structure, the MEP systems and architectural elements or spaces. The services often conflict with each other and with the structural system. In off-site assembly, this can occur between prefabricated elements but more significantly between a prefabricated element and an element built on site. Taking an element to be reworked is expensive. If not properly coordinated, prefabricated elements can cost more than ever considered on-site. Using BIM tools during the design phase, clash detection can be significantly minimised.

2.3.2 Sequencing

Designing for assembly requires architects, engineering and construction professionals to test sequences before construction. This might cover:

- developing early schematic sketches to practice construction process;
- using digital tools to map the construction sequence;
- going back to the source material and to detailing of connections and assemblies to ensure that sequence is well executed;
- detailing the order in which subassembly elements are assembled, thinking simultaneously of the actual construction operations.

Some other considerations:

- To avoid inefficiencies in schedule or critical path and increase on-site assembly: flatten the manufacture-to-assembly sequence capitalising on using fewer manufacturers because too many trades can slow a project down
- For component and panelised elements, the assembly sequence on site must be cautiously ordered. Within each load of a truck, the components must be placed in the reverse sequence to accommodate the erection process. In the contract, it is specified who is responsible for the elements damaged in transit and how rewards will be made.
- The specifications of the prefabrication should indicate how the module, panel or component will be picked up because depending on the weight and size, different shapes will be used (e.g. strap or wrap-around belt for the lighter elements, or cranes for the larger objects) and depending on the material and its fragility, the methods of collecting the elements may also vary.

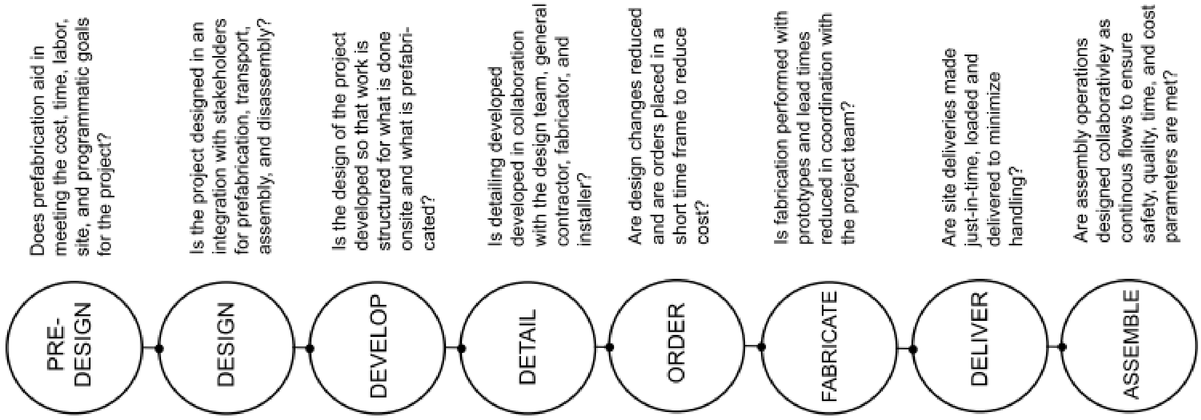


Figure 2.12 Outline of the off-site process of prefab construction and the considerations to be made at each level of project delivery. [9]

2.3.3 Transportation

Transportation presents a major in the design of the elements and how they come together in the overall structure.

The process of breaking down the elements to make them transportable limits the size of the panels, modules or individual components, as well as the final shape of the building by determining the joints, reveals and dimensions of the elements. Also, building sub-assemblies must be protected during transit to reduce damage

Besides transport and assembly, the sequencing that influences the staging of the design must also be taking into account. Although ideally, elements manufactured outside the construction site should not be standing still, staging occurs in all construction sites. How the materials are protected is critical, especially if they are finished and ready to be installed. Care must be taken to ensure that subassemblies are installed as soon as possible.

For transporting construction products from manufacture and fabrication site to the assembly site, there are basically two primary methods:

- -Transport in containers. Containers are standardised in size, collection points (lifting method and location), attachment between adjacent units and chassis and shipping covers by the International Organization for Standardization (ISO), an international organisation that develops standards in different industries to be consistent across international borders.
- Cargo shipping (also called “dimensional” shipping). It applies to all panels, modules or components with abnormal sizes, that are too wide, high or long to fit into ISO standard containers. It includes rail, truck, ship, aircraft and, rarely, helicopter.

2.3.4 Remarks on Prefabricated architecture

As Smith states in his book, architects who deal with prefabricated buildings must think more like product designers, because it is essential to work on the development of the production method as an integral process. Cost and time taken in a project to manufacture it determines its feasibility in the market. Product development is the process of including all the activities that take place from market interpretation to the design of final products. Prototype production and testing activities are included in this equation. Analogically, architects working with prefabricated architecture must see their ideas integrally from the concept phase to the final use.

3 THE USE OF BIM IN DBR PROJECTS

Scope of the chapter: to introduce the BIM methodology in relation to DBR projects based on the main literature research and review; to expose the main challenges that architecture and engineering have nowadays in relation to the new technologies that may allow them to make progress and better developments for future.

3.1 Digital Prefabrication

Based on the book from R. Smith, *Prefab Architecture* [9], nowadays, there is a shift in the paradigm of the ideology in production. The implementation of digital tools for design and fabrication phases eased this evolution, through the technology of the Computer-Aided Design and Computer-Aided Manufacturing (from now on referred to as CAD and CAM, correlatively).

These technologies have origins in the mass production from the Industrial Revolution and Digital Automation (from now on referred to as DA). DA is the process to automate machines for doing the human labour work, always controlled by the instructions previously given by computer numerical control (from now on referred to as CNC), which are numerical commands set in the computer.

During the '90s, software applications from mechanical engineer and parametric platforms like CATIA appeared. Since their existence, architects and engineers started to rationalise the design process in the creation of extremely irregular geometries. These applications stored information concerning "*materials and methods of production with the human interface so that design decisions and their impact on production logistics could be integrated*"[9]. This idea is similar to the one implemented in the fields of architecture and construction with the use of the methodology Building Information Modelling (from now on referred to as BIM). This methodology gives the power to digital design and manufacturing to be more innovative, have better quality, and have better control of the cost estimation.

The success in the process of prefabrication requires an integrated delivery, and this depends on a well-planned overall strategy defined since the very beginning of the project. One main factor in this is the definition of the contract structure -usually known as Delivery Method, addressed to the case study in chapter fourth-, where all the players in the project are defined as well as the ways of collaboration between them throughout the development of the project.

The advances in digital tools are providing opportunities for increasing fabrication capabilities. BIM and automation processes (CNC manufacturing) can add value to the principles of integration in prefabrication. Both contemporary movements allow for greater levels of process collaboration and product customisation. Using these tools with an integrated delivery framework, prefabrication is increased and improved.

3.2 BIM methodology in Prefab architecture

The increased productivity in construction has occurred, in the first place, through the DA in product design -that includes CNC and CAD/CAM software in the process, and in second place, throughout Digital Integration in the sharing of information throughout 3D models in BIM.[9]

The main difference between BIM and CAD/CAM software is that in the case of BIM programs, they are entity-based and allows for information to be associated with 3D objects which are specifically building objects (floors, walls, windows or roof types for instance). As CAD/CAM software does not have embedded content, all of the information relies on the designer or modeller to develop and is linked directly to CNC output. For digital fabrication output, information can be exchanged from BIM platforms to CAD/CAM.

BIM existed from almost 30 years ago, but It was not until the first decade of the 21st century that emerged in the AEC industry. Some factors that led to occur it are:

- project owners' dissatisfaction for the cost of delays and typical change of plan for construction projects;
- greater collaboration between participants in construction projects;
- demands for complex BIM tools from pioneering architects to make real their projects ideas (like Frank Gehry developing "Digital Project" software with his project Guggenheim Museum Bilbao)

The adoption of BIM in the AEC industry relies on the enhance that promises: "*Architects can increase their productivity, contractors can shorten construction times and reduce waste, and owners can manage their properties more easily*."[9]

Traditionally, the AEC Industry system works based on separate sets of information that are shared carefully among owners, designers and builders. The inefficiencies of this system caused the calls for greater collaboration within project teams. BIM allows this requirement to effectively collecting and integrating a huge amount of information over the lifecycle of a project.

3.3 Collaboration

Architects gain a lot from a more collaborative environment: in their work, they essentially create, gather and organise information. Both the value of their work and their role in the overall construction process depend on the extent to which other participants in the construction process depend on that information.

In the current process, the information contained in a set of drawings and specifications falls far short of what is required to build a building. Contractors, manufacturers, vendors and others must add a huge amount of information to that received from designers to actually construct a building. The information categories are for constructability and details contained in shop drawings and other presentations. If the information added by builders were available during the design phase, architects would be in a position to incorporate it into their designs rather than struggle to respond to it as they do now.

3.4 Parametrisation

Parametric modelling is the capacity to alter features of the BIM for simulation resulting in have them updated in real-time. A parameter may be changed in a BIM model and automatically reconfigures the entire project to reflect the modified parameter. There are software applications developed for particular purposes to be undertaken during all the building project phases of design, development, and construction. Examples of those functionalities are for performing scheduling in time and cost modelling, free-form modelling, of various analyses as structural, green, programming, code review, and other analyses on a BIM model.

It may be argued that the major profit of the BIM is in productivity gains. When BIM technology is used, the time required to produce detailed construction documents is reduced. If this time saving can be moved to the forefront of the process in pre-design and schematic design to enable project stakeholders to make integrated decisions regarding function, form, productivity and methods of prefabrication and construction, not only will time be saved in design delivery, but also in construction delivery.

Linking the BIM model to manufacturing enables this process to be further rationalised. However, this change in operations will demand project stakeholders to move the design process forward, and therefore change their traditional billing cycles on a project.

Architecture and engineering firms use BIM to improve project delivery and project execution. Although it is hard and utopic, to achieve a complete BIM model is the goal to put it to use in the real world.

3.5 Benefits of BIM for DBR

BIM is the future of the prefabrication. By linking time to three-dimensional information, the simulation of the construction process can anticipate the challenges that will arise during construction in a daily schedule. In contrast, two-dimensional paper documents do not allow this type of analysis. BIM tools have the capability to interact with automation equipment, such as CAD/CAM methods. Because the model accurately represents the properties of the objects for manufacture, the CNC allows machining to precise dimensions. BIM has the potential to let multiple manufacturers and builders produce objects in their shop simultaneously and then deliver and assemble them on-site without problems due to the dimensional accuracy of the model and manufacturing equipment.

To take advantage of BIM for manufacturing and prefabrication, information at the construction level must be included in the model. This usually happens in two ways:

- The construction model is a detailed design that expresses the intention of the designer and the client. Contractors are expected to produce their own stand-alone construction model and documents which include shop drawings and presentations from subcontractors. This method is comparable to the way in which traditional construction delivery occurs in a Design-Bid-Build (DBB) contract structure (the different project delivery methods are explained in this thesis in chapter fourth when analysing the case study).
- The construction model is a detailed design that will be further detailed for use in all aspects of construction, planning and manufacture. The design model is in this method a starting point for the development of the construction team.

Regarding the construction, the potential of BIM models relies on:

- allowance for quantity take-offs, from which it can be obtained specifications and properties for producers;
- improvement in the planning and scheduling of subcontractors, as it allows to ensure the timely arrival of people, equipment and materials;
- reduction in cost;
- better coordination on the job site;
- better coordination of materials and products during the early stages of an integrated process.

3.6 Key challenges and aspects

With regards of the methodology itself, as Smith refers in his book, the greatest but hard to achieve-implementation of BIM would be an open-source platform where construction projects would be conceived, programmed, designed, visualised, subjected to various simulations, reviewed for code compliance and built directly from the digital model, which would then serve the owner for the facility's operation and maintenance. [9]

In this conception, the BIM model(s) would be a series of interconnected data structures to which all the participants in the project would have direct access. The realisation of this objective would change the way projects are created at each stage, leading to new models of design and construction practice. Although this objective is theoretically feasible, it faces several obstacles. Signs of progress are being done every time more. However, many architectural firms are using BIM only to develop 2D drawings in a more automated way, so the link to specifications, product information and prefabrication is still missing. The responsibility for this progress is not limited by the technology alone but is determined by the organisational and environmental framework in which the technology is deployed.

In relation to the potential of BIM for DBR, the creative process in architecture has been transformed thanks to that process automation made production much more agile and has meant a significant change in design processes. Design paradigms are being transformed at unparalleled speed. Computerised processes have made it possible for architects and designers to have great flexibility in their creative process, and to become more and more rationalised in their pursuit to parametrise building elements. Some examples of the changes in paradigms are the following:

- Generative design for relocatable buildings: new paradigms in the creative process, allowing more flexibilisation in the modularisation of buildings parts.
- Designing robotic construction and automated processes for the building assembly and disassembly (buildings that could be built by themselves).
- Building with full automation in the construction process, with all phases included, without human labour (already reached on with 3D printers, totally programmed. Figures 3.1 & 3.2)

Figure 3.1 Example of 3D printing for construction. Left: Cobod company of 3D printers[14]; Right prototype of 3D printed house in Belgium[15].

4 CASE STUDY

Scope of the chapter: to present the case study, introduce the history of the building typology and outline general characteristics of how, where, and when the project is being held. To give an overview of how the project is organised within the company, the main actors involved in the process and how the model information flows. Concepts and practices of the BIM environment are referred to, and it is made personal assessments and critical points of view for the use of BIM in the project.

The case study is the Slovenian Pavilion for Expo Dubai 2020, one of the most massive architecture, engineering and technology events in the world. It is the representative building of Slovenia, and its design reflects the main characteristics of its land, people and culture under the concept of "*Green Smart Experience*". It shows sustainability, modernity and creativity of the nation under its green environment and valuable economy.

Figure 4.1: Exterior view render, from the design phase—image produced by the thesis' author.

Figure 4.2 & 4.3: Exterior view renders from the design phase—images produced by the thesis' author.

4.1 Project context

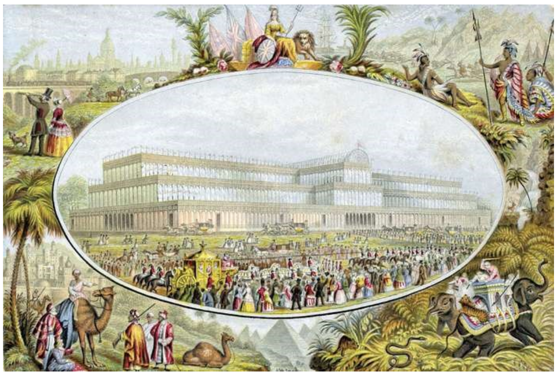
The Slovenian Pavilion is a project for a world's fair, also known as World Expos. As it was presented in the second chapter, world expositions are huge international exhibitions designed to present the achievements of countries. They take place in different parts of the world, at a specific location, for a certain period -usually between three to six months- and they are designed under specific topics or slogans which encompasses universal themes that affect human life [16].

These exhibitions have existed since ancient times when merchants occasionally set up camp at central crossroads and entertainers found a willing, festive audience[17]. In the mid-nineteenth century, after the Industrial Revolution, these events began to be celebrated as Universal Exhibitions with a large number of nations involved. Each participant country had the opportunity to design and construct a building to show the characteristics of its culture, economy, industry and history[16].

Since 1928, World Expos are managed and regulated by the Bureau International des Expositions (BIE). It aims to bring order to exposition scheduling and to set up the rights and responsibilities of the host city and participants[18]. From the early 21st century, these huge events are held regularly every five years, and they kept the tradition to have large entertainment zones where visitors can enjoy rides, exotic attractions, food and drinks [16].

Nations showed up with several inventions in Universal Expos along the time. Best examples were the elevator in 1853; the sewing machine in 1855; the calculating machine, 1862; the telephone presented in Philadelphia in 1876; the Eiffel Tower, the gas-powered auto in Paris, 1889; the controlled flight, the wireless telegraph, the ice-cream cone in 1904; television presented in New York in 1939; computer technology and fax machines, 1964; advances in robotics in 1985; and many more [17].

There are also several emblematic buildings constructed in these expositions: the Crystal Palace in London (1851) and the Eiffel Tower in Paris (1889) are the most memorable examples of nations' achievements in the history, both prefabricated constructions made in iron and characterised for its huge scale and fast assembly process, unprecedented features in constructions by that time.



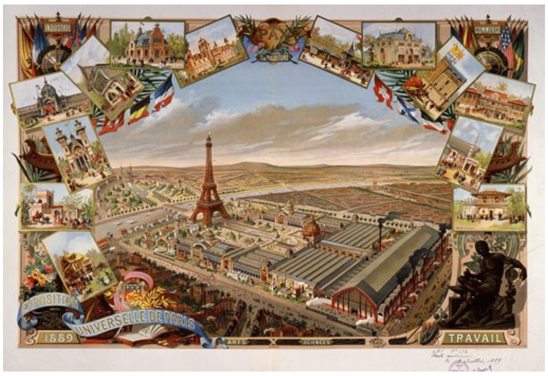


Figure 4.4 (Left) Illustration of the Crystal Palace at London's Great Exhibition, 1851 [18].
Figure 4.5 (Right) Announcement of the Universal Exposition of Paris, 1889 [19].

Currently, almost all countries in the world take part of the World Expos, and they participate constructing a representative building for their nations, to showcase themselves with innovative construction solutions, materials, and inventions in architecture. These buildings are known as **pavilions** are when the fair is over, they are dismantled, relocated, or reused for other purposes.

4.1.1 Pavilions building typology

The conception and construction of exhibition pavilions have resulted in pieces that have been fundamental to understanding the development of the History of Architecture. This building typology is characterised for being **temporary** and **dismountable**; hence their ephemeral nature allows a broader range of experimentation and creativity. The freedom of a program allows the architect to explore and create new lines of research in all architectural fields [16].

Despite the wide range of expression and innovation that the pavilions allow, there are specific characteristics in all of them related essentially to the **time management**. As they are temporary constructions, they need to be **light and quick to build**, so it is essential the use **of prefabricated and industrialised systems**. Consequently, it is also important the use of serial and transformable systems, to admit modifications according to the needs of the exhibition. On the other hand, and because of their context, this type of architecture contains implicit political, social and economic aspects, because they are used as a way of publicity of the country they represent [16].

For all the mentioned reasons is that this type of architecture is of great relevance to the development of the History of Architecture. They promote architectural researches from all approaches: formal, spatial, constructive and socio-cultural [16]. Also, they are the cause of innovative solutions along with the motivation to implement new technologies and **methodologies to accelerate and agile processes** for obtaining better performances.

4.1.2 Expo Dubai 2020

The 2020 World Expo takes place in the city of Dubai, located in the United Arab Emirates, Western Asia. This edition of the Universal Expo has a theme called "Connecting Minds, Creating the Future", and it will have three subthemes: Opportunity, Mobility and Sustainability, each one with its own representative building[20]. Countries from around the world developed their projects integrating these concepts. The case study is the representative pavilion for the Republic of Slovenia, a south-eastern European country.

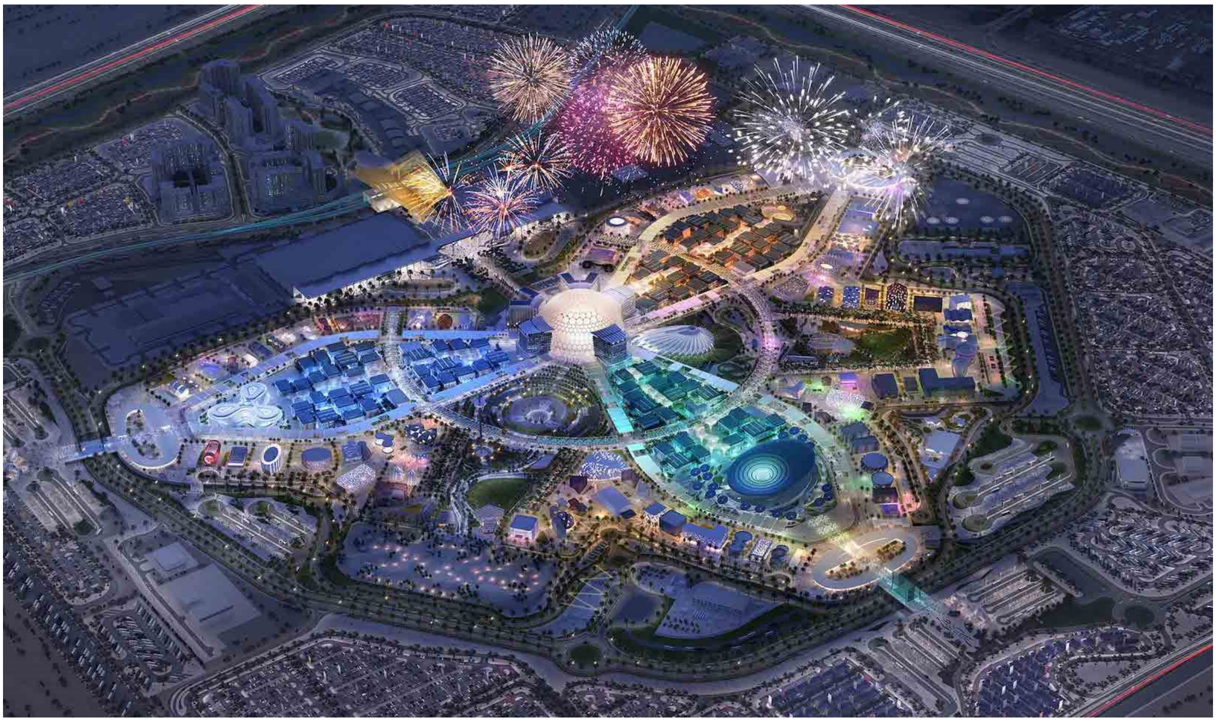


Figure 4.6 Project for Expo Dubai 2020 [20]

4.1.3 Slovenian Pavilion's design concept

The design concept is based on the idea of *"Slovenia as a green oasis of Europe"*[21]. Each of its storeys refers to some specific characteristic of the country:

- ground floor represents the value of Slovenia's drinking and purify water existing on its nature;
- first floor exposes the country's large green extensions of forests, and
- second floor -designed for VIP visitors- will exhibit the nation's economy.

Figure 4.7: Interior view renders, from concept design phase. by Magnet-Design [21]

On the ground floor the concept of the purified water is represented with a large water surface which alludes to the rivers, lakes, and sea of Slovenia; surrounding this, in the central part of the building's ground floor there are the four cardinal points designed in stone, showing the country's position at the crossroads of transport routes (Figure 4.9).

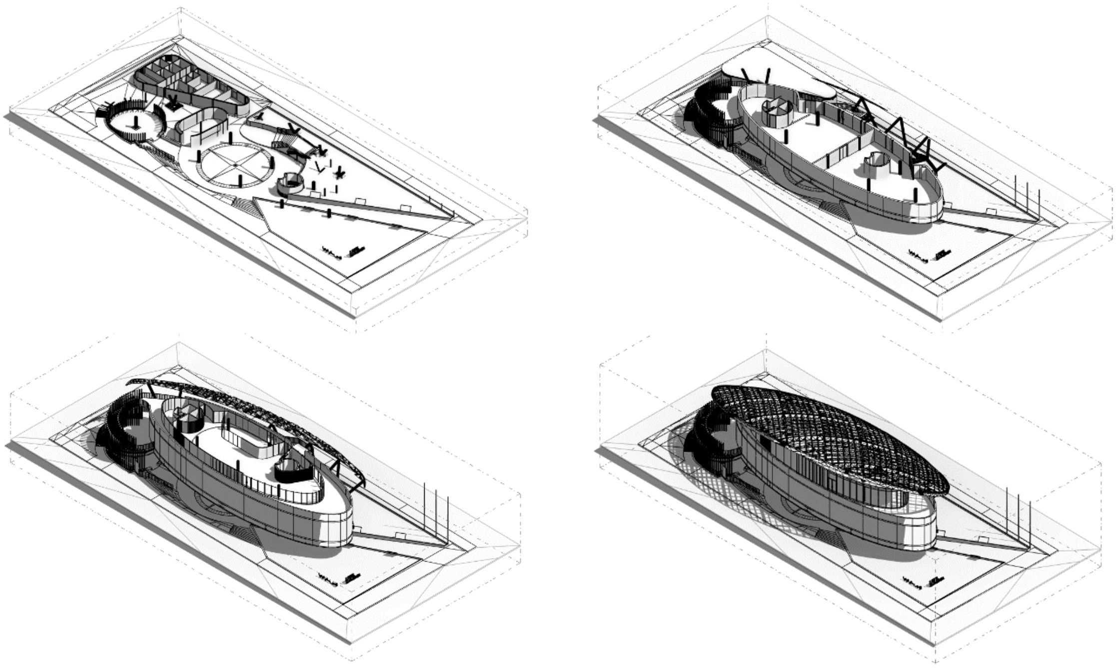


Figure 4.8 three-dimensional views of each floor -images by thesis' author

The green characteristic of the country's geography is represented through the climbing plants hanging from a long curve green wall along the whole surface of the first-floor wall. This green wall will be kept cold and hydrated, providing cooling refreshment for visitors.

Figure 4.9 Exterior view render, from the design phase -image produced by the thesis' author.

The Pavilion's timber roof is designed as a sieve and commemorates the long tradition of woodware products manufacturing of a southern town called Ribnica. Wooden sieves and other woodcraft goods from this place were the first Slovenian products to be sold abroad the country four hundred years ago.

Figure 4.10 site photos of the timber roof during construction. Photos provided by the PMC.

4.1.4 Background project

The previous edition of the Universal Expo was in 2015, and the hosting city was Milano, in Italy. The Slovenian Pavilion constructed in that edition was dismantled, transported back to Slovenia and assembled in the region of Pomurje after an open call was done from the government to present projects for the reused of the building. Nowadays, the ex-pavilion is a Regional Promotion Centre that promotes the economic tourism activities in the degraded area of Pomurje[22].

Figure 4.11 Slovenian Pavilion in Milano World Expo, 2015[23]

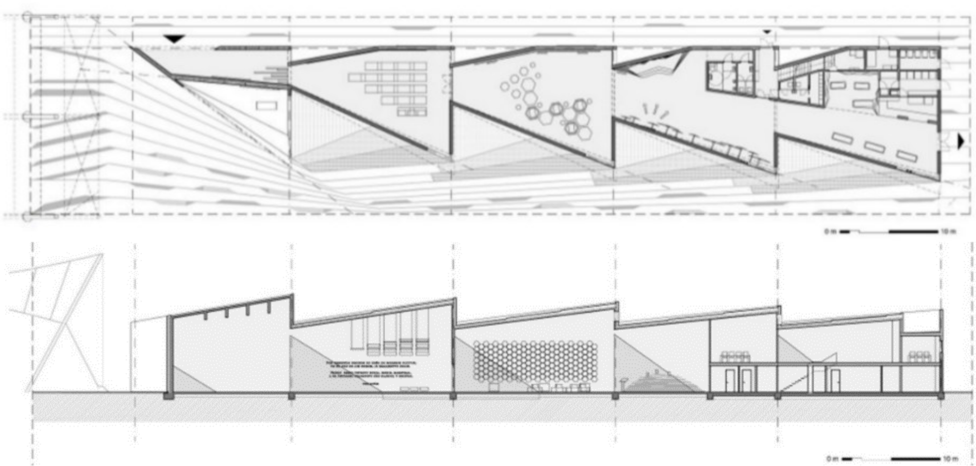


Figure 4.12 Floor plan and section of the Slovenian Pavilion in Milano World Expo, 2015[23]

The temporary building was designed under criteria that allowed its future relocation: prefabrication, modularisation, and lean constructions are its main characteristics.

Figure 4.13 »Expano« building, ex pavilion in Milano's World Expo 2015. Photos from the thesis' author

In the same way the relocated Slovenian Pavilion for 2015 was reassembled and repurposed as "Expano" building for the north-eastern area of the country, the current pavilion for the world expo 2020 will be dismantled, shipped and relocated in some Slovenian area when the expo will be finished.

By the end of this thesis work, it is still not decided where and when the Slovenian Pavilion for Expo Dubai 2020 is going to be relocated and how it will be repurposed.

4.2 Project organisation

4.2.1 Project delivery method

The context of collaboration in any building project is an essential factor for its realisation. In prefabricated projects, team members need to make early decisions to organise off-site production, which requires a collaborative and integrated process of delivery[9]. The project delivery method (from now on referred as to PDM) is the way to organise the different services to execute a project in the phases of Design, Construction, Operations, and Maintenance of the building. In this case study, the PDM is executed for the phases of Design and Construction.

Despite there are many methods for delivering a project, there will be exposed three of the most common ones: Design-Bid-Build, Design-Build and Integrated Project Delivery (see Figure 4.14). BIM has different approaches for each of them and those will be discussed after presenting their main characteristics.

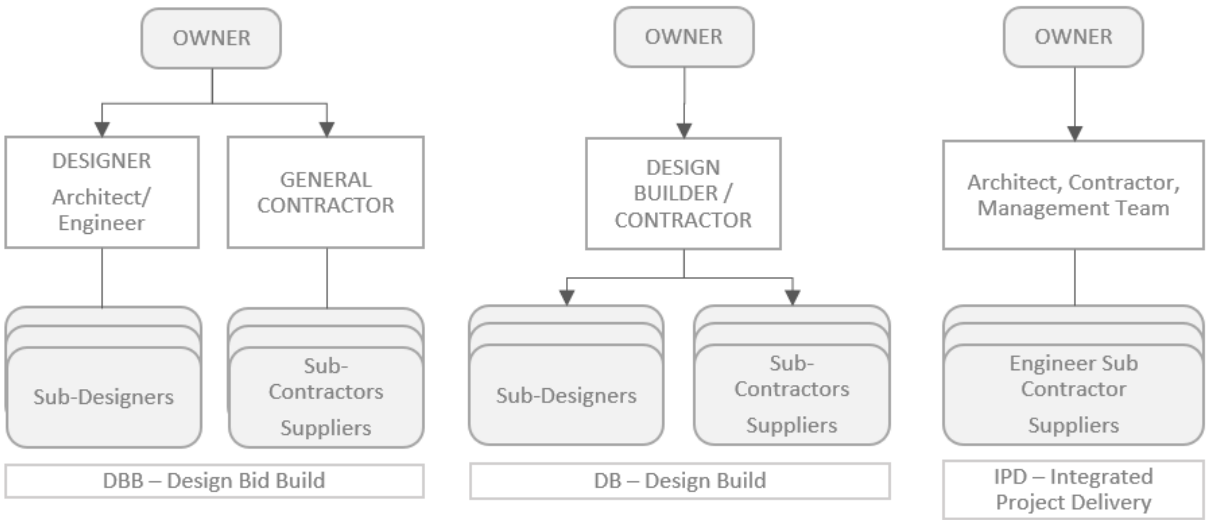


Figure 4.14 Schema comparing DBB, DB and IPD methods

The Design-Bid-Build method (from now on referred to as DBB) is the traditional model for public sector infrastructure projects: bids are solicited from contractors based on contract documents where the owner specifies information about the project details and a set of blueprints. Afterwards, a contract is adjudicated to the most responsible and lowest tenderer [24]. The tendering may be done for particular phases of the project; therefore, the designer and the contractor are different actors.

As it was introduced in the third chapter, in DBB contractors are expected to develop their own independent construction model and documents that include shop drawings and presentations from subcontractors; fact that is seen by architects as a relief from risk and liability during the construction process because the drawings submitted by design teams for construction are intended only. The transfer of responsibility after the tender is for the contractor. This procedure requires contractors and their subcontractors, including manufacturers, to develop all proposals from scratch. Matching the design intent of the design team with the drawings required for fabrication results in many rounds of presentations, communication and, most often, errors in the on-site assembly. Nevertheless, the design process success as long as designers provide BIM model information to manufacturers and retailers and allow them to develop design information as needed both to maintain design intent and to refine the design for manufacturing [9].

On the contrary, in a Design-Build (DB) project delivery method, the owner solicits bids for joint companies that develop the design plus the construction of the project, hence the companies have integrated teams of architects, engineers and builders. As Ryan Smith describes in his book "*Prefab Architecture: A Guide to Modular Design and Construction*", there are substantial benefits in a DB contract:

- Reduce the overall project duration;
- Allow for early decision-making regarding prefabrication systems;
- Improve coordination and constructability;
- Reduce construction time[9].

The benefits of this method are clear in terms of cost and quality, an additional benefit with prefabrication system[25]. DB also *"allows for the delivery process to potentially create a smoother flow of information between design and construction organisations"* and allows project players to *"focus less on specific deliverables between organisations and more on overall deliverables to the owner."*[26]

The method IPD aims to improve project efficiency and reduce "waste" in project delivery through involving all possible participants (people, systems, business structures and practices) in all phases of design, fabrication, and construction. It is considered as waste any type of process that does not add value to the final product; for this reason, IPD is associated directly with the philosophy of Lean construction.

The selection of a design and construction PDM depends mainly on the client's characteristics and requirements. The success of a project delivery method relies on the level and quality of collaboration and communication between the actors involved. Regarding BIM, it is crucial how the different teams and stakeholders are willing and able to collaborate, organise and exchange the information during the project[24].

PDM and BIM

The implementation of BIM in a project facilitates a considerable amount of work. For example, it is easy to get the necessary cost estimation of the project from the model when using BIM software, valuable information for making the tender. After the contract is awarded to the contractor, their team will receive the BIM models, and they have to update the project. While the progress is being made, both architect team and the client will be informed about it. Nonetheless, the success in implementing BIM depends on the performance of the team to work collaboratively in one or various digital models [26].

Eastman C. *et al.* explained in their book *BIM Handbook* the comparisons between BIM applied to different PDM. DBB method has the highest challenge in using BIM because the contractor is not involved in the design process, and that means it must build a new model after the design is completed. The case of the DB contract type is a great chance to take advantage of the possibilities that BIM technologies offer because only one entity is responsible for both phases Design and Construction. IPD projects are the best method for the constructor to be involved since early stages of the design process, which means an increase of the benefits that BIM methodology and Lean Construction offers, as well as BIM collaboration methods and tools[26].

PDM in the case study

The Pavilion's delivery method is Design-Bid-Build (DBB), where the owner (Slovenian Government) made separate bids for the design and the construction. Hence, these processes were not held by the same companies.

As it was explained, implementing BIM in a DBB process is a tedious task in comparison to other methods of PDM. This type of project delivery method (DBB) is not usually the most cost-efficient approach to design and construction[26]. The communication flow and coordination between teams of different companies take much longer than when there is only one entire company working on the complete process of design and build. In DBB methods, usually, there are double processes when something needs to be changed from the concept design phase to the executive project.

The PDM method selected for a project is key for the performance of the team. The project success relies on the collaboration's quality within the teams, between the companies involved, and throughout the BIM environment and processes adopted. In the project of the Slovenian Pavilion, the PDM limited the scope of the application of certain benefits that could be achieved with BIM technology.

4.2.2 Stakeholders and actors

From the design phase to the construction of the Pavilion, there are many actors involved. Based on the experience done through this dissertation work, it is shown the main actors that took part in the project and its construction.

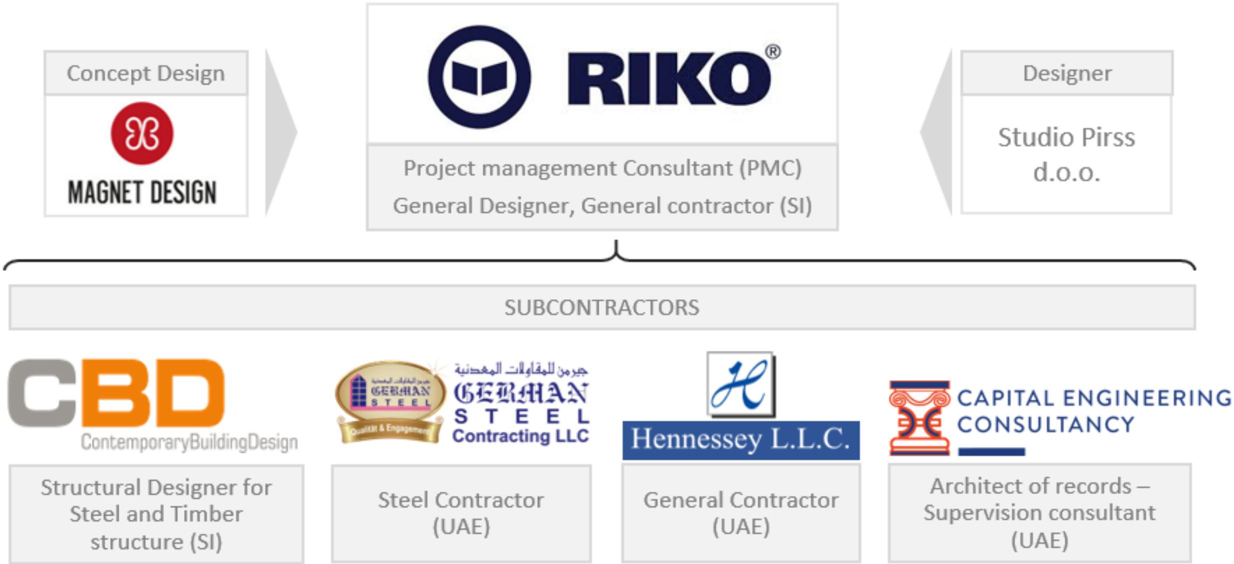


Figure 4.15 Main companies involved in the case study project.
Diagram based on the experience made with the company through this dissertation work

Riko is the Project Management Consultant (from now on referred as to PMC) and is responsible for the building's construction. They won the public tender for the Slovenian Ministry for economy and development, and they received the project commission of the Slovenian Pavilion from the concept design phase previously developed for another company. Since then, Riko was responsible for developing the project design and the executive documentation for construction and is in charge of select, contract and manage the rest of the companies with whose will construct the project.

Each of the sub-contractor companies developed their part of the building project according to the executive documentation that concerned them. The division of the project -regarding the different actors involved and the BIM models that were used during the development of this dissertation thesis- is structured as follows:

- A company from Dubai specialised in steel structure made the structural model: they developed the technical solutions and executive drawings for its construction as well as they were responsible for the fabrication and installation of the steel parts;

- A company from Slovenia made the timber roof model: they developed the technical solutions of the roof and executive documentation for its assembly, as well as they were responsible for the fabrication of the cross-laminated timber parts. Those pieces were shipped from Slovenia to Dubai and built up in the site construction once the steel structure was erected.

Other parts of the building were produced and developed for different companies, like the green wall that was produced by a Slovenian company Knauf Insulation, who designed it and built it up on-site with plants raised locally in a nursery.

With regards to BIM implementation, the challenge for the PMC in a DBB project as the current is to coordinate the stakeholders in charge of each part of the model. The PMC needs to have a coordination flow immersed in a full BIM environment. If the PMC were able to federate the models received from the stakeholders, their work would be much more fluid, and it would not only rely on the models provided by the parties.

Federated BIM models have the potential that they can be updated every time, checked and supervised more consistently and thoroughly.

This current section about actors involved directly relates the concepts discussed in section 4.4 and those that will be presented in 4.6 and 4.7. More assessments are done in those parts.

4.2.3 Model breakdown structure

This section will be addressed from the experience made and observed during the work of this thesis. It is merely purposed to study the aspects of BIM implementation in projects, and the case study is used as an example to compare desirable BIM practises with real case applications.

The organization and division of the BIM models in projects impact in their overall performance. A clear and strict division of disciplines is usually made when working in BIM projects, setting rules of whom models which elements, how they are shared and the criteria or objectives of the collaboration. This information is established in the BIM contracts (known as BEP: BIM Execution Plan), made before the execution of the projects.

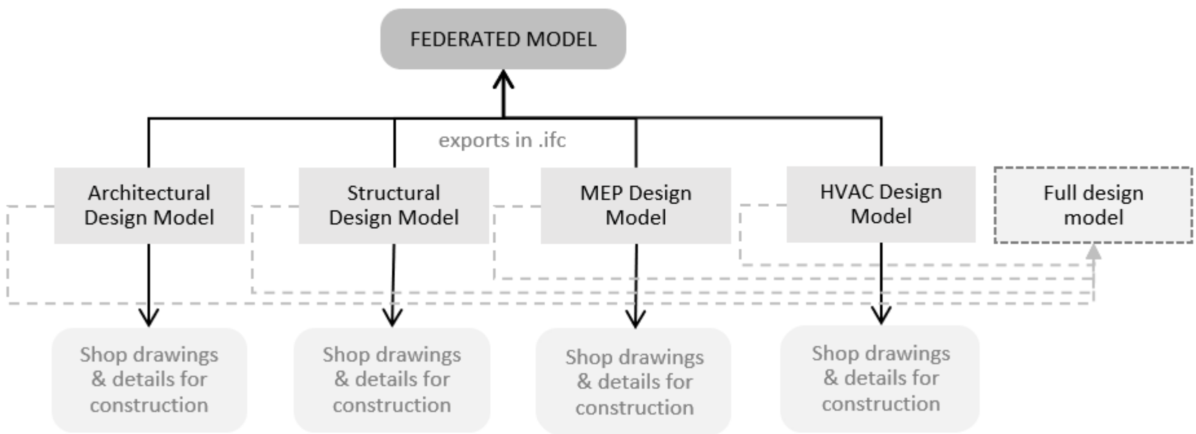


Figure 4.16 Organization of BIM models for federation

In this project, several actors participated, interacted, and were coordinated in a long-distance way, regularly communicating online to complete the project. The way in which they organized the BIM models were as following:

- One of the 3D models of the project was for the discipline of architecture, it was in native format, modelled with the BIM software Revit. It had all the architectural elements and materials of the project.
- The other primary model was an IFC format file and consisted mostly on the structural elements: the steel structure, the timber roof, the concrete foundations and some other elements that did not belong merely to structure, such as the green walls and stairs.

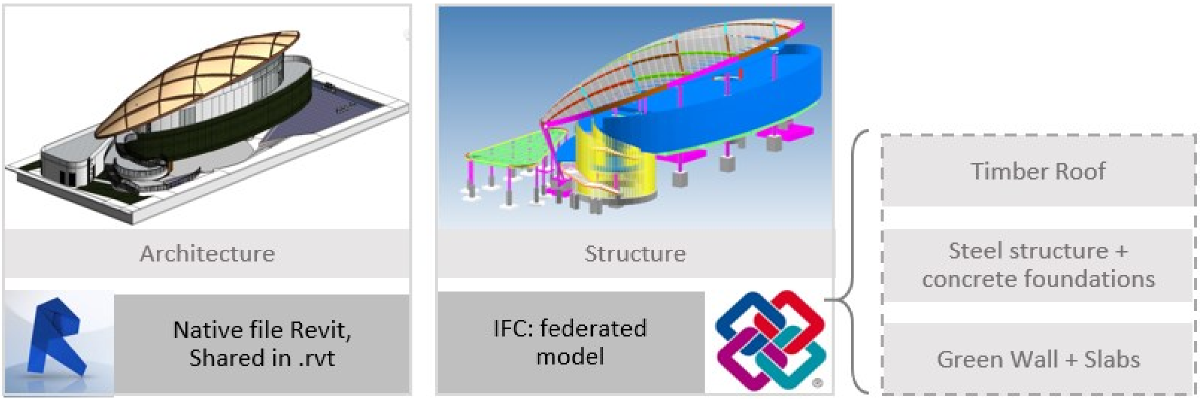


Figure 4.17 Graphic of the main models mentioned

Therefore, the main two models were divided by their disciplines: architectural and structural. As the exchanges were done through .ifc files, it was not possible to reach an integrated model with the native files of each discipline. This impacted for example when it was required to do pre-visualisation renders of the project for the detail design phase because the series of software tools required to do visualization work correctly when 3D elements have their origins in native files. Like the mentioned, there are more repercussions related to interoperability issues. Many workarounds can be done as it will be shown in the next chapter through other software able to manipulate IFC properties with certain limitations. However, it is always better to work in an integrated way setting the export requirements for each discipline and BIM models to avoid issues in the workflow of other BIM uses to be executed.

As a personal appreciation and in regard to what the author contributed in the project, it was noticed a lack of correct manipulation of the models' information when they were exported as IFC to be exchanged. The IFC elements were not all correctly mapped, issue which made a tedious task to work consistently with the files to manipulate them. Examples of these drawbacks faced will be exposed when presenting the demonstration of chapter five.

Besides, the absence of a BEP for additional BIM uses contributed to shortcomings related to interoperability issues, information lost, or information needed but wrongly loaded. One example of this can be identified in the model of the timber roof, which is an IFC that it is not possible to use extract information from its BIM elements because they do not present any data. Hence, to calculate the volume that the roof elements may occupy in a certain space (like in a container) is not possible from the IFC file received. This information is only stored in the native model, that it is owned by the author of the roof structure.

4.3 Project Process

4.3.1 General timeline schedule

By the period of this diploma work development -March-September 2020- the Pavilion was being built. In the following timeline is shown chronologically the series of events and the main circumstances around the project to let it happen since its design concept until its future relocation.

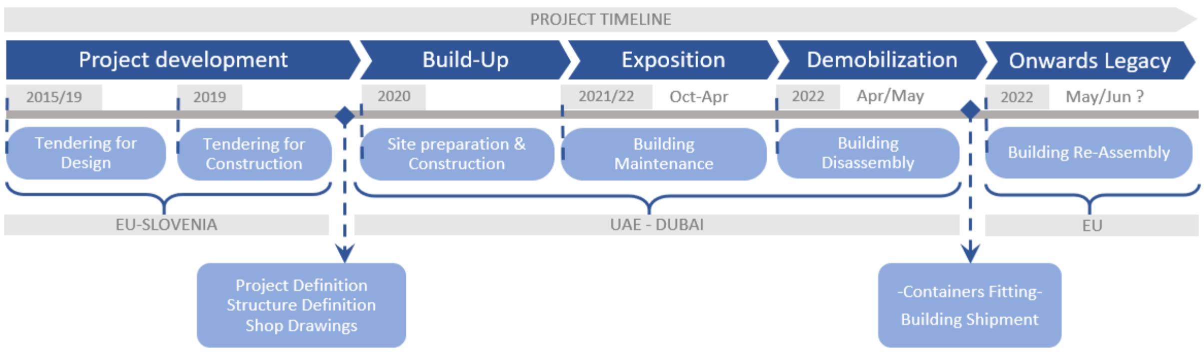


Figure 4.18 Macro-schedule timeline of the project. Graphic developed with information available on the web [27] and information received from Riko company

During the whole project timeline, there are some phases held on the EU and some in the UAE.

The **Project Development** consisted in public tenders launched by the Slovenian Government, one for developing the design concept, and afterwards another one for biding its construction, which was won by a local constructor company, Riko d.o.o.

The **Build-Up** phase takes place in Dubai, and it has a tough schedule. For this phase, it is necessary to do the **Project Definition** for architecture, structure, MEP systems, along with their executive documentation for construction. The constructor company, in addition to different stakeholders from Slovenia and Dubai, are the responsible parties for this phase.

During the period of the **Exposition**, it is necessary to do building maintenance. For example, one of the main tasks will be the periodical care and conservation of the green wall. The use of BIM for facility management during the period of use of the building would ease this work.

For its temporary character, once the fair is finished, the pavilion built in Dubai will be disassembled: it takes place the **Demobilisation phase**.

After World's Expo, it is aimed for the pavilions to be relocated on their country's origins for their reuse, principally as cultural spaces. They start to be part of the nation's legacy, thus the final phase "***Onwards Legacy***" occurs, and a new lifecycle for the building starts in its new allocation.

In between these two final phases, it will occur the **shipment of the building** to Europe for its relocation and reassembly in the Slovenian territory.

For this final stage of the project mentioned is that it is addressed in this dissertation work some **demonstrations of automation for the process for fitting building parts into containers for their shipment and future relocation.** This topic will be exposed in detail the chapter five.

4.3.2 Collaboration process

In the construction of prefabricated buildings, careful and constant coordination of the project is essential. As it was discussed, coordinations regarding technical and constructive solutions for the project definition were made between the stakeholders with the supervision of the PMC. For example, a great collaboration between the timber-roof team in Slovenia and the steel-structure team in Dubai was needed to achieve the correct design for the roof to be correctly supported by the steel structure.

Working together over long distances on a project of this scale requires clear and constant communication between team members and the different collaborators of each discipline.

The combination of steel and wood structure in this type of construction as the pavilion, cannot tolerate a margin of error greater than 0.2mm in the design -in the construction no more than 1cm-. This is the reason why the coordination process was carried out meticulously, and they communicated between the two teams in charge of these tasks periodically. The models were sent via email, together with annexes about the latest updated changes and requirements for adjustments or modifications.

The company that required changes sent its model via email; the receiving company opened the file, checked the changes, verified if they were possible and adjusted its model. Then, they sent back its updated model and so on, until the correct resolution was reached (a final design solution where the roof rested appropriately over the steel structure). For further coordination details or decisions to take, they organised on-line meetings between the teams involved, always supported and supervised by the PMC. The communication was made by email; therefore, files were **exchanged and not shared** in a digital collaboration area.

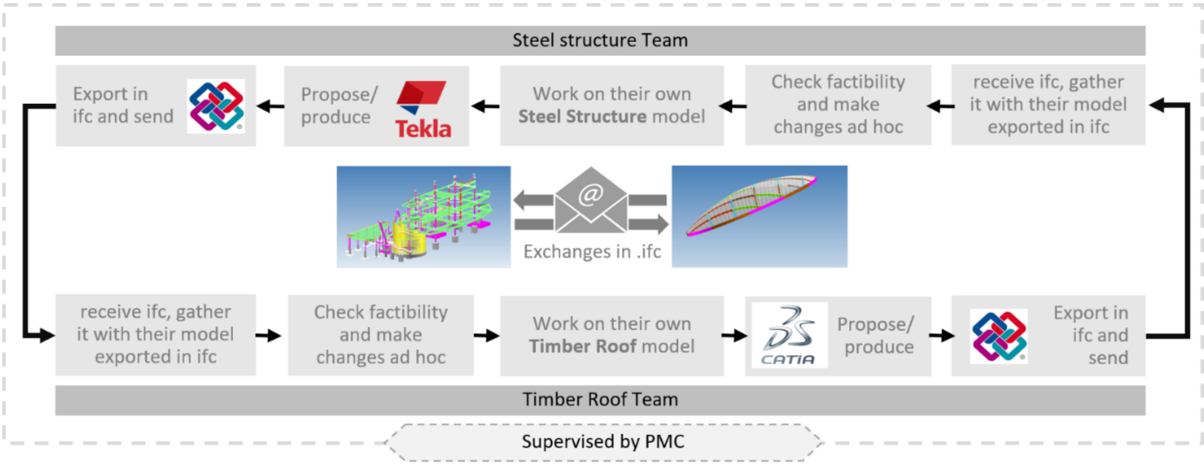


Figure 4.19 Schema of the communication flow between Structures teams

Beyond the successful results of this project, the coordination processes could be improved by establishing a Common Data Environment (files from now on referred to as CDE) for sharing files instead of exchanging files.

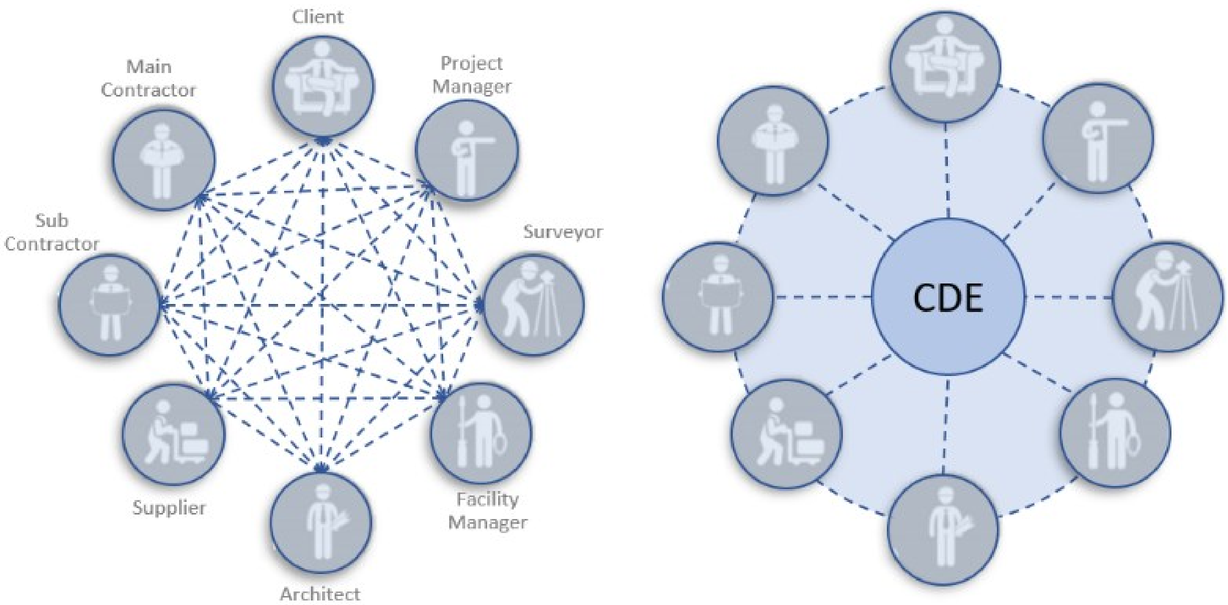


Figure 4.20 Exchanging data vs Sharing Data.

To establish a CDE requires its development, coordination and management, as well as having a trained team and an IT department who implement and maintain the CDE. The information exchange processes must also be studied, developed and adjusted to the company that establishes it, and kept it up to date periodically. It is not an easy task when the project does not follow and Integrated delivery project approach.

4.4 Overall project results -based on BIM principles

The Slovenian Pavilion project was successfully carried out despite the remote coordination and the inconveniences faced due to the global pandemic that outbroke the world when the project was still in its first stages of construction. Without the advantages provided by the digital technologies used in the execution of the project, it would not have been possible to achieve that level of precision in the design and erection of the pavilion structures.

With the BIM approach, the company avoided cessation of construction work and managed the work and execution of the project at long-distance with local workforce even though they have never used timber material as a structural element.

Figure 4.21 Progress of the site construction by March-April 2020. Foundations works on the image above, steel structure erection in the image below. Photos provided by the PMC

Figure 4.22 Progress of the site construction by July 2020. Cross-laminated timber roof. Photos provided by the PMC

Figure 4.23 Progress of the site construction by September 2020. Works on green wall and finishes. Photos provided by the PMC

5 OPTIMIZATION OF THE RELOCATION PROCESS FOR THE CASE STUDY

Scope of the chapter: explain the proposed workflow for the design process of a relocatable building in BIM; to demonstrate an application example of that proposal in the case study.

5.1 Assumptions and queries

It has already been presented what BIM technology is and how essential it is in prefabrication and its future. The main question triggering this thesis work is: **How can BIM support DBR building projects?**

Assuming then that BIM is key to the future of DBR projects, many other questions arise from this central question, such as:

- What is the planning process for packaging relocatable building elements? Is there a process to be followed? What possibilities exist?
- How can we use a BIM model in the process of calculating building packaging? How can we benefit from using a BIM model in that process? What requirements do we need in a BIM model?
- How do we leverage and use the information from BIM elements in the life cycle of a building?
- How can we classify the building's BIM elements to sort them by different criteria?

Ways to optimize the design of relocatable buildings have been explored in this thesis work to answer these questions, with a particular focus on their future packaging for shipment.

5.2 Process analysis

Based on the case study, there are several processes planned for the relocation of the temporary buildings, starting from their design phase. The chart below exposed chronologically the steps that are part of those processes:

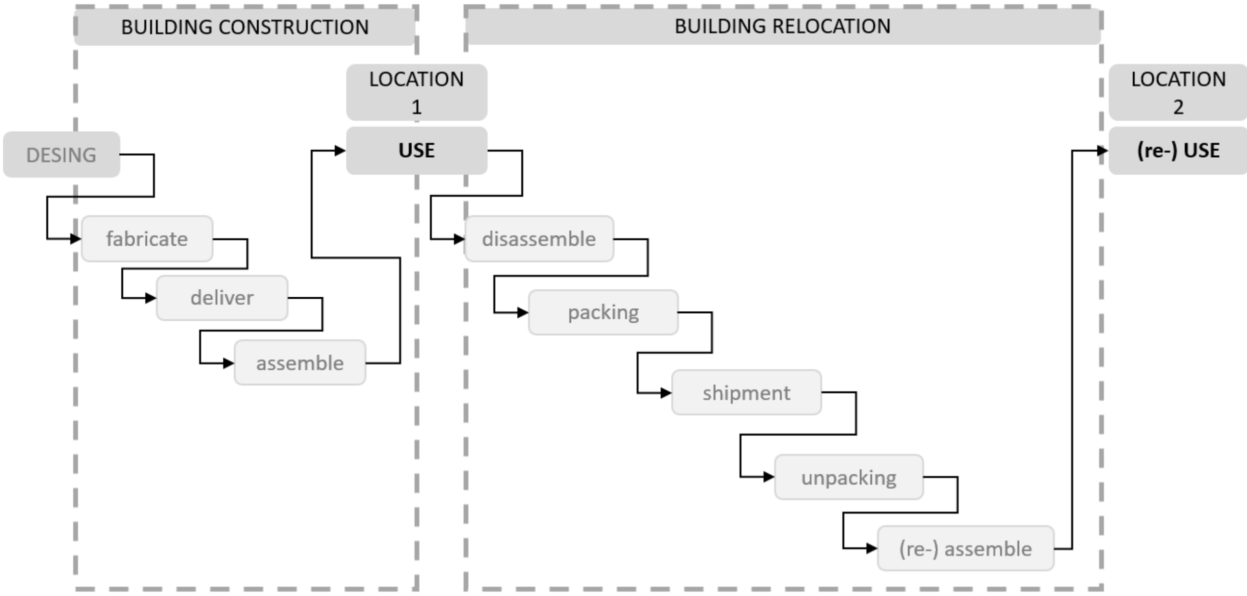


Figure 5.1 Process construction and relocation for the temporary building of the Pavilion

The procurement of the Pavilion's design and construction did not contemplate the development of the successive building-life phases. Demobilization and transport will be part of a future tender to be launched by the Slovenian Government. Nevertheless, the Pavilion was designed contemplating that those future stages should be carried out in the most effective way possible.

In order to successfully relocate the building components, these elements must be designed with specific transport variables, such as the maximum size of the containers in which they will be packed, or the way in which the parts will be placed inside the containers to achieve maximum efficiency in the use of space.

Of course, several other variables come into play when planning the logistics of filling the containers. In these processes, there are specific tasks that are repeatedly performed and that take much time; **time that can be saved with digital automation processes**. In this way, it is possible to achieve **process optimisation** for better results.

In this section of the thesis, it will be presented a proposal for the process to be carried out when planning the packaging of building elements to find improvements of the design of the pieces if there are parts that will not fit in the containers. A part of the contribution from this proposal is to identify change requirements of elements in the early stages of the design process, performing these type of processes as a demo to apply to the BIM models received for different participants in the design.

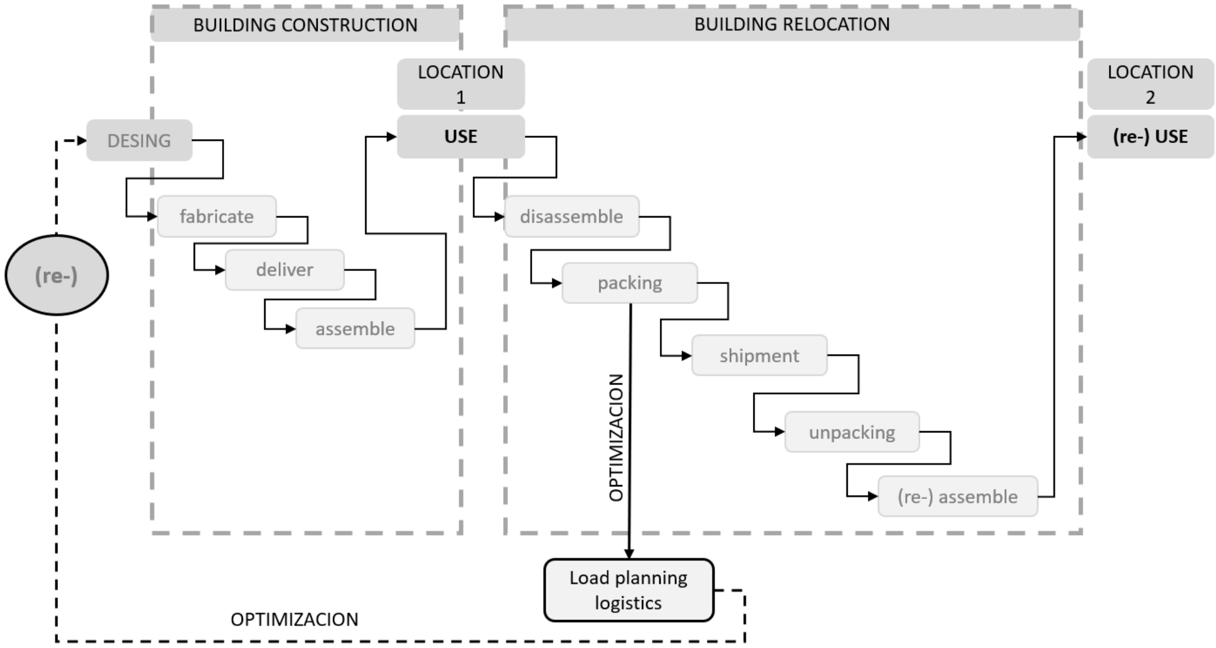


Figure 5.2 Process construction and relocation focused on optimization of the design for relocation

As it can be seen in the chart above, from all the stages of the design and construction processes for relocatable buildings, work will be done on the PACKING BUILDING ELEMENTS phase, considering optimization methods for load planning logistics.

5.3 Current workflow for building packing

The criteria for placing the building elements inside containers depend on different requirements, such as the element's materials, their size or weight. Also, if they need separation between elements, for example, in the case that they are too fragile or too light to be one upon the others.

All types of load-logistics are combined and taken into account when designing the way to ship the building elements. If some elements do not fit in containers, they must be re-designed according to the container's size. Generally, there are more variables involved in these decisions, such as the cost of the type of container to be chosen.

Currently, the workflow in the company for calculating the number of containers to be filled by building components is a manual process. This means that within the software tools, the estimation is done by graphically placing the building elements modelled in BIM software-into a 3D volume that corresponds to the size of the container chosen to deliver the building parts.

The Pavilion's contractor also works with prefabricated houses, which are shipped to New York. Figure 5.3 shows an example of the steel structure of those houses placed inside containers, a process that is was made manually with the software AutoCAD. Figure 5.4 shows the containers with the elements of the wooden roof of the Slovenian Pavilion, a calculation also manually made in the same software by the company in charge of the design and production of the roof structure.

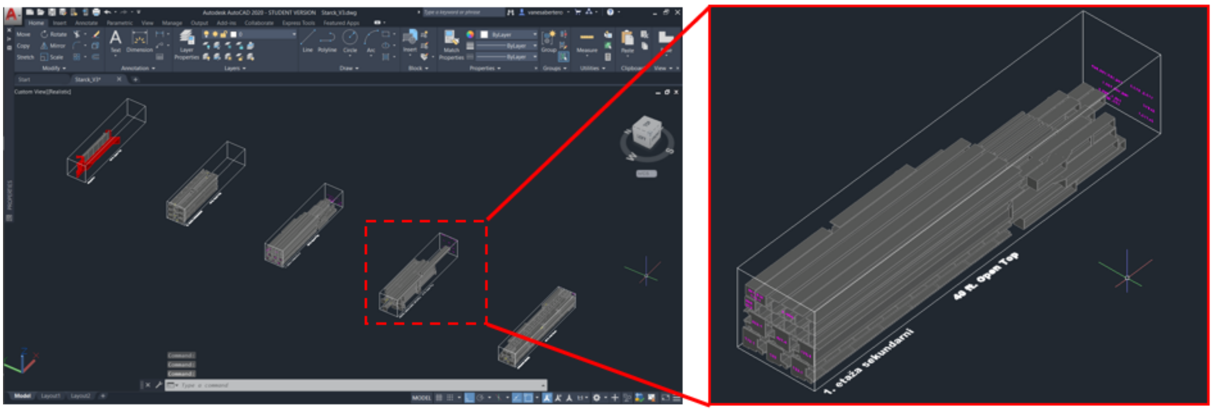


Figure 5.3 Building elements placed in containers. Project for houses from Starck with Riko d.o.o.

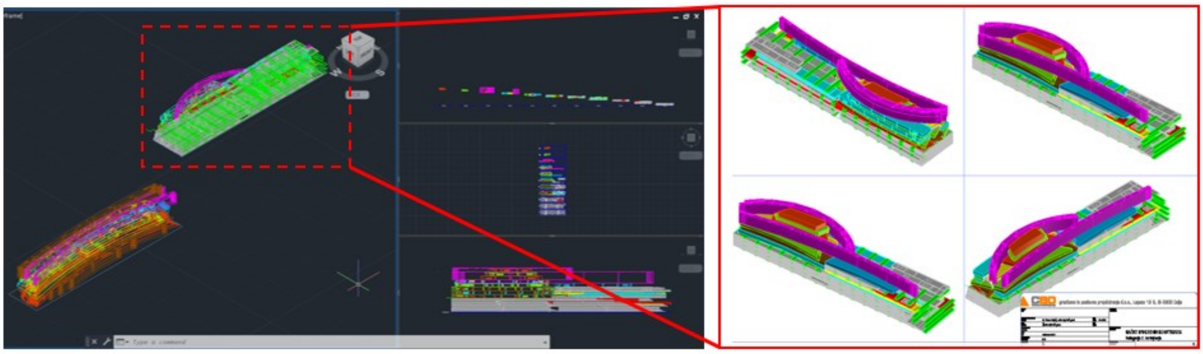


Figure 5.4 Building elements placed in containers. Project for Slovenian Pavilion from Riko d.o.o.

The disadvantage of doing these processes manually, is that if there are any changes needed to be done to the structure throughout the detail design process, the building elements must be redefined and all the process needs to be re-done. There is too much repetitive work that can be avoided through the automation of processes to agile the updating of models when receiving modifications from other teams working on the project. As well, achieving automation in companies can improve those internal processes for applying to then in more projects.

Taking the current process into account, one objective in the proposed workflow in this thesis was to automate this type of manual process so that repetitive work can be more productive, time can be saved, and results can be achieved with greater accuracy. In the following subchapter is it presented.

5.4 Proposed workflow

The following graphic corresponds to the proposed process to follow for fitting building elements into containers through BIM tools, obtaining a **model for transportation** from a **design model.** Part of the process is to automate the subprocesses for packing of building components. This workflow aims to reach **optimization methods for load planning logistics.**

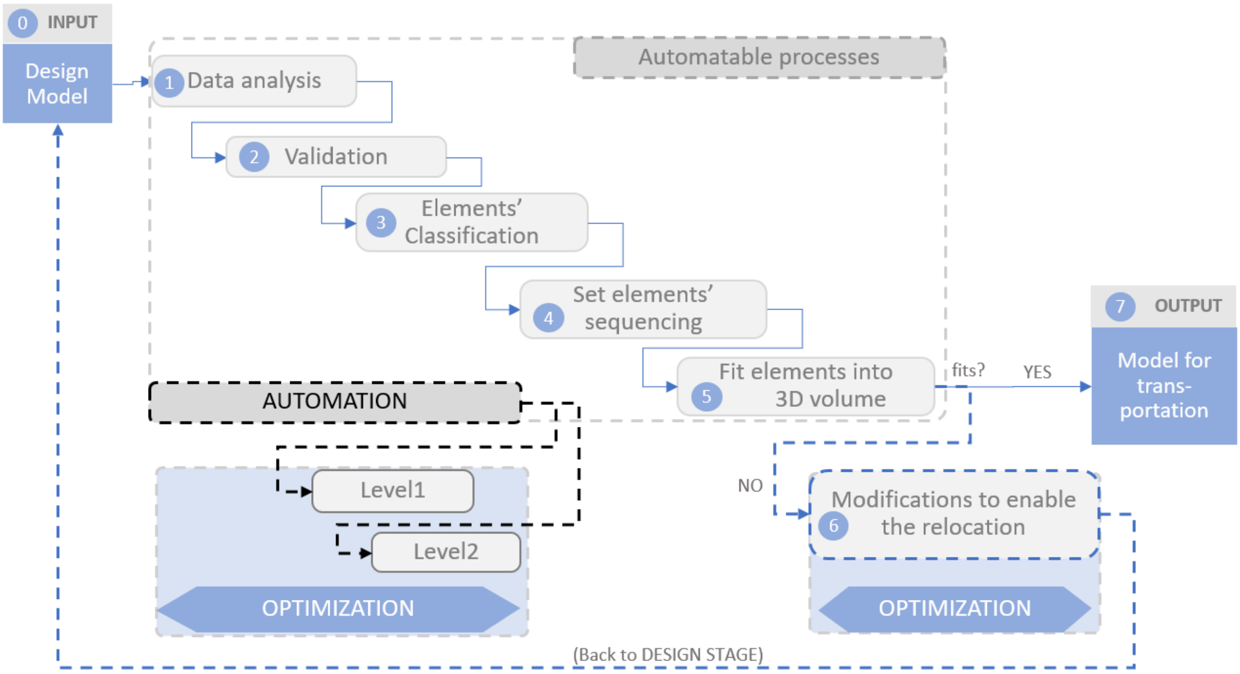


Figure 5.5 Breakdown for the proposed process of packing building elements

As well, it can be identified necessary changes on elements that do not achieve requirements previously determined. Those changes are the new input for re-design the project. The contribution of this workflow is to enhance the design process (of relocatable buildings) identifying those chances in early-stages of the planning process, avoiding costs overruns and saving time.

It will be presented a demonstration of the application of this workflow in subchapter 5.5, with different BIM tools and software, followed by partial results and discussions.

Each of the subprocesses 1 to 6 are briefly explained below, and with mayor details also in the demonstration subchapter 5.5.

0. **INPUT.** Design Model. In this case, it was the Steel Structure IFC file provided by the company.

1. **Data analysis**. Identification and analysis of the elements in the model. Identification of correspondence between real elements and Object classes. Checking the correct elements' mapping.

2. **Data validation**. Application of processes for validation of the data**.** Preparation of the model to be used for the classification of elements.

3. **Classification of the elements**.

    a. **By material: for transportation reasons.** To identify elements that first can be relocatable and which ones do not.
    b. **By size: for space reasons.** To identify which elements cannot fit in the containers. Then, to classify by size which ones can fit in what type of container**.**

4. **Set elements' sequencing.**
    a. Determinate an **order and priority** of the elements inside the containers (which are on the bottom? which on the top? Etc*).* Also important here: the element's weight.
    b. Find out **rules for organisation** inside the container, and their flexibility -for change them.

5. **Fit elements into a 3D volume.** Define the sizes of the containers to be used. Place elements inside the containers. If they fit, then the Output occurs. If not, process 5.

6. **Modifications to enable relocation.** If the elements do not fit in the containers, identify modifications that may optimise the relocation. Possible questions

    a. Is it necessary the intervention of a structural engineer to find out solutions?:
    b. Will be needed to change the technology?
    c. Will be needed the consideration of additional joints on the elements?
    d. Will be needed the consideration of redesign the project?

7. **OUTPUT.** Model for transportation. With desirable identification of the elements sorted by their destinated containers.

AUTOMATION: The different levels of automation are applied to some processes, those highlighted inside the frame. There are two levels defined; they correspond to the order in which different tools for automation can be applied.

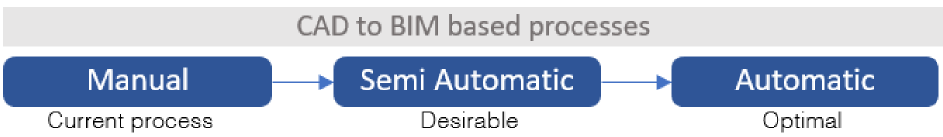


Figure 5.6 CAD to BIM-based processes

As the Figure 5.6 shows, it is desirable to reach semiautomatic processes and in an optimal scenario, automate processes and reaching automatic processes. It will be assumed that the term "semi-automatic" refers to automated processes to achieve the expected results more quickly, with few human interventions to control it. On the other side, Automatic will be called the processes prepared to "run behind the scenes", without human intervention in its development.

5.5 Demo application

This section is dedicated to present the step-by-step approach done to validate the proposed workflow just presented. The first intention was **to calculate the numbers of containers for the shipment of the building.** Then, **to automate the processes needed to proceed with those calculations.**

Different workflows were implemented corresponding to the progressive evolution of the information management within the model, and according to what the model, its properties and information quality allowed to do

In response to this, it was worked with certain limitations in the main project; therefore, some other workflows were applied to a simple file as a prototype project.

- One workflow was applied to an IFC file from the Pavilion's project, and it is demonstrated in some of their BIM elements such as beams or columns.
- The other workflow was applied to native file (.rvt), a small and simple prototype, with the necessary qualifications to complete the processes and test how they behave in better conditions (adequate information of the BIM elements)

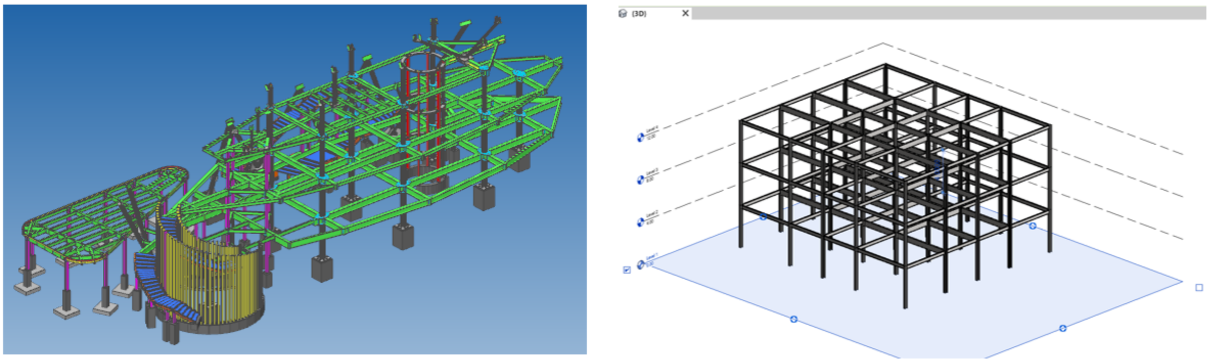


Figure 5.7 graphics of the two files used for demonstration of the transportations processes.

5.5.1 Workflow applied in the case study: managing IFC Files

From the federated model of the case study structure provided, it was only possible to work with the Steel Structure sub-model because its BIM components contained information that could be manipulated as an input in the process. Although the element information was not completely accurate, its level of completeness compared to the other files was much higher. In the rest of the IFC files, it appears that there has been a complete loss of information in the elements, so it has been decided to rule out their use.

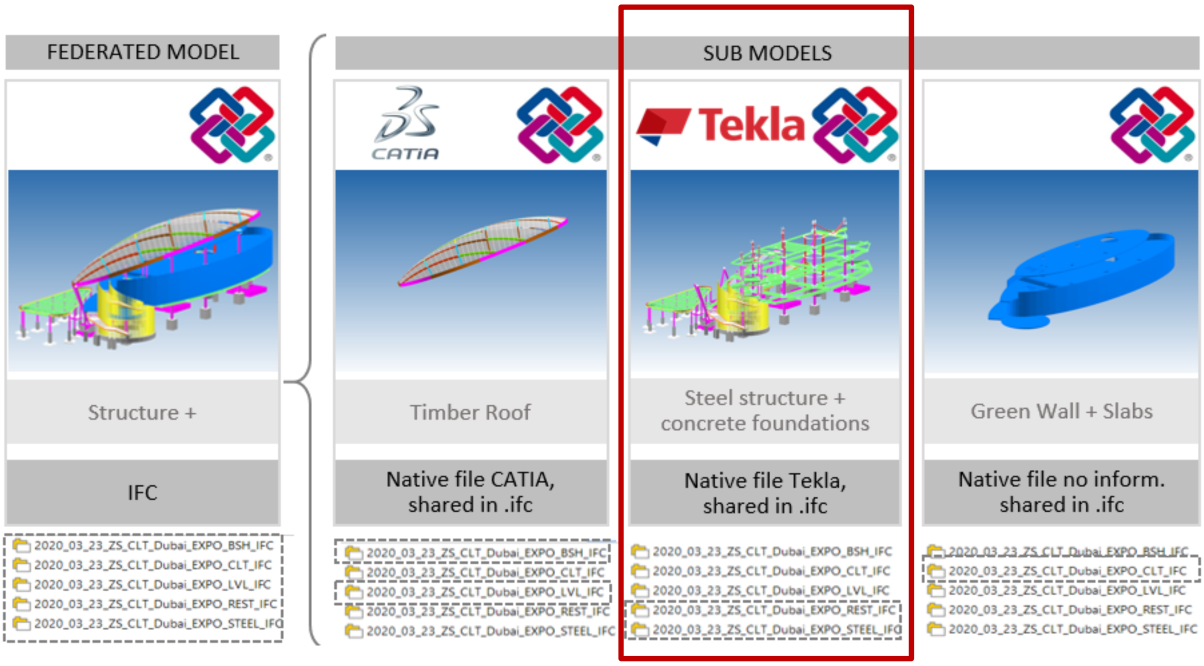


Figure 5.8 Breakdown composition of the federated model and the chosen IFC file for demonstration

ABOUT THE SOFTWARE USED: SIMPLEBIM.

Since the file to work on was an IFC file, it was chosen a software appropriately to open and manage these type of files.-Simplebim is one of the very few software in which it is feasible to edit properties of IFC files. The main advantage of its use is that the errors contained in IFC files can be solved by different procedures; hence, working with them flows in a better way.

In this software is possible to create and apply templates prepared for the user's needs: for validating the information, deleting properties, modifying or adding new properties, creating visualisation sets, sort information required, create groups of elements by predefined rules, and other applications.

Templates can be used as a step to automate specific workflows when the tasks are reiterative. For example, every time the company receives the IFC file, they sort out elements which are not necessary to work with a lighter file:

The logics in the using of templates is as a macro file, which is a recorded input that imitates a sequence of repetitive mouse actions, commonly used for the replacement of monotonous tasks in Excel. In this case, as it was said, Simplebim's templates will work in the same way as a macro for Excel spreadsheets.

For the IFC Pavilion's project files, it was necessary to analyse, process and validate their information before starting to work with the models, because not all the information contained was needed in the particular case of this workflow (see Process 1).

PROCESS 1. DATA ANALYSIS

<u>OBJECTIVES</u>

- Identification & Analysis of the elements in the model
- Identification of correspondence between real elements and Object classes.
- Checking correct elements mapping.

<u>TO DO:</u>

A. Open model in IFC file's viewer (Used: BIMCollab)
B. Visualisation of the model by type of elements
C. Identify any inconsistencies

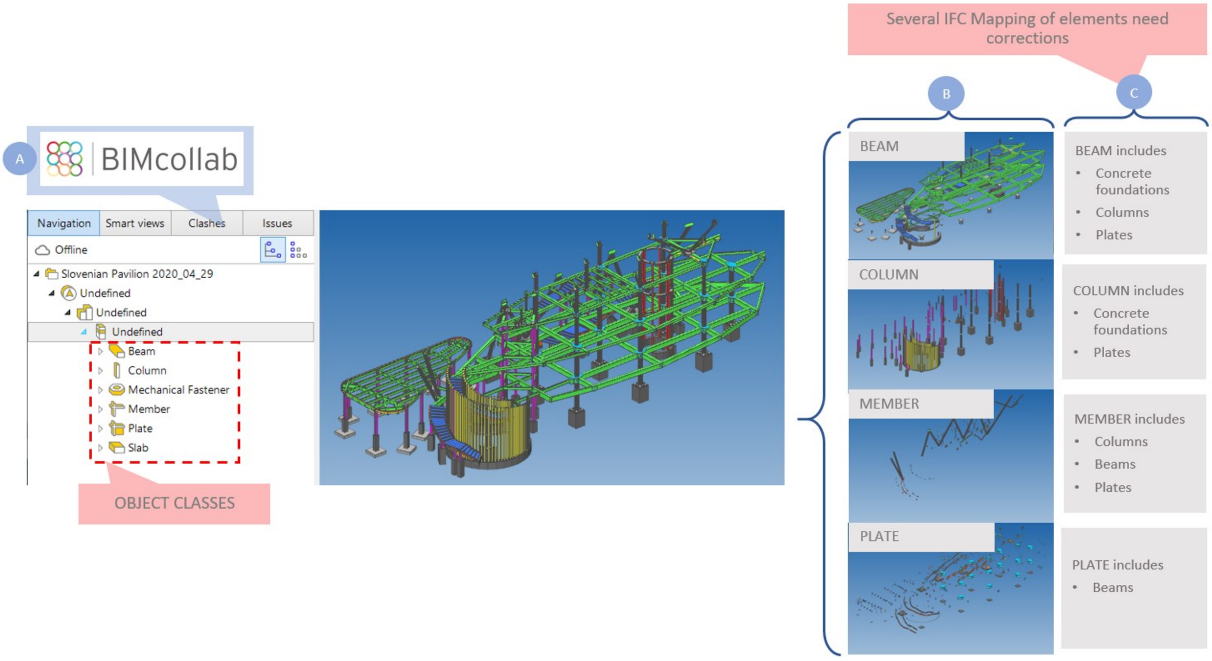


Figure 5.9 Graphic of the resulted process 1.A

In this project, there were identified inconsistent information in the object class mapping of the elements. They needed correction to work properly in the successive processes. It will be done in process 2.

PROCESS 2. DATA VALIDATION

OBJECTIVES

- Application of processes for model data validation.
- Preparation of the model to be used for the classification of elements.

TO DO:

A. Open model in software for IFC properties edition (Simplebim)
B. Identify properties on each Object class, that can help to correct the issues found in process 1).
C. Exclude not necessary elements
D. Export IFC File and check the changes applied are working

Results from previous process (N° 0)

IFC Mapping of elements	Needs correction?
BEAM	Y
COLUMN	Y
MECHANICAL FASTENER	N
MEMBER	Y
PLATE	Y
SLAB	Y

Figure 5.10 Results from the previous process number 1.
From all the elements in the model, which one needs corrections. Current demonstration applied to BEAMS.

A). Simplebim software interphase. Highlighted in red selection in the 3D view: BEAM object class. Between BEAMS properties, there are identified two properties that contain the different types of elements which do not correspond to the object class Beam (highlighted in red frame "Name" and "Layer Assignment Name")

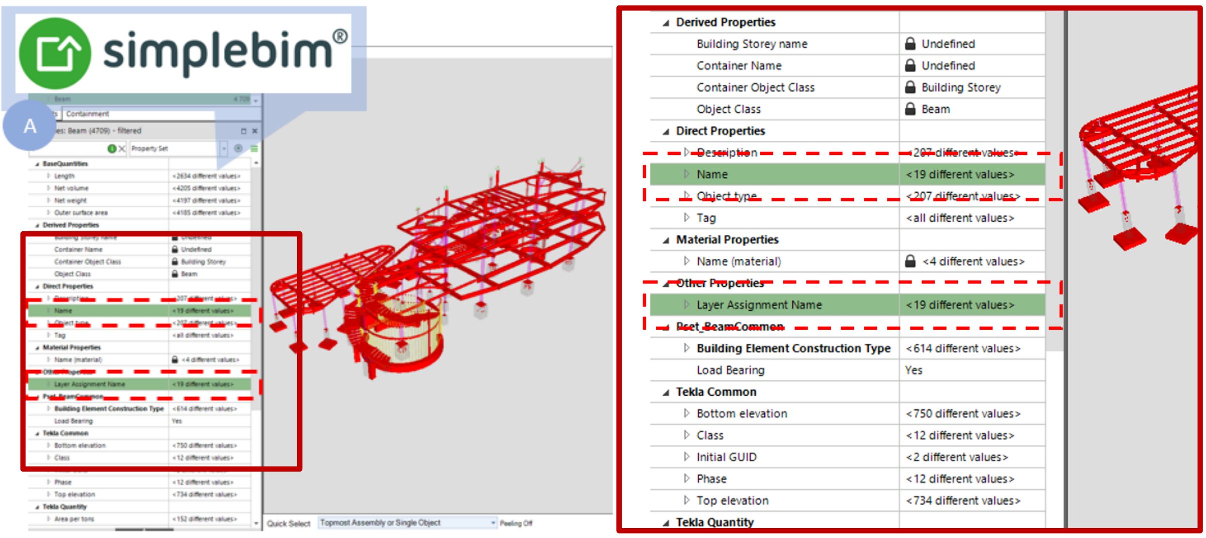


Figure 5.11 Zoom to the process in point A

B). Selection of "BEAM", one of the types of elements under the property "Layer Assignment Name": Identification of incongruencies → for example concrete foundations under this identification Beams.

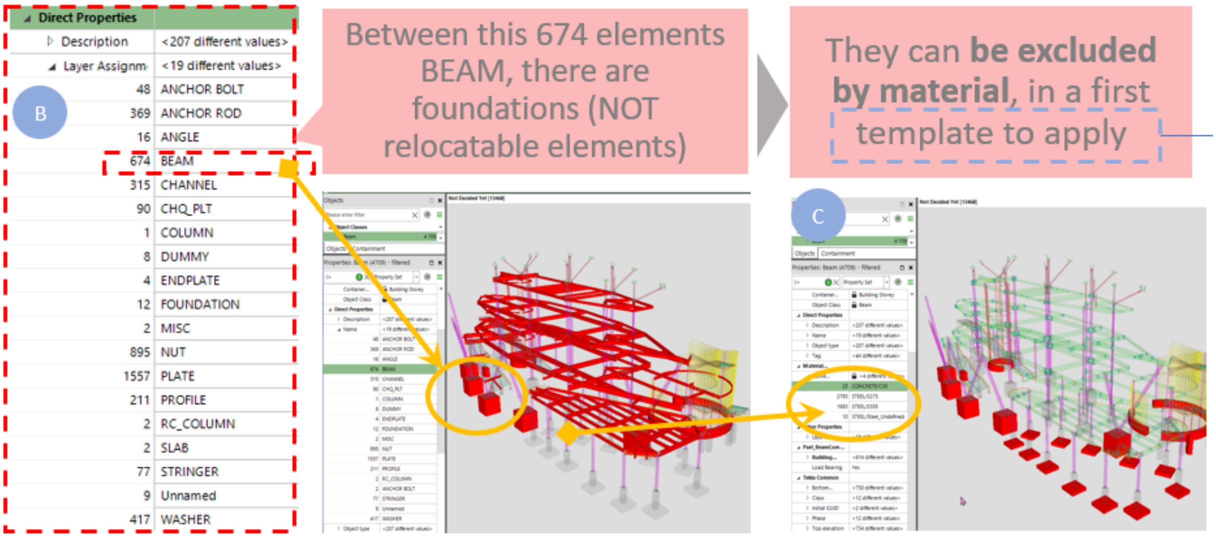


Figure 5.12 The different elements defined by the property "Layer Assignment Name"

C). Selection of one of the concrete foundation elements to identify properties by which it is possible to sort them out: MATERIAL. Exclude this element. Preparation of the Template with this action.

D). Opening exported IFC, without concrete elements.

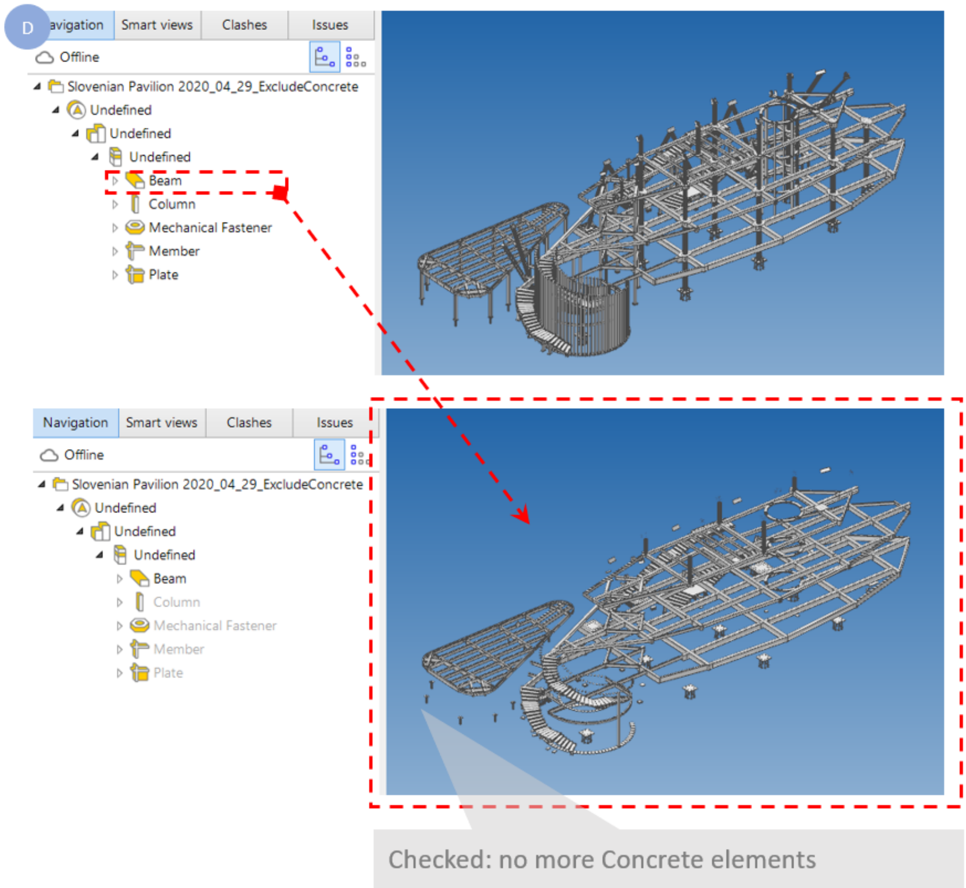


Figure 5.13 Graphics from point 2D.

After this process, the next step is to **set all the necessary rules to validate, edit and correct the model**.

The rules can be defined differently between them, but arriving at the same result. It depends on how the model results after applying each template (if it has the expected results). For example, it could be sorted out first all the elements which ARE NOT BEAMS and COLUMNS so then resulting in a file with only those elements, but some beams and columns were defined as MEMBER or PLATE. Therefore, it is better to apply simple sequencing rules and checking every time if the exported IFC is behaving as expected.

PROCESS 3. CLASSIFICATION OF THE ELEMENTS

OBJECTIVES

- Classification By material (for transportation reasons) To identify elements that first can be relocatable and which ones do not.
- Classification By size (for space reasons) to pinpoint which elements cannot fit in the containers. Then, to classify by size which ones can fit in which type of container

TO DO: Set all the different criteria to sort the elements. Examples:

A. By Material
B. By size.
C. Export Excel Spreadsheet with data required for fitting the elements into containers (preparation of the input for next process)

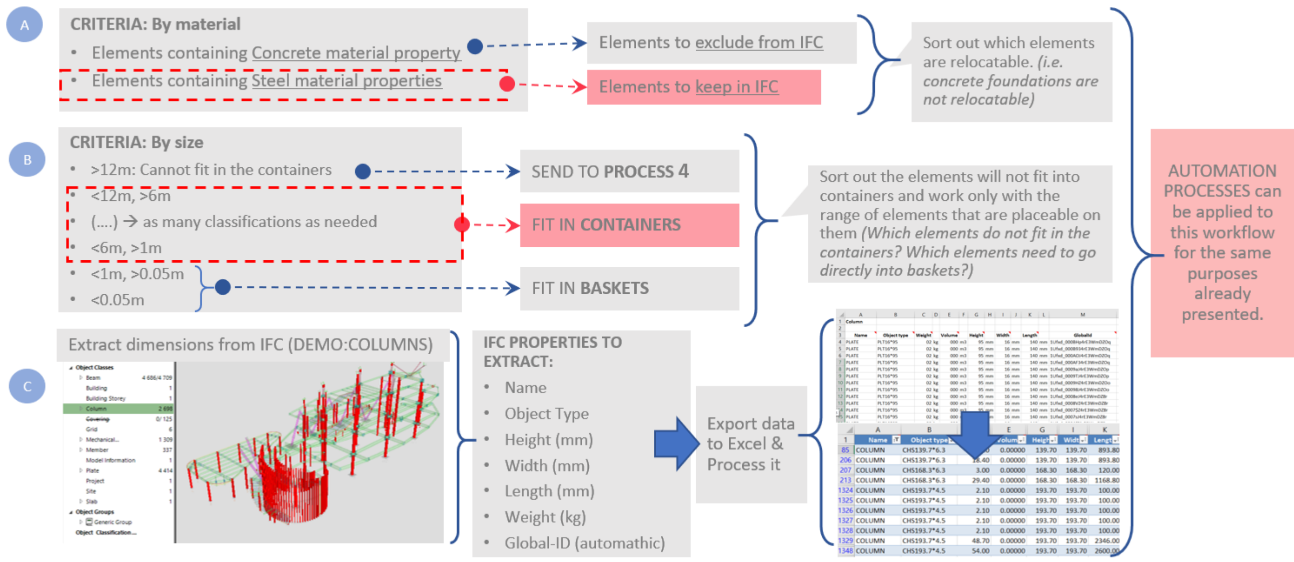


Figure 5.14 Graphic of the process 3

AUTOMATION PROCESS. LEVEL 1

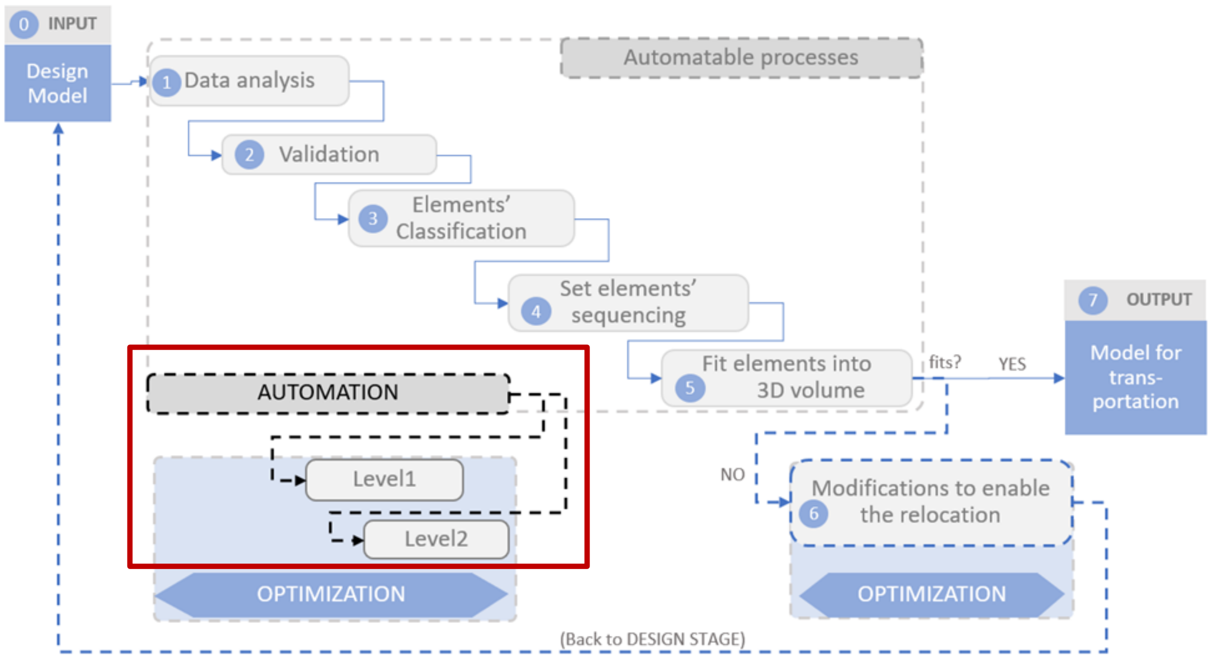


Figure 5.15 Automation processes and levels proposed within the proposed workflow

<u>OBJECTIVES</u>

- Automate the model editing
- Automate repetitive processes through a Macro, to apply in the future every time it is needed.
- Set the data exchange requirements

<u>ADVANTAGES</u>:

- Transition from a MANUAL process to a Semi-Automatic Process
- More productivity and fewer possibilities of making mistakes in the process, a faster validation process.

<u>TO DO</u>:

A. Open the excel spreadsheet that Simplebim allows to use as a template
B. Set the rules for excluding the elements identified in the Process 2.
C. Run the template inside the software modifying the IFC file, check if works correctly.

It is intentionally demonstrated here the workflow of this process only with some simple elements. The objective of the 1st level of automation if to configure templates than can automate reiterative tasks inside the IFC files, with purposes of validation and corrective actions.

A&B) Configuration Sheet: Group

Define Groups Based on Property Values

NOTE: Do not specify any operator for Yes/No properties

Group Name	Object Class [+]	Property [+]	Numeric Operator ...or...	Text Operator	Case Sensitive	Value [+]	And/Or	Group Type	Parent Group	Group Category
Concrete	All	Name (material)		Contains	No	Concrete		Rule Based		

Figure 5.16 Example of Group Configuration Sheet

The criteria to automate the exclusion of the concrete elements was through creating first a group that contains them. It means that all elements which have the value "Concrete" in its "Name (Material)" property, will integrate the Group named Concrete.

Configuration Sheet: ModelView

Definition of elements to include and exclude from the model

Include/Exclude Objects Based on Object Class or Group

Object or Group [+]	Include
All	Yes
Grid	No
Concrete	No

Figure 5.17 Example of Model View Configuration Sheet

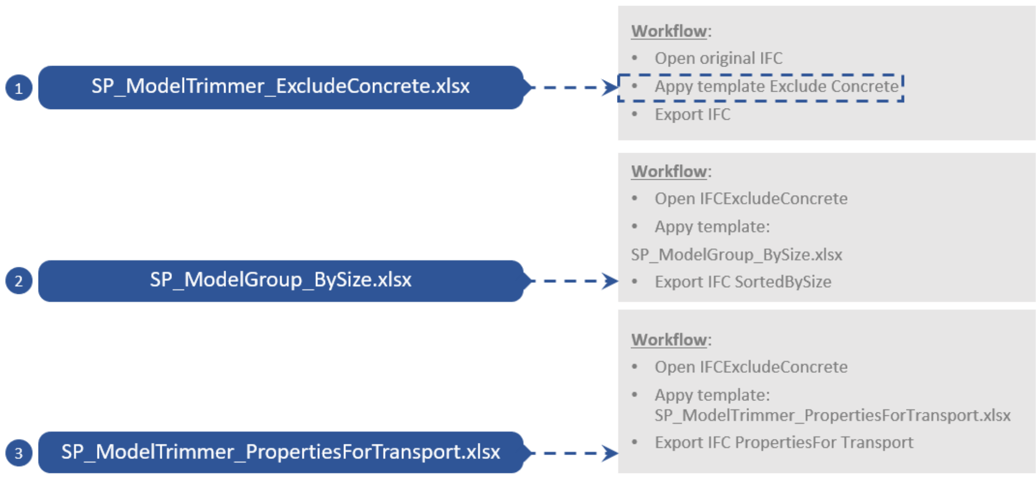


Figure 5.18 Graphic of the process followed in point 1.B.

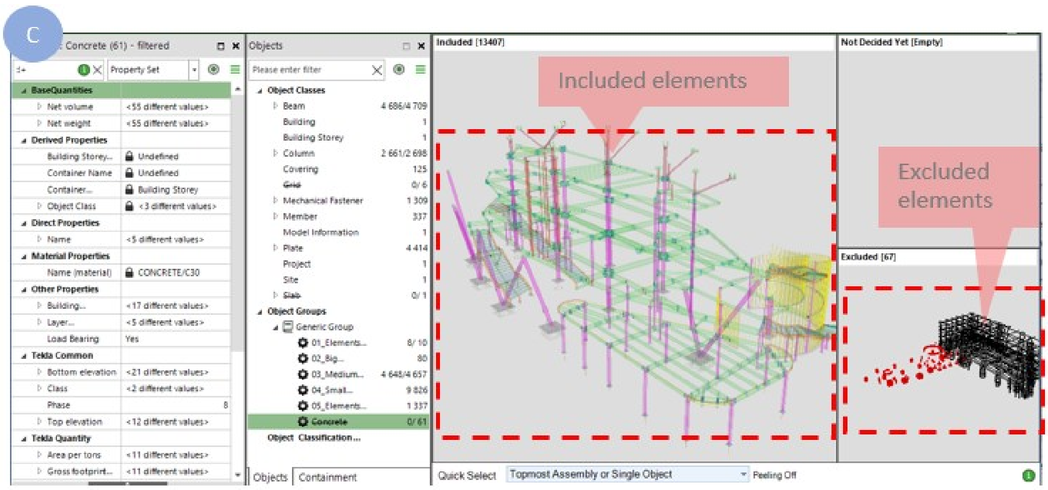


Figure 5.19 Graphic of the process followed in point 1.C

AUTOMATION PROCESS. LEVEL 2

OBJECTIVES:

- to automate the application of reiterative macros to accelerate this sorting process of objects and properties (with all the elements of the building: beams, plates, small elements in general).

ADVANTAGES:

- Transition from a Semi-Automatic Process to an Automatic Process;
- More productivity and fewer possibilities of making mistakes in the process.

TO DO:

A. Prepare as many templates (excel spreadsheet of Simplebim) as needed for completing all the requirements to create a quality IFC file, following the workflow from LEVEL 1 OF AUTOMATION

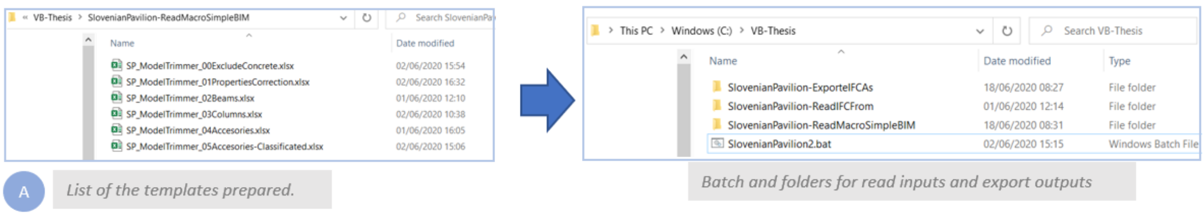


Figure 5.20 Graphic of the process followed in point 2.A.

B. Prepare a Batch file setting the input .ifc file, the excel file to apply to it, the output .ifc file

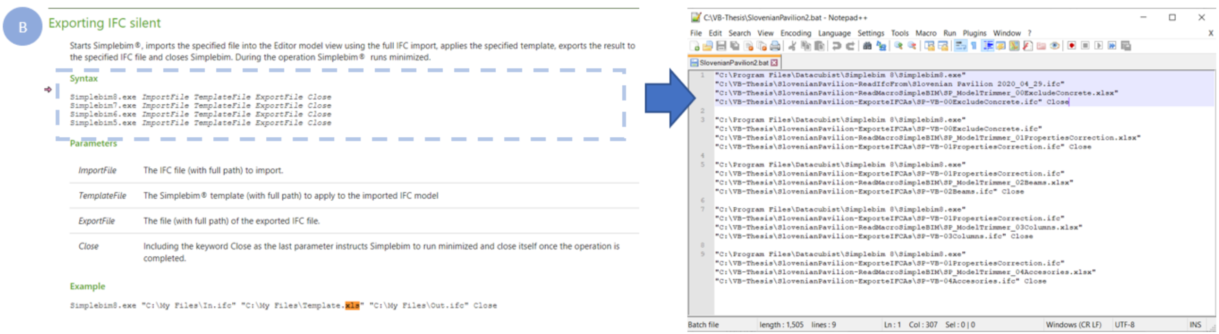


Figure 5.21 Graphic of the process followed in point 2.B

C. Run the batch file. Verify the resulted .ifc files and their quality.

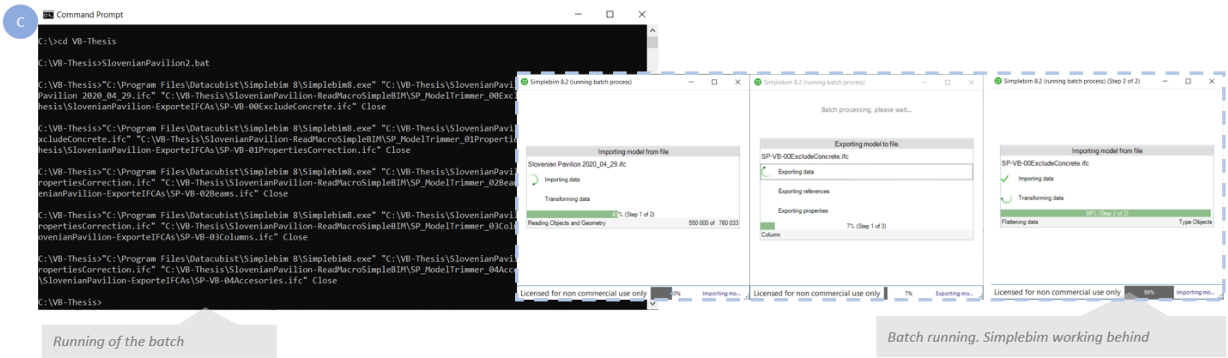


Figure 5.22 Graphic of the process followed in point 2.A

D. It is intentionally demonstrated here the workflow of this process only with some elements of the project.

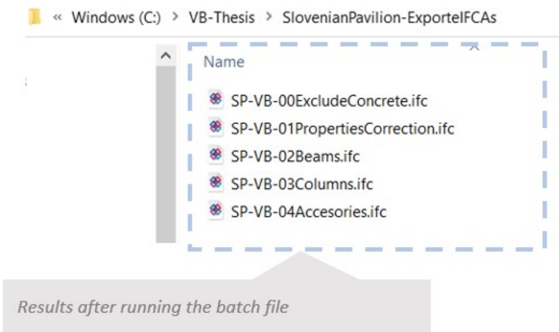


Figure 5.23 List of IFC files as Output of the batch process

The objective of the 2nd level of automation is to run several templates which contains numerous rules to validate and correct the IFC file, **following a path or line to not overlap the processes inside templates.**

The power of this automation process lies in the **amount of time can be saved,** and the **minimisation of errors** that can be achieved every time an IFC file is received and is needed to run one and another time the same processes

PROCESS 4. SET ELEMENTS' SEQUENCING

Process not covered in the demonstration.

PROCESS 5. FIT ELEMENTS INTO A 3D VOLUME

<u>OBJECTIVES:</u>

- Calculate the number of containers to be used.
- Identify if there are needs for changes in the sizes of containers

<u>TO DO:</u>

From the previous process, input excel file with information needed

A. Prepare clean data to automate the placement of elements in containers
B. Load data into calculation software & Visualisation of results

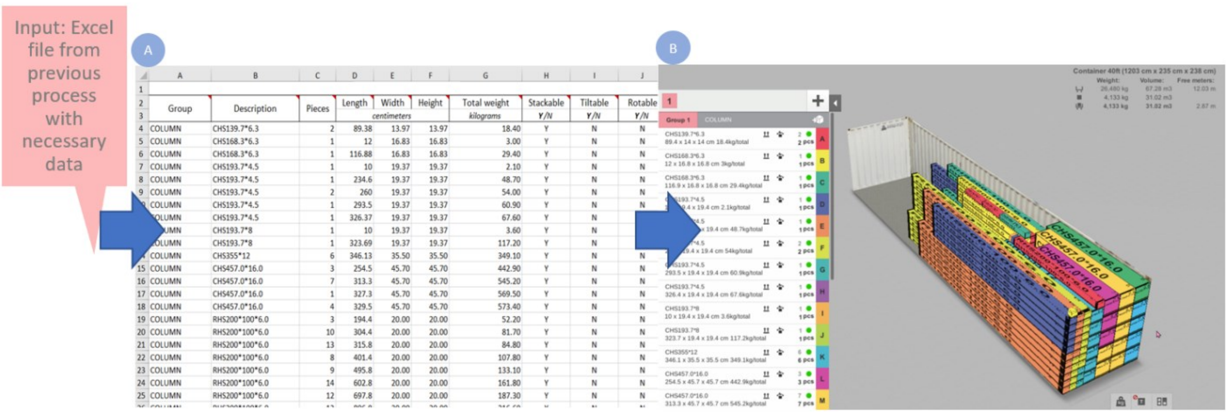


Figure 5.24 Elements data processed by loading software calculator

For this step, it was used an online loading software calculator called EasyCargo. There are many more available; it was selected this one for their friendly-user interface and good visualization results.

PROCESS 6. MODIFICATIONS TO ENABLE THE RELOCATION

Process not covered in the demonstration.

5.5.2 Workflow applied in a simple prototype: managing native files

As an optional method instead of using a software as EasyCargo, it would be to develop a script with the specific algorithms to calculate the space that would occupy building elements in a certain maximum volume where they need to be placed for their packing and future transportation.

In this way, it could be automated the process with a script, in Dynamo. In a simple prototype structure.

For applying this solution is essential to have an IFC model with the correct mapping of elements and properties that need to be used, or the native file in Revit as it is shown in the graphics below.

In this workaround, it was demonstrated how the data was correctly read by SimpleBIM, exported in a spreadsheet, and then read it by a Dynamo Script from the excel file.

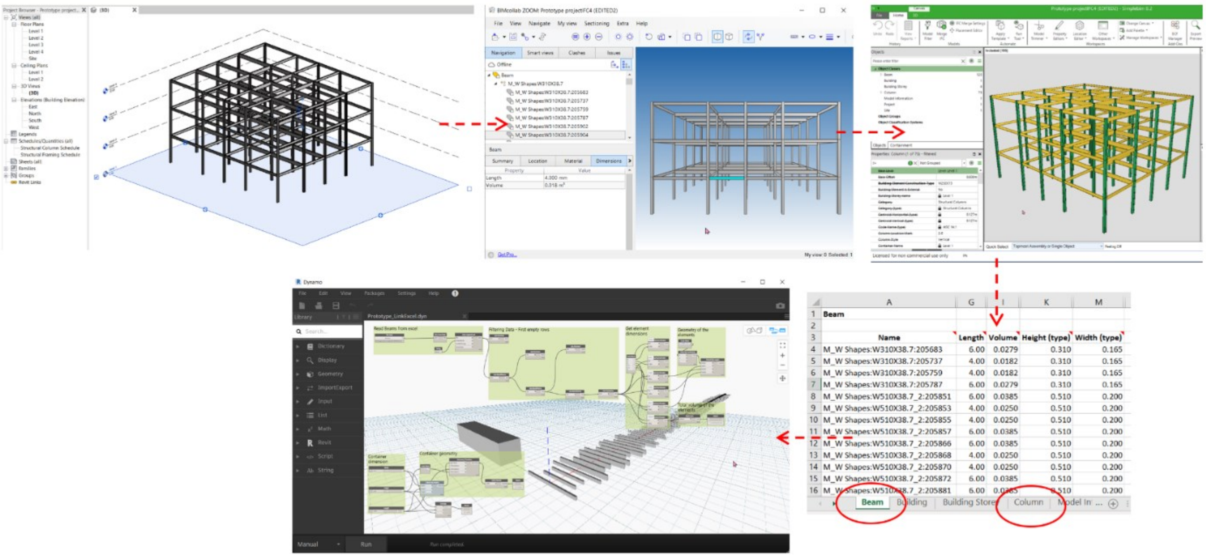


Figure 5.25 Workflow with a prototype in Revit to dynamo

For this solution, it is necessary to develop an algorithm to calculate the optimum space to be occupied for the elements.

This solution is not covered by the scope of this study.

5.6 Results

In the demonstration done on the case study, some processes worked as expected, but others were not able to function. They will be presented below.

WHAT DID WORK. As an advantage of the applied process, it was possible to quickly identify which elements of the structure did not respect the maximum sizes corresponding to the containers where they were going to be located.

In the same way, it was possible to establish different rules and restrictions to verify if in the BIM model they were complied, obtaining quick feedback of which elements should be resized or redesigned.

In comparison with a manual process, this procedure is saving lots of time to the designers. Furthermore, it can be identified in the early stages of the process design.

WHAT DID NOT WORK. With regards to the overall process applied in the case study, it was expected to be obtained a specific number of containers in which the entire building structure could be packed. However, this final result could not be reached. There were several limitations, including the following:

- The proposed criteria for classifying the elements of the structure by size did not flow correctly because the elements had a wrong IFC mapping; hence, when separating the elements by type, they were mixed or repeated, resulting in inaccurate information. For example, among the IFC elements "Column" others were mapped under the same name, such as plates or beams, since they appeared with this classification in their properties.
- The software used for the calculation of containers (EasyCargo) allowed loading a spreadsheet file with a specific maximum number of elements, while the model of the structure has around 13500 elements, including 2700 columns, 4700 beams, and a significant number of plates and member elements. This would mean running the program several times, manually and separately each time. Follow this procedure would imply two main problems:
    - one is that it cannot be ensured that the containers are filled to the maximum capacity so that it will cause wasting of space and it will result in many more containers than actually will be needed for transport the structure;
    - another problem is that by running the program manually multiple times, it can be made several mistakes in the process, and the result would not be reliable.
- For the reason mentioned above, the process for calculating the volume of elements into containers was applied to a selected part of the building, specifically the columns. It was observed that the result, after processing the data from the spreadsheet, showed a container where each element placed inside is calculated as a prismatic volume, wasting the space between

elements that could be used by placing them close to each other so that they fit together. This issue results in the cases of placing profiles elements as I, C, U, or even curved elements, with excessive waste of space.

Due to the last reason exposed is that it was made a prototype in a native file with a design author tool, to apply on that model visual programming script and process the data following the steps without issues of information.

On one side, it is proved that

- ▲ achieving automation of the processes for the workflow is possible;
- ▲ automation decrease the time spent doing reiterative tasks, although they need time to be well developed;
- ▲ BIM tools and software allows to manage and process the information contained in BIM elements of prefabricated buildings models;
- ▲ the workflow presented is one way of achieving data processing for load planning logistics.
- ▲ the workflow presented gives a good outcome in the way of designing structures contemplating the space they occupy and being able to optimize it under the criteria of minimizing empty space in containers and maximizing the savings of money.

On the other hand, it is deducted that:

- ▼ Data processing of big files requires special focus on the first steps of Analysis and Validation: setting rules clearly defined and sorting out only the necessary element properties to be processed.
- ▼ To obtain the best use of o containers' space where the building in question will be packed is necessary the application of dedicated algorithms and more powerful and dedicated tools.

SUGGESTIONS. Based on the demonstration in the case study, and replicable to other projects -with some adjustments:

- Create a list of requirements for the site where it will be first assembled.
- Identify which processes can be automated to avoid repetitive tasks in the design process.
- Identify where it is possible to optimise processes.
- Periodically check the IFC models to ensure the quality of the information stored.
- Make a list of requirements adjusted to the project itself with the requirements to be met by the models exported in IFC, so that all team members are aware and do not drag errors in their handling every time there are changes or modifications to be made.

6 CONCLUSIONS

In this thesis work, it was proposed a workflow that automates the packing of disassembled building components for shipment. This process is applicable to relocatable buildings and tries to identify which elements should be redesigned when they do not meet a specific set of requirements. In order to be able to design DBR buildings more efficiently, special »DBR design guidelines« should be developed.

BIM methodology could ensure the automation of certain processes that represent tedious and repetitive tasks, and that can have a large margin of error when done manually. The BIM tools used can be very diverse. Those used in the case study are limited to this specific project. Many more tools can be used, depending on the level of knowledge of the team that develops the project, as well as for the size and scale of the building. The main contribution of this work was to be able to identify necessary modifications on the project in time, to avoid cost overruns and time waste.

LIMITATIONS. This thesis is limited to apply the workflow proposed to a type of relocatable building which must be completely disassembled and reassembled again at its future destination.

Case study limitations: demonstrations of workflow applied to the structural discipline of the building to a certain extent: only to one type of elements that are part of it. The causes were the scale of the building itself, the quality of the IFC models delivered, the information provided to the thesis author, and the short time in which the work was carried out.

GENERAL CONCLUSIONS. The use of BIM technologies supports DBR projects by

- contributing to the early detection of necessary modifications to be made in the design phase of the buildings, thus providing valuable information for the design process
- allows automating repetitive tasks
- allows vital information to be loaded into the BIM model elements for future use in the project life cycle

PARTICULAR CONCLUSIONS. Preparing the BIM models for processing involves careful work:

- the IFC format for the exchange of model information is of vital importance, since the different programs that can intervene in the process are prepared to read the IFC information mapped on them, and are not necessarily compatible with each other.
- The IFC models must be of good quality in order to operate with them in different programs that can correctly read the information of the elements
- a classification of the building's component elements must be chosen that is appropriate for the specific case, in order to be able to use as a parameter for the classification of elements

- By running automation processes with macros, batch files, it is possible to automate certain control tasks of the IFC models and classification of the structure's component elements. In this way, it is possible to automate repetitive tasks with a lower degree of error in the result and in shorter execution time.
- It should be checked and verified that the elements are well mapped to be exported in IFC. If not, there is a great risk that the information will later be useless for processing and use with other programs that support reading IFC files.

FUTURE CHALLENGES. Although this work has studied only one specific case, there are many research challenges that can be applied in other types of relocatable structures with minimal adjustments or changes in their approach.

For other types of temporary constructions, it is suggested to analyse the procedure covered in this thesis including other tools that work on the basis of BIM as well, reading IFC files which is the most promising format on the AEC market today that allows interoperability.

Some potential and further developments that are open to being further studied could be to apply workflow for different contexts:

- Buildings that do not need to be disassembled: but folded, deflated, dismantled. What processes would be applied to them?
- Volumes for transport that do not necessarily correspond to containers, which could be of another geometry.
- Buildings that are moved in themselves, without the need to be disassembled -or that the dismantled parts would be the minority-. What would happen if we talk about transportable structures, without the need to be dismantled?
- What if the requirements were as different as a structure assembled on the Earth, and that needs to be taken to space? A structure that needs to be assembled by mechanical, automated means, without total human intervention.

The correct information attributed to the elements is essential, and the manipulation of models with correctly mapped information is an indispensable requirement.

A particular outcome may be to achieving a type of project phase as "Design for packaging", designing the rules to respect, like small elements such as bolts, anchors, nuts, will go into boxes; medium elements in containers; big elements to be redesigned. Furthermore, through algorithm applications it can be done variations on the volume of containers and boxes to adjust sizes, optimizing space and costs.

Other applications that could be made from BIM model data processing for relocatable structures:

- Coding of elements by type, size, or container in which they will be placed.
- Optimization of the location of the elements inside the containers, for example by type of material and its level of fragility, by weight (heavier at the bottom, lighter at the top) by volume (larger elements at the bottom)
- Consider separating parts by means of separating elements so that they are not damaged
- Preparation of BIM models with display filters and different criteria tailored to the user, e.g. display of the parts for the building assembler.
- Information load into the BIM elements in the construction phase (both assemble and disassemble processes) for further development of the As-Built model for facility management.

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