
Adoption of 4D BIM in Relation to Sustainable Building Design

Master Thesis

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Faculty 2

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Conceptual Formulation



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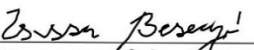
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Conceptual Formulation

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Signature of the Supervisor


Signature of the Supervisor

Introduction

Construction management has been developed over the few decades and one of the key procedures is through construction planning and scheduling (4D BIM), (Gould and Joyce, 2003). 4D BIM basically explains the four-dimensional development of software, that enables merging of schedule-based information associated with time and different components of 3D construction models (Yang et al., 2021). The adoption of 4D BIM grants project teams to perform accurate, comprehensive design and construction based on visual planning, detecting spatial and temporal errors before the actual on-site constructions begins (Singh, 2020).

With the growing and complex style of design and construction across the world, there's need to adopt modern approach of design of buildings that are environmentally sustainable (container architecture) with the advancement in technology (Adan, 2013).

Sustainability in building design and construction in recent years has been a top agenda for the international society, reflecting on the architecture of cities and display of strong race in the construction industry away from traditional building design (Abdelazim et al., 2021). Sustainable building design can be referred to as high performance building that are affordable and eco-friendly (Wang and Adeli, 2014). In recent years, it has reduced the carbon footprint and further supports sustainable development, maintenance, and servicing of the building (Granlund, 2021).

Review from previous research shows that sustainability within the building process has reflected more on the sustainable building design and construction (J. Ayarkwa et al., 2022). Such research has covered the following areas, for example application of BIM in sustainable design and its benefits for proprietors, understanding green certification and its implementation, the key drivers of environmental sustainability in construction, adopting green building technologies in buildings, barriers of environmental sustainability and understanding the organizational performance in sustainable-led construction project (J. Ayarkwa et al., 2022) (Emami, 2018).

However, with respect to existing research, the need to further understand how 4D BIM can be integrated to sustainable building design is important and the research tends to adopt container architecture as key form of sustainable building design (Adan, 2021). Shipping containers over the years are known for disposable items, or waste causing global waste crises and failing to adhere to recycling and reusing purpose (Conserve Energy Future, 2022). In order to control waste crises across the globe which forms part of global warming and greenhouse gas emission, the research tends to use container architecture as case study from Nigeria as approach for sustainable solution on building design using 4D BIM as a tool (Conserve Energy Future, 2022).

Research Questions

This research study aims to answer the following questions.

- What is the level of adoption of 4D BIM usage in sustainable building design?
- What are the potential capabilities of 4D BIM adoption in respect to sustainable building design?
- What kind of training and education opportunities are available for construction professionals regarding 4D BIM use in sustainable Building design?
- What are the ways to promote 4D BIM in sustainable building design?

Research Methodology

The research will focus on qualitative research method and quantitative research method.

Literature Review:

To answer the first and second research questions, literature review will be utilized through books, journal/newspaper articles on 4D BIM and video channels (YouTube).

Online Survey / Questionnaires Collection:

With respect to the third question, proper survey will be carried out through the Internet (Social media network and via email). The online survey will target directly on professionals in the construction industry including Construction and Real Estate Management students at master's level in Nigeria. To gather more data's, the survey will be carried out by other students of Architecture within the region in Nigeria and other locations outside the region.

Interview

For detail information on the second, third and fourth research question, an attempt will be made to have first-hand information from design and construction companies in Nigeria who utilizes 4D BIM tools. Such interview will be physical and via email with already prepared questionnaire on the research topic.

Case Study

This approach will allow for in-depth knowledge on the first and fourth research question to gather more data collection on notable sustainable buildings already design and constructed with 4D BIM. And as such expand and explain the issues encountered and solutions to the issues.

Timescale

Activity	Start Dates	End Dates
Propose Research Topic Draft 1	January 2022	March 2022
Conceptual Formulation Draft 2	March 2022	March 2022
Conceptual Formulation Final Draft	March 2022	April 2022
Literature Review	July 2022	December 2022
Online Survey + Questionnaire Collection	October 2022	December 2022
Interview	October 2022	December 2022
Case Study Approach	October 2022	December 2022
Enter Data into Computer + Analysing Data	January 2023	March 2023
Draft 1 of the Master Thesis	March 2023	April 2023
Update Literature Reading (All Chapters)	April 2023	May 2023
Draft 2 of the Master Thesis to Supervisor and await Feedback	May 2023	June 2023
Final Layout of Thesis	June 2023	June 2023
Final Master Thesis Submission	June 2023	July 2023
Presentation Preparation	July 2023	August 2023

Resources

Library Website of the Metropolia University and HTW Berlin: <https://metropolia.finna.fi/> and <https://bibliothek.htw-berlin.de/en/>

Access to Elsevier Website: <https://www.elsevier.com/>

Access to Google Scholar: <https://scholar.google.com/schhp?hl=en&as>

Access to Google Books: <https://books.google.com/?hl=en>

Access to ResearchGate: <https://www.researchgate.net/>

Access to Synchro Professional tool: <https://www.bentley.com/>

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Abstract

The prime focus of this research is to develop a utilization process of 4D BIM for container architecture, especially for the design, sustainable building, and construction time schedule. The supported knowledge of sustainable building design forms the integral concept for this research. In detail, the term sustainable building means container architecture used for decision-making throughout the design model using BIM, and the application of BIM further supported the development of the research methodology and framework.

Thus, two research methods form the quantitative and qualitative methods. The literature review concerning sustainable building, container architecture and building information modelling is developed as a quantitative method, and the case study approach forms the qualitative method in developing the framework for the utilization process of 4D BIM.

In the utilization process, the framework developed for renovating container architecture is a new topic yet to have professionally emerged in construction. Although, an existing framework is available for container architecture based on new construction highlighted in the literature review. As a result of the developed framework, five theories are adopted from the discussion. The first theory for the limitations of container architecture (planning phase), the second theory is finding a problem-solving approach (planning phase), the third theory is model development (design phase), the fourth theory is BIM quantity extraction (execution phase), and the fifth theory is developing a construction time schedule.

In conclusion, the developed framework made the research successful because a construction time schedule for the renovation of container architecture yielded a case study building of the BRLO craft beer warehouse to execute within six months, which is significantly efficient to cost and time.

Keywords: 4D (Fourth Dimensions), BIM (Building Information Modelling), Container Architecture, Design, and Sustainable Building.

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List of Abbreviations

1D	One Dimension
2D	Two Dimensions
3D	Three Dimensions
4D	Four Dimensions
5D	Five Dimensions
6D	Six Dimensions
7D	Seven Dimensions
8D	Eight Dimensions
9D	Nine Dimensions
10D	Ten Dimensions
BIM	Building Information Modelling
CO2	Carbon Dioxide
CPM	Critical Path Method
DIN	Deutsches Institut für Normung
DPD	Digital Project Delivery
DWG	Drawing
FIFA	Fédération Internationale De Football Association
GHG	Greenhouse Gas
HFC	Hydrofluorocarbon
HOAI	Honorarordnung für Architekten und Ingenieure
HVAC	Heating, Ventilation, and Air Conditioning
IFC	Industry Foundation Classes
LEED	Leadership in Energy and Environmental Design

LOB	Line of Balance
LOD	Level of Information
MEP	Mechanical, Electrical, And Plumbing
PDF	Portable Document Format
PERT	Program Evaluation and Review Techniques
SAP	System Analysis Program Development
TIF	Tagged Image File
UPVC	Unplasticized Polyvinyl Chloride

1. Introduction

At the beginning of the research, the module of this Chapter introduces the general information to the outer reader specifying the detailed content of the study. The research consists of six Chapters beginning with the first Chapter, which describes the general introduction; the second Chapter forms a review of the literature; the third Chapter highlights the theoretical framework adopted; the fourth forms the validation Chapter; the fifth Chapter includes a discussion, and the sixth conclusion Chapter.

The contribution and relevance of the introduction Chapter is the background knowledge of the research (see sub-chapter 1.1), which is a relevant Chapter for the outer reader to have evident importance for the study. Furthermore, the research problem is being discussed (see sub-chapter 1.2), providing awareness to solve the issues related to the current research. Understanding the problem further generates the aim and objectives required to solve the problem (see sub-chapter 1.3) before designing a research methodology or design (see sub-chapter 1.4) respectively.

1.1 Background of the Research

The management of buildings within the construction sector has undergone numerous applied developments and impacts over the decades, demanding lots of changes in the standard of projects planned and delivered by professionals for their clients. These changes, in most cases, arise during the design and construction phases, directly affecting the project's duration and cost, especially when the buildability of the planned design becomes complex and requires more technical expertise. The delays caused by the professionals or clients make the project unsustainable due to disputes and resolutions before completion.

For instance, in the present 21st century, most project development requires sustainability because sustainability forms the integral and determinate factor to be considered regarding a project's planning and construction phase, thereby mitigating

long construction time and cost during the development phase. For a project to be regarded as sustainable, factors require consideration based on the kind of material used, the method of construction, the technical equipment adopted, the level of environmental hazard being controlled, and the professional knowledge directly impacted.

For example, a shipping container is regarded as a sustainable building design method because the recent development of these shipping containers and adoption in the construction industry is gaining more widespread knowledge based on affordability, creative innovation, and rapid usage in residential, commercial, and leisure buildings. One among numerous remarkable uses is the concluded FIFA World Cup hosted in Qatar 2022, identified as the first recycled shipping container stadium built out of 974 containers fully reusable and improving the sustainability of material usage as shown in Figure 1 (Desk, 2022).

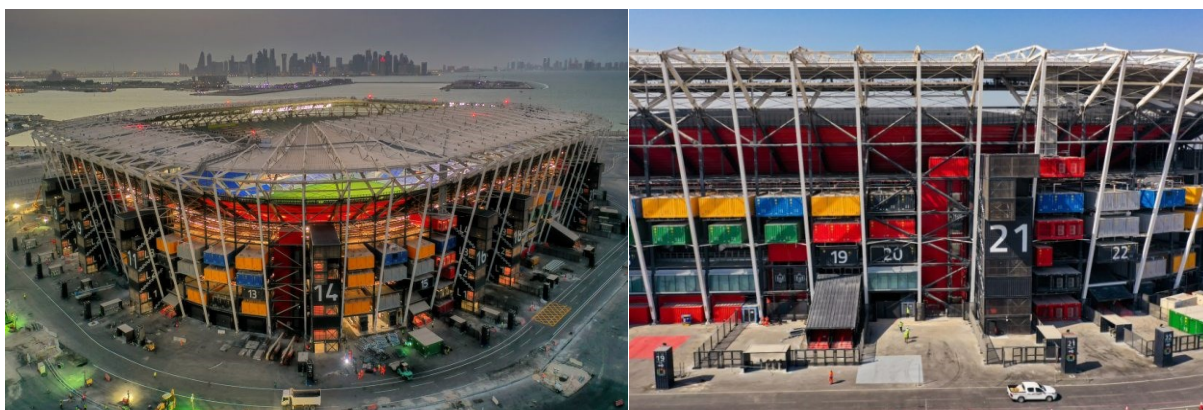


Figure 1. Recycled shipping container at stadium 974, Doha, Qatar (Desk, 2022).

The illustration in Figure 1 proves a practical example of sustainability based on the material usage and efficiency in reusing the shipping container for new construction development. The benefits of adopting this container architecture relate to the economic, social, and environmental gains which apply to construction time, cost, and management of the project.

Hence, developing this shipping container into a building requires knowledge of design. The planning and designing of the container building further require the knowledge of building information modelling because BIM forms the core success for

developing visual communication, analysis of the time, cost, and practical implementation during the construction phase.

The concept and adoption of BIM was a motivating factor for the researcher undergoing the research, focusing on 4D BIM for cost and time management. The researcher's key concern is how this 4D BIM will be used for container architecture because of its recent development in the construction industry. The contribution and framework development of how the 4D BIM will be utilized for this container architecture is a step in improving its adoption and developing building codes, regulation laws, and approval permits, which are limitations and valuable for professionals during the planning, design, and construction phase.

To find a lasting solution to the utilization problem, the researchers' knowledge of BIM will be a fundamental requirement in determining practical and constructive solutions based on work experience. Thus, developing the research requires a detailed explanation of the problem statement (see sub-chapter 1.2) respectively.

1.2 Problem Statement of the Research

The steady growth in the construction and real estate market over the years has witnessed increasing demands for spaces, especially in residential and commercial development (EW Real Estate, 2022). This development revolves around adopting building information modelling, which has achieved tremendous gains, especially in three-dimensional models, and little knowledge of other dimensions like 4D BIM.

Research shows that the adoption of fourth-dimensional models by construction professionals remains low according to statistical information in 2023 developed in the United States, describing estimating at 38.3% and scheduling at 28.5%, used on wide-scale or some specific projects without relation to sustainable building design, and little feedback generated from such projects (Statista, 2023), (Boton et al., 2015, pp. 59-60). The complexity and little knowledge of 4D BIM generate critical problems of the research with the small amount in use in the construction sector. For example, a lack of proper project planning or the use of a traditional method makes the

completion time of any project a vital issue related to project high cost overrun (Ogunde et al., 2017). Nevertheless, the need to avoid unnecessary costs, waste and continuous growth of carbon emission requires proper adoption of 4D BIM and the use of sustainable materials like shipping containers, which over the years are known as disposable material or waste that also affect greenhouse gas emission and global warming (Conserve energy future, 2022).

Based on other statistics and records within the last 14 years from the German construction sector, numerous backlogs in project completion have continued to be a significant problem, even with the large volume of building permits granted compared to the completed buildings (Schürt, 2020). The result of these problems has several influences, which have increasingly caused the construction backlog based on a lack of proper cost estimation, style, and technique which involves conventional methods becoming more complex for less skilled and unskilled professionals (Schürt, 2020).

The mitigation of this waste, long construction time of projects, high cost overrun and over-dependence on the traditional method of construction requires a vast knowledge of 4D BIM to be adopted. The research will further adopt and discuss more on the utilization of 4D BIM to make residential and commercial buildings sustainable, avoiding long construction time, high cost of construction and meeting the zero carbon-neutrality plan of 2050 proposed in Germany as discussed in Chapter 1.3 respectively.

1.3 Aim and Objectives of the Research

With the zero carbon-neutrality plan (sustainability), the research aims to encourage and adopt 4D BIM, a leading figure for less construction cost, by applying sustainable materials like container architecture compared to dependencies on the conventional construction method.

In answering the question, certain objectives will be discussed.

a). What is the level of adoption of 4D BIM usage in sustainable building design?

In investigating the research, information about 4D BIM is crucial to how it has been applied thus far in making building designs more sustainable.

b). What are the potential capabilities of 4D BIM adoption concerning sustainable building design?

To explore more ideas, the present and future gains using 4D BIM are essential when applied to sustainable buildings compared to conventional building design.

c). What training and education opportunities are available for construction professionals regarding 4D BIM use in sustainable Building design?

The Study approach is an important objective to collect information if knowledge of 4D BIM and sustainable building design is accessible and obtainable by construction professionals.

d). What are the ways to promote 4D BIM in sustainable building design?

After detailed evaluations, the research must show that using 4D BIM and a sustainable building design approach will encourage profitability and prove that zero carbon neutrality is possible if the conventional building approach is reduced.

The research questions to be answered in detail require research methods to be selected and analyzed in Chapter 1.4 respectively.

1.4 Research Design

Every research develops a design and methodological plan for solving problems by data collection, tools used for data collection, a technical approach from the data collected, analyzing the data collected and making proper findings as solutions (Robbins, 2009). In understanding the research, the researcher has developed six

Chapters involving the current introduction Chapter (see Chapter 1). Thus, in analyzing a more holistic approach for each of the Chapters, the content of the current research methodology further explains a detailed graphical representation of the design approach set and adopted as a relationship between Chapters shown in Figure 2.

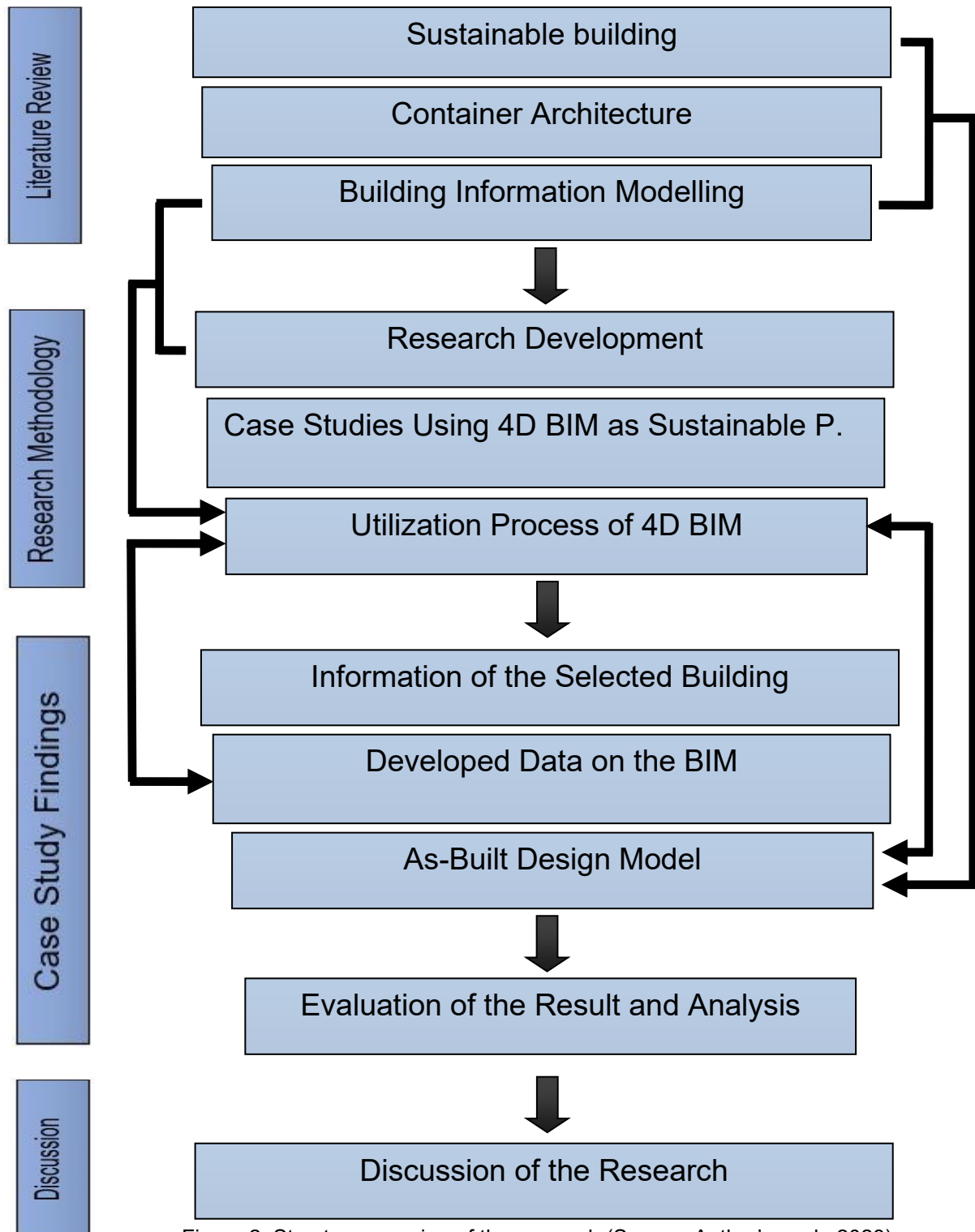


Figure 2: Structure mapping of the research (Source: Author's work, 2023).

The illustration of Figure 2 gives the outer reader a clear concept of the structure in which the research is developed. The development concept includes two methods of research being explored and focused on qualitative and quantitative research methods. The qualitative adopted is used to answer the aim and objectives of the research and forms the systematic and subjective perspective of the research in which case studies are utilized. In contrast, the quantitative method forms the scientific knowledge to be utilized through literature survey (Haradhan, 2018) and (Apuke, 2017).

Therefore, the second Chapter is the review of literature; the need to have this Chapter is to highlight all the knowledge that contributes to the research, and the knowledge will be utilized in answering objective questions one and two talking about sustainable building design and 4D BIM. In developing the Chapter, four sub-chapters are discussed under other sub-section. The first Chapter discusses the knowledge of sustainable building (see sub-chapter 2.1); the information gotten is being translated concerning container architecture as a sustainable method (see sub-chapter 2.2). Then the generated information on container architecture draws the needed idea of explaining building information modelling (see sub-chapter 2.3) because of developing use cases of models related to the topic and discussing the research outcome (see sub-chapter 2.4).

The third Chapter develops a theoretical framework which is a tool for solving the problem of research. In explaining the Chapter in more detail, four sub-chapters are being discussed under other sub-sections. Developing the framework helps answer objective question three, described in the research hypothesis and answered based on the stakeholders involved in this project and the knowledge required for understanding the project (see sub-chapter 3.1). The stakeholder's knowledge enabled the researcher to adopt five case studies helpful in developing the framework based on possible software understood and utilized by the professionals in carrying out the 4D BIM use process (see sub-chapter 3.2). The deduced knowledge was translated into the designed framework for utilizing 4D BIM based on container architecture (see sub-chapter 3.3) and a concluding outcome (see sub-chapter 3.4), which finalized the theoretical framework.

The fourth Chapter, namely the validation Chapter, is designed to validate the framework following all the necessary procedures highlighted (see sub-chapter 3.3).

In developing this Chapter, four sub-chapters are being discussed under additional sub-sections, and a case study of the BRLO craft beer warehouse is selected for renovation and validation of the framework. The information about the BRLO craft beer warehouse is being discussed (see sub-chapter 4.1) to give a background knowledge of the need for the use case. Collecting the building data and identifying the problems related to the use case enabled the researcher to develop a problem-solving approach (see sub-chapter 4.2). With the information generated, an as-built model is developed to validate the potential of utilizing 4D BIM for the container case study due for renovation (see sub-chapter 4.3). The final phase of the validation Chapter discusses the results and analysis to show the outer reader that the validation is reliable and can be adopted in further research (see sub-chapter 4.4).

In finalizing the research, the discussion Chapter (See Chapter 5) talks more about the general knowledge from the review of literature, frameworks, and validation Chapters. The Chapter is developed under three sub-chapter, discussing the design model (see sub-chapter 5.1), followed by the limitations that the research is being highlighted (see sub-chapter 5.2) and headway for future research areas based on the limitation (see sub-chapter 5.3) before the conclusion and final Chapter respectively.

2. Literature Review

The component of this Chapter begins with a clear literature review of sustainable building, presenting container architecture as a sustainable building method and a review of building information modelling. The researcher's information gives the outer reader a clear understanding of what sustainable buildings mean when building information modelling is adopted or executed. This Chapter specifies notable amounts of data to back up the research sequence.

The first part (see sub-chapter 2.1) provides an overview of information about sustainable building, the principles and advantages, and sustainable residential and commercial building as factors necessary for the research. The second part (see sub-chapter 2.2) includes a detailed overview of container architecture as a sustainable building method, the principles, the types, the construction time schedule, and the problem faced during the construction time schedule. The final and third part (see sub-chapter 2.3) highlights building information modelling as an essential asset for the research, 4D BIM as a critical component, the capabilities, the level of adoption of this 4D BIM, and a summary of chapter 2, respectively.

2.1 Sustainable Building

Before giving more detailed information about sustainable building, the researcher provides a brief content of this current Chapter to give the outer reader a more informed knowledge included in this section. This first section (see sub-chapter 2.1.1) provides the main overview of the meaning of sustainable building, and the second section (see sub-chapter 2.1.2) provides a detailed principle and advantages of sustainable building. In contrast, the third section (see sub-chapter 2.1.3) explains more knowledge of sustainable residential and commercial buildings and a summary of sub-chapter 2.1, respectively.

2.1.1 Meaning of Sustainable Building

Sustainable buildings can be referred to as buildings with minimum disadvantageous influences on the natural and built environment because of essential qualities like environmental, social, and economic performance (John et al, 2005, pp. 319 - 328). Also, it can be defined as structures which are built in a manner that is environmentally friendly to users, putting in mind the type of material used, reduced level of resource adopted, and the healthy condition of the occupants (Smiciklas et al., 2012, p. 5).

Thus, the structure of designers in the built environment and builders began to focus on reducing the over-dependence on fossil fuels and reducing construction costs in homes and buildings, resulting in sustainable buildings (Neyestani, 2017). The advancement of this idea in building designs over the 20th and 21st centuries has proven the presence of sustainability, which was developed from research to reality in the construction industry. This motivation has further quest competitive practices among designers and construction companies due to climate change and increasing shortage of resources (Federal Ministry of the Interior, Building and Community, 2017).

This significant practice brought a clear idea of sustainable building, to be buildings which are designed, built, can be renovated, and reused to meet the goal of reduction in CO₂ and GHG emissions, making resources efficient and ecologically friendly to humans (Akadiri et al., 2012). In contrast, it can be a new design or existing construction, in which its design approach and function define the space, the provided indoor climate, security, relationships of the surroundings with minimal or zero environmental impact, and comfort for users, which in turn improves the performance of the building (Berardi, 2013). These objectives profound the principle and factors for considering sustainable building at the early stage of the design process as explained (see sub-chapter 2.1.2), (West Oxfordshire District Council, 2012).

2.1.2 Principles and Advantages for Sustainable Building

Based on nine different reviews of literature, the researcher developed the six important and relevant principles for sustainable building according to (Yilmaz, 2006), (Gardimalla, 2008), (Chicago Faucets, 2018), (Acciarr, 2022) (Hafez et al., 2023) (Hasselaar and Morawska, 2023) (USGBC, 2014) (Khamidi et al., 2010) and (LISC Bay Area, 2007) to give the outer reader direct information been adopted and discussed as listed below.

a). Site optimization potentials: In achieving the goal of sustainable building design, selecting an appropriate site is important based on the locations, the building orientations, and the kind of landscaping, and installation used, which affects the ecosystem, transportation, and energy adoption. Therefore, construction projects require efficient utilization of site layouts that will be productive, safe, and capable of reducing conflict between influencing factors, for example, material management, logistics deliverables and flexible environment use through its optimization on-site (Chicago Faucets, 2018).

b). Preserve water resources: Installing freshwater collectors and automatic taps on showers, basins, and dual flush toilets is an important approach to sustainable building because it helps avoid unnecessary wastage and conserve the available water used in the building. The development and implementation of the materials make the building affordable for users with protection laws to cover the conservation and preservation of the water sources, thereby improving the sustainability and cost reduction of the operation cost, maintenance cost and building lifespan (Gardimalla, 2008).

c). Improvement of Energy Usage: Using fossil fuels in buildings is a major environmental issue related to sustainable buildings (Yilmaz, 2006). With the ongoing Russia-Ukraine war, most governments have begun to consider more alternatives to adopting renewable energy, a productive and cost-efficient resource for sustainable

buildings when designed (Acciarr, 2022). In achieving renewable energy, this step is an important area that reduces the GHG emissions generated from buildings because natural sources of energy automatically reduce pollution and raw materials like wind, for example, can be recycled as material to generate energy meeting safety and indoor environmental quality requirements (IEQR) (Hafez et al., 2023, pp. 2-4).

d). Increasing indoor quality and environment: Research shows that between 40-50% of global carbon emissions are generated from buildings (Yilmaz, 2006). Therefore, architects and designers of the built environment need proper strategies and adoption of daylighting, operable windows, proper air quality control, acoustic elements, ergonomics, and thermal conditions when designing buildings for occupants (USGBC, 2014). These strategies highlighted practically improves the health and well-being status of users, the standard of the environment and reduce the generated GHG that is emitted through the building, which is further classified as fine particles from terminologies (Hasselaar and Morawska, 2023, pp. 1-2).

e). Enhancing operation and maintenance measures: Architects and designers must continue collaborating with facility managers in building maintenance. The improvement and use of sustainable building enable a rapid reduction in the cost of maintenance, energy and water saving, and waste reduction, which improves the healthy environment of the occupants (LISC Bay Area, 2007). Thus, proper maintenance contributes to the sustainability of a building in different forms; for example, it keeps noxious to a minimum level, likewise making the building more durable, which in turn reduces the energy and resources emission and finally gives the architects and designers an informative component to install in the building during the construction or reconstruction phase (Khamidi et al., 2010, pp. 47-48).

f). Utilization of building materials: The materials used can form an integral part of sustainable building. For example, recycled shipping containers which is a material proposed for the basis of the research. In recent years its techniques in defining reduction in environmental impact and less construction cost make it an eco-efficient

material for sustainable buildings (Yilmaz, 2006). Therefore, global warming activities require sustainable materials as an essential solution to reduce the impact of GHG emissions from the building because of the less construction time, recycling process, and affordability as an important factor in making a sustainable building.

Therefore, the principles highlighted above are being utilized in planning and designing sustainable residential and commercial buildings discussed (see sub-chapter 2.1.3) and validation chapter (see sub-chapter 4.2.3). Furthermore, highlighting sustainable building principles and discussing their advantages is important to give the outer reader a clear knowledge of the values when constructed. Based on five literature reviews, six advantages of sustainable building are selected, identified, and discussed based on their relevance according to (Madkour, 2007), (Braganza, 2019), (HL Design Group, 2010), (S Jones, 2019) (Andersen et al., 2020).

a). Affordability: The availability of the raw material in excess, which is shipping containers around the world, makes its purchase cheaper because it is said to be expensive to return to an area where exportation is being carried out, causing environmental waste. To avoid wastage, most containers are easily sold at a cheaper rate to serve as housing skeletons and structural elements, which is advantageous as compared to the use of cement for the casting of structural elements of conventional buildings (Madkour, 2007).

b). Reliable in construction and architecturally sustainable: Over time, steel as a raw material for container buildings has proven to be durable, acting as an architectural beauty and helping in carrying heavy loads or high columns, resisting different weather conditions and corrosion. These form the basic structural element of the building, which over time can last for 20 to 30 years. After its usage, it forms a recyclable material reducing environmental wastage and tackling climatic actions caused by the livelihood of humans (Braganza, 2019).

c). Less construction time: Because of its modular composition and finishing of its off-site works, it is considered a decreasing factor in time spent in construction, which

speeds up 40% of completion time leading to efficient construction of buildings as compared to conventional houses, helping in saving the cost of construction projects. The construction time of this shipping container is a necessary topic for this master thesis because of its recent development and overlap in determining the possible reconstruction or renovation time. Thus, this point will be useful for validating the research (HL Design Group, 2010).

d). Environmentally friendly: Recycling purposes have made shipping containers an alternative and beneficial material for a building to be considered sustainable compared to conventional buildings. Recycling this container material is the foundation which helps save environmental pollution, and such, reprocessing requires less energy than the production of new building materials forming the basis for it being environmentally friendly to users (Madkour, 2007).

e). Labour efficiency: Professionalism is considered an essential factor which increases construction costs due to the cutting and welding of steel members. Over time when compared to conventional buildings in terms of labour cost, it is less expensive, requiring only steel professionals and few concrete engineers as compared to conventional buildings of concrete specialists, wood framing engineers and steel engineers, which requires more labour cost and is also time-consuming to accomplish. The portability of the container home makes the construction time faster and, in turn, reduces the labour involved in building the container home over time (S Jones, 2019).

f). Less GHG emissions: The increase in GHG emissions caused by conventional buildings has drawn ideas for an alternative process to be carried out to reduce global warming. Adopting recyclable materials like container architecture from research is an immediate alternative to global warming because it helps reduce carbon emissions, a strategy the construction industry uses to reduce the high number of emissions from buildings. The less generated emission from shipping containers further makes the building more sustainable, eco-friendly, and habitable, representing the importance of home construction (Andersen et al., 2020).

For the construction of homes, these advantages highlighted above for shipping container architecture are essential, beneficial, and proper for the generation of cost and time for construction of various types of residential and commercial buildings respectively.

2.1.3 Sustainable Residential and Commercial Building

The term “sustainable residential and commercial building” are buildings that are resource efficient and environmentally planned, designed, constructed, operated, and maintained throughout the life cycle of the building (Golubchikov & Badyina, 2012, p. 3).

However, green buildings are not only regarded as sustainable, but other factors contribute to making residential and commercial buildings sustainable based on the following facilities and considerations; connection to shops, educational facilities, transportation network, jobs, health care, ability to withstand natural and climatic disasters when the building is constructed and aiming to reduce energy consumption, waste, and greenhouse gas emissions over the building life cycle are a vital consideration for sustainable residential and commercial buildings.

Many techniques and technology are commercially available and tested, which equally help reduce energy when used, and provide a substantial benefit to residential and commercial buildings when constructed. Before discussing the technology available, it is necessary to review some fundamental principles applicable to energy-efficient designs and operation of residential and commercial buildings, using the United States and China as case study references illustrated in Figure 3 (Levine et al., 2007, p. 393).

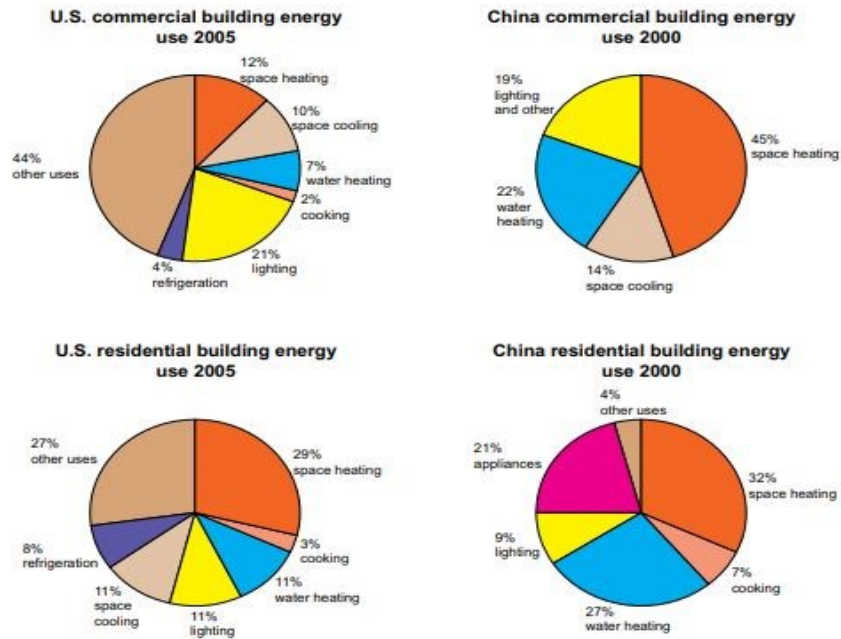


Figure 3: Residential and Commercial energy use in the United States and China (Levine et al., 2007).

From the above Figure 3 illustration and breakdown, the most effective energy use in residential buildings is space heating for both regions; water heating in China dominates the second energy use, followed by electrical appliances in the United States. The use of energy in commercial buildings also shows that China and the United States are widely dominated by space heating, which is closely related to buildings in the EU, amounting to 2/3 of the total energy use during the winter periods and lighting, using air conditioning system during the summer period, this consumption of energy makes buildings unsustainable and require technology in reducing its usability.

Based on recent development and trends in energy use and GHG emissions illustrated a few examples describing the abundance of opportunities, techniques, and technology to help achieve a reduction in GHG emissions to about 70 to 80% in residential and commercial buildings (Levine et al., 2007, p. 391). Some of the trends are discussed as follows.

a). Building forms, orientation, and attributes: During the planning stage, architects must make clear decisions related to the forms of residential and commercial

buildings because of their influence and opportunities to help reduce energy use. The orientation of the building can act as a self-shading device for effective and efficient opportunities for passive ventilation and a source of cooling, making residential and commercial buildings sustainable.

b). Minimizing halocarbon as a source of emission: A good number of refrigerators, air conditionals, fire protection systems and insulation products contribute to greenhouse gas emissions and high global warming. HFC refrigerator systems accommodate less or zero ozone depletion, creating less emission generated from refrigerators and air conditioning appliances, which is vital for sustainable residential and commercial buildings over their life cycle (Levine et al., 2007, p. 395).

c). Proper thermal envelopes: The shell of the building refers to thermal envelopes; the improvement and adequate installation create an opportunity for reduction in heating or unwanted mass transfer from the interior to the exterior of the building. The idea of thermal envelope practices decreases the total cost of residential building energy consumption by a good percentage and a zero increment on commercial buildings when heating and cooling are considered (Demirbilek et al, 2000, pp. 38-39).

d). Windows: The energy performance of residential and commercial buildings is considered based on the types of windows installed. Multiple layers of glazed uPVC windows are considered a low conductive source of emission based on the coating on one or more layers available for heat loss. Window glazing that absorbs solar radiation has a large fraction and reduction in solar heat gain of about 75%, helping in reducing the high demand for cooling loads (Levine et al., 2007, p. 396).

e). Lighting systems: A good amount of energy can be reduced by 75 to 90% from lighting using daylight, as discussed under windows, using efficient devices and task lighting. Halogen and fluorescent lighting systems significantly reduce energy consumption in residential and commercial buildings during the life cycle because the

illumination generated absorbs less emission and task lighting, which is popular in Europe (Levine et al., 2007, p. 402).

The review of techniques and technology available and described above requires its applications on residential and commercial buildings, based on the research and to make buildings sustainable, respectively.

Summary of Sub-Chapter 2.1

The findings in this sub-chapter summarize the definition of sustainable buildings and the need to adopt innovative ideas away from over-dependence on fossil fuels that increase features of CO₂ and GHG emissions. Furthermore, some fundamental principles highlight the steps that make buildings more effective and sustainable, discussing how residential and commercial buildings can be sustainable and applying trends during the building's life cycle respectively.

2.2 Container Architecture

Regarding this Chapter, the content describes container architecture as a sustainable building method (see sub-chapter 2.2.1), the principles that make container architecture sustainable (see sub-chapter 2.2.2), an in-depth explanation and types of container architecture available for the construction of residential and commercial buildings (see sub-chapter 2.2.3), the construction time schedule of container architecture (see sub-chapter 2.2.4), the problems arising when using container architecture (see sub-chapter 2.2.5), and a summary of sub-chapter 2.2 respectively.

2.2.1 Container Architecture as a Sustainable Building Method

Container architecture is a form of building that describes the process of reusing steel for structural and architectural components of buildings for human habitation and its activities (Radwan, 2015, pp. 1562-1566).

The biggest problem of human habitation is the livelihood over the years and the opportunity of buying where to live, which has continued to occur with the need for necessary solutions (Grębowski & Kałdunek, 2017, pp. 1 - 2). Review shows that the cost of building materials over the years has been high and has risen in buildings; for example, concrete, which had been a significant building material used for several decades, shows its increasing cost, which has affected the buildability and cost of homes for people to live (Sulong, 2010).

This cost and over-dependence on concrete brought the invention of shipping containers which are also known as sea or cargo containers, in 1956 by Malcom Mclean, an American trucking entrepreneur, reshaping the architectural space with tremendous innovation and its first completed design in the Netherlands in 1986 (Architecture & Design, 2021). In making it a sustainable building method, the primary building material known as steel is designed to minimize waste and reduced dependence on concrete because steel is said to be a 100% recyclable material which is cheaper and easier to build than concrete when used in the construction of buildings (Robinson & Swindells, 2012).

This thriving success has continued to improve the usage of the shipping container and make it an iconic globalization of sustainable buildings which are habitable, structurally stable, and less expensive than the concrete used for conventional buildings (Socrates, 2012). The innovation of container architecture continues to show creative transformation and modification, which have been utilized in the different approaches of structures, ranging from sculpture production, office buildings, residential buildings, sports stadiums and many more, which has gained lots of advantages in the construction industry (Morin, 2020).

Research has further described that the architecture of buildings using shipping containers has withstood the ability to stack over time, estimating that about 17 to 20

million of these containers are cut across the world today (HL Design Group, 2010). With the popularity of this architecture, the shift and heavy reliance on cost-effective building solutions have triggered that sustainable buildings using shipping container architecture can reduce the GHG emission generated within the building and further make designs more eco-friendly for occupants of the building, reducing over-dependence on conventional building resultantly (Overstreet, 2021).

2.2.2 Principles of a Sustainable Container Architecture

With the rapid urbanization around cities in Germany, a continuous need for the construction of new commercial and residential buildings, among other types of buildings of steady growth, is required. However, the question will always arise based on the level of sustainability adopted on these buildings, which often those facilities are built without precise analysis, resulting in GHG emissions (Sljivic et al., 2021). For a building to be considered sustainable during its life cycle phase, designers need to adopt some of the principles listed below for planning, which are environmentally friendly, as shown in Figure 4 (Smith and Timberlake, 2010).

DO	DO NOT
Use recycled materials	Use all new material
Use recyclable materials	Use single-life materials
Use a few materials and components	Use many different types of materials and components
Use natural and non-toxic materials	Use toxic and hazardous materials
Use easily separable materials	Use composites that are inseparable
Use mechanical or natural finishes	Use composites that are inseparable
Use mechanical or natural finishes	Use applied coatings and finishes
Provide permanent identification of material type	Use materials that end of life reuse is unknown
Use mechanical connections	Use chemical connections and adhesives
Use a changeable adaptable system	Use fixed unchangeable systems
Use modules, panels, or components	Use non-standard sizes or configuration systems
Use standard construction methods	Use highly proprietary systems
Separate building systems	Compress systems requiring one and all to be changed
Make materials able to be handled	Make systems that require difficult labor sequencing
Provide a means for handling	Neglect construction sequence process during design
Provide realistic tolerances	Make building too tight
Use fewer connections	Use infinite fasteners and connectors
Design durable joints and connectors	Design one time assembly connections
Provide parallel sequencing disassembly	Detail construction process to accommodate linear path
Use a structural/assembly grid	Make every component and joint entirely unique
Use lightweight materials and components	Use heavy and cumbersome materials and components
Permanently identify points of disassembly	Make assembly and disassembly obscure
Provide spare parts and onsite storage	Make a proprietary system where there is just enough

Figure 4: Recommended methods for environmentally friendly buildings (Smith and Timberlake, 2010).

The principles highlighted in Figure 4 above further help designers in the selection and type of shipping container architecture and design as described in section 2.2.3 below.

2.2.3 Detailed Explanation and Types of Container Architecture

Construction experts' development and use of container architecture are becoming predominant progress within the construction industry, which is part of the modular and prefabrication process in architecture (Shen et al., 2019). Much research has attempted to define the term container architecture, and some recognized the development as shipping container architecture, which explains the architecture fully characterized by the process of using and reusing steel as a product and structural material for a specific human activity (Radwan, 2015).

Some articles refer to it as cargotecture. Cargotecture, invented in 2003 by Hybrid Architecture of Seattle, portrays it as a functional building that can be partially or fully designed with shipping containers to serve the purpose of business or home for occupants with needs for housing (Tiger Containers, 2016). As a result of its definition, research further describes that the shapes, sizes, and modes of construction differ worldwide, giving its life performance between 20 to 30 years when constructed (HL Design Group, 2010).

The following are five standard types and sizes of shipping containers used worldwide for general purposes and the construction of buildings.

20 Feet Dry containers: This multi-purpose container is made of steel, vertically corrugated on both sides, including the front part of the container. The container consists of a double door at the rear, with roof covering and corner fittings horizontally corrugated, as shown in Figure 5 and detailed dimensions in Table 1 (Shen et al., 2019) and (Starmarine Services Ltd, 2015).

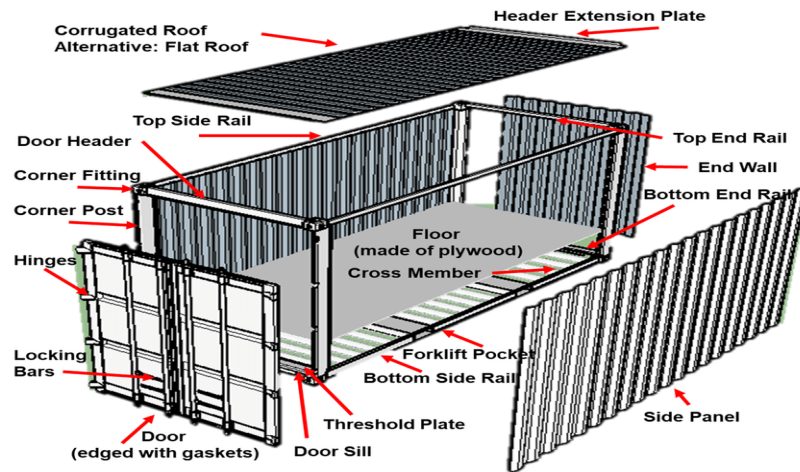


Figure 5: Schematic diagram of a 20 feet standard shipping container (Shen et al., 2019).

Dimensions*	Length	Width	Height
External	6096 mm	2362 mm	2590 mm
Internal	5944 mm	2337 mm	2388 mm
Door Openings		2337 mm	2286 mm
Weights*			Capacity*
Max. Gross	Tare	Max. Payload	
24000 kg	2080 kg	21920 kg	33.9 cub.m

Table 1: The dimensions and weight of the 20' shipping container (Starmarine Services Ltd, 2015).

40 Feet Dry Container: The capacity and size are much bigger than the 20 feet dry container. It is also designed with steel frames, corrugated vertically on each side and front of the container with covering on the top and openable doors, as shown in Figure 6 and detailed dimensions in Table 2 (Christian, 2020).

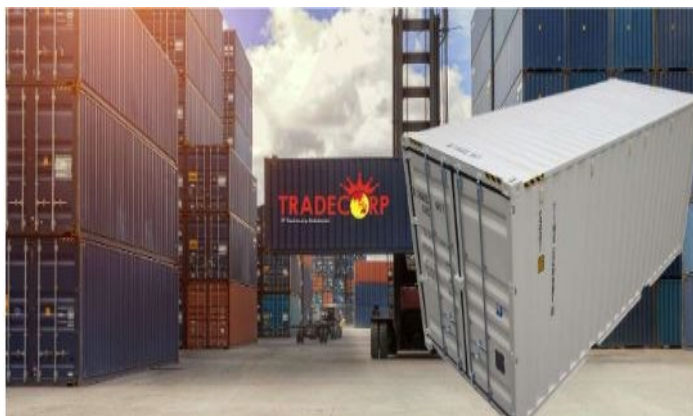


Figure 6: Pictorial diagram of fully stacked 40' dry container (Christian, 2020).

Dimensions*	Length	Width	Height
External	12192 mm	2438 mm	2591 mm
Internal	12014 mm	2286 mm	2388 mm
Door Openings		2337 mm	2286 mm
Weights*			Capacity*
Max. Gross	Tare	Max. Payload	
30480 kg	3900 kg	26580 kg	67.7 cub.m

Table 2: The dimensions and weight of the 40' shipping container (Starmarine Services Ltd, 2015).

Other types of shipping containers used for the construction of buildings are, 40 feet high cube container with a size of 12192mm length x 2438mm width x 2896mm height weighing about 30480kg, wide pallet container which is mainly used in Europe slightly have a width of about 2.5 meters as compared to others and rigid top container which comes in different sizes like 20 feet, 40 feet and 40 feet high cube designed for slabs or roofs to be easily removed, allowing for several advantages show in section 2.1.2 for fast constructability during construction (Starmarine Services Ltd, 2015).

2.2.4 Construction Time Scheduling for Container Architecture

For proper understanding, one essential task of construction project management is the planning initiated and the scheduling carried out in terms of cost and time for effective project management (Hancher, 2003). A Construction schedule which deals with the visual development of all necessary activities to be carried out during the design process and construction of buildings defines the time frame and cost for such projects using BIM software (Discover Containers, 2021). With lots of knowledge on construction schedules found from research, it is unfortunately difficult to pinpoint any generated schedule related to shipping container architecture because of its recent

evolution worldwide. According to detailed research, ideas further share that container architecture cannot be of the same design but can always share similar characteristics, which this research will be tailored to as explained below (Discover Containers, 2021).

a). Planning of shipping container: The allocation of budget can take four days (4) to generate depending on the organization, followed by the development of draft designs which involves plans for about twenty (20 days) before site information is assembled for three days (3) and then a completed material selection for about two days (2) closes the planning phase for six week duration time of all activities to be carried out putting in mind that there is available land approved and building permit is given for the design and construction of the shipping container architecture (Discover Containers, 2021).

b). Preparation of approval design and execution planning: This stage is said to be the longest stage focusing on about 9-12 weeks as described, based on activities to be carried out like completion of design plans (10 days), generating execution plans (5 days), giving appropriate and final budget (2 days), getting approval for structural designs made (10 -15 days), requesting for a building permit can take (15 - 25 days) depends before a general contractor is hired within an interval of (3 days) from client request (Discover Containers, 2021).

c). Preparation of site and erection of foundation: The next stage is the construction phase which involves the activities described under the following durations, identification and purchase of the shipping container (5 days), site clearing and provision of the access road network on site (5 days), excavation and preparation of foundation layout (5 days), running service and utility lines on site (2 days) and laying of foundation which can take (5-15 days) bringing a total of four to seven weeks (Discover Containers, 2021).

d). Modification and erection of the container: It is recognized as the fourth stage involving the modification of the container to meet the design requirement provided by the architect and the structural engineer. Activities can take three to nine weeks to accomplish under the following; spraying of paint on the container to avoid rust and act as an air seal externally (1 day), positioning of the container to the foundation (2 days), modification and cutting of necessary openings to link two or more containers together (1-15 days), framing and roofing of the container (1-5 days), installation of windows and doors (1-10 days), piping of services (3 days) and framing of the interior 5 days (Discover Containers, 2021).

e). Completion to occupancy: Depending on the capacity of the container house, it can take days or months to complete based on the specification provided. For a simple plan container building, the following activities are required, insulation of the interior (1-10 days), drywall finishes (2 days), provision of flooring (2 days), installation of utility fittings, HVAC appliances (2-10 days), interior decoration and painting (1-5 days), cladding in some cases can be done externally which is optional (1-10 days), landscaping of the exterior (1-5 days), testing and cleaning (1-5 days) and handover of the building to be done within a day, completing the construction schedule of about forty-two weeks or ten months to complete a simple container building (Discover Containers, 2021).

Therefore, this concept of schedule and construction of shipping containers generates significant problems during construction because of its recent innovation in the building industry, as discussed (see sub-chapter 2.2.5) respectively.

2.2.5 Construction Time Scheduling Problems for Container

Architecture

Based on a review of different kinds of literature, according to (Equipment Management Services, 2019), (Hogan, 2015), and (I Container Home, 2021) these

are the five key listed problems affecting construction time scheduling for container architecture being highlighted and discussed in the following section.

a). Construction permits and building codes: The evolution of container buildings is still in progress and new; as such, many conventional building permits and codes are already generated, which do not match the container buildings' new development and design specifications. This problem is a significant concern causing construction setbacks based on compliance with construction and zoning regulations of using shipping containers to construct buildings. Therefore, professionals in the development and urban planning departments require quick and urgent attention to developing reliable building codes, regulations, and zoning laws to speed up and improve container building approval and construction time going forward (Equipment Management Services, 2019).

b). Modification: The usage of two or more containers requires technical professionalism. In most cases, combination and welding have been critical problems affecting the construction of container buildings because the corrugated steel, when cut and not appropriately joined, causes structural weakness, linkages and rust to the steel frames when constructed for use. The concern related to the problem requires specialization and recommendation of architects and designers whose essential knowledge focuses on the shipping container because proper coordination of the design phase amounts to reliable structural strength and safety of the container building upon construction or reconstruction process (e-architect, 2021).

c). Insulation: Based on weather conditions and acoustic effects, insulation is required internally when using container architecture, and if it is not done correctly, it affects the connection of service lines like electrical and plumbing lines because of the consideration carried out by designers not to reduce the usable space of the container. Thus, specialized professionals related to planning, design, and construction of the shipping container should be involved more to avoid construction setbacks which can result in building failure and lack of sustainability when used for habitation (Hogan, 2015).

d). Space constraints: Modification and use of space are rigid because containers already have a fixed dimension allocated to them, making the headroom of some container homes lower after considering HVAC systems needed to be installed, especially when using a single container module for housing. Therefore, suggestions and alternative approaches should be designed to avoid space constraints that automatically reduce the flexibility and allocated space within container buildings, amounting to a loss of user attraction and diminishing the container building concerning the word sustainability (I Container Home, 2021).

e). Finding experienced contractors and construction site issues: It may look easy for the container to be built, but it requires experienced contractors during construction to avoid future issues. The contractors employed during the construction phase require in-depth knowledge of the sizes, materials, and technicalities for the buildability of the shipping container, for example, using a crane. If cranes are not used, it becomes difficult to move the weight load of the containers to the correct positions during construction, and the required knowledge of the contractor and its workers amounts to proper construction time and saving costs for the building. The time and cost saved further improve the adoption of this container building (I Container Home, 2021).

Therefore, these problems highlighted above require urgent attention, and if solutions are developed accordingly, it will improve the useability of container architecture respectively.

Summary of Sub-Chapter 2.2

The findings in this sub-chapter summarize container architecture as a sustainable method, defining its fundamental innovation as steel which is 100% recyclable and making steel a key factor of sustainable building. Furthermore, the principles and the types of shipping containers available for residential and commercial buildings are highlighted. A review of the construction schedule was highlighted for the container

architecture to be planned and constructed, and the problem facing container architecture was extensively discussed respectively.

2.3 Building Information Modelling

The overview of the module describes the meaning of building information modelling (see sub-chapter 2.3.1), fourth-dimensional building information modelling for planning, design, and construction (see sub-chapter 2.3.2), the capabilities of 4D BIM when adopted in sustainable building design (see sub-chapter 2.3.3), the level of adoption of 4D BIM usage thus far in sustainable building design (see sub-chapter 2.3.4), and a summary of Chapter 2.3 respectively.

2.3.1 Meaning of Building Information Modelling

“BIM” refers to building information modelling or building information management. It is defined as a digital process or method of representation of the physical and functional characteristics of a building, which enables stakeholders to collaboratively design, construct, and operate a facility throughout its lifecycle (Besenyői, 2023, pp. 7 - 8).

Over the years, different definitions continued associating with modelling technology and communicating, producing, and analyzing how building models are characterized (Eastman et al., 2011). These characteristic forms the development and implementation of building information modelling (BIM) tools, which has practically increased the innovation and productivity of companies in the construction industry, adopted by architects and engineers to manage projects effectively (Sinenko et al., 2020).

BIM is essential for this research, and identifying the process or dimensions is required. The dimensions consist of ten modelling process, 1D for project

collaboration, laws and contracts, 2D for workflows and implementation of plans, 3D for modelling and information, 4D for schedule and sequence, 5D for accurate cost estimation, 6D which deal with the addition of sustainable information of the design to its green design and 7D for facility and asset management, infrastructure and real estate management, 8D for as-built and LOD levels of information, 9D for lean construction and 10D for industrialized construction (Onungwa et al., 2017) and (Kiritharan, 2021). This dimension is further described in Figure 7, as shown below.

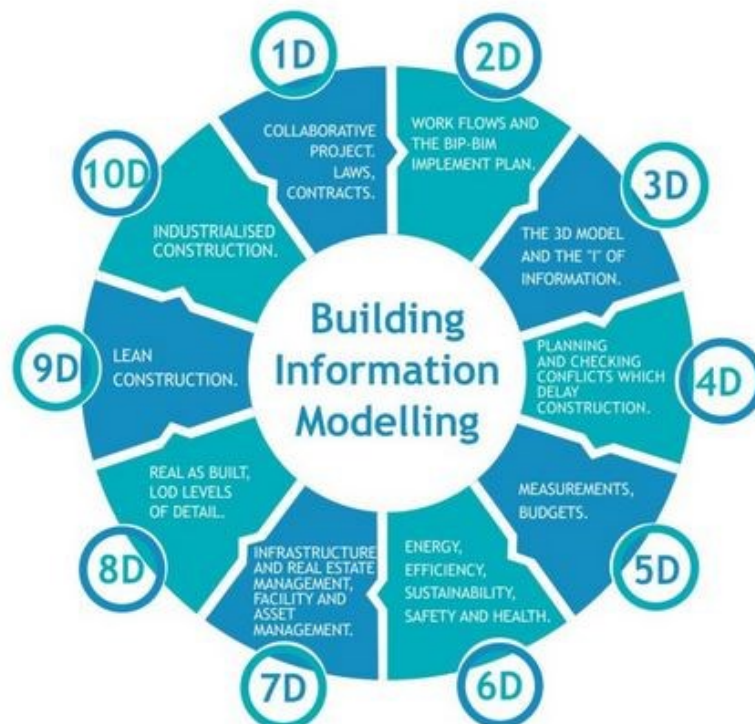


Figure 7: The Ten Dimensions of BIM (Kiritharan, 2021).

Figure 7 describes the ten-utilization process or dimension of BIM. For this research, 4D BIM is the focus dimension because it helps define the construction cost, time schedule and management of the entire building life cycle. Therefore, more detailed information regarding 4D BIM will be discussed (see sub-chapter 2.3.2) respectively.

2.3.2 Fourth-Dimensional Building Information Modelling for Planning, Design and Construction

Understanding these concepts and 4D BIM acronyms is crucial for successful planning, design, and project scheduling, which results in the construction of the planned building. The researcher, therefore, provides an overview of the meaning of 4D BIM for the outer reader to have in-depth knowledge before the planning, design, and construction phase.

4D: The term refers to 4th Dimension. In scheduling, it integrates 3D BIM models with project schedules to visualize, simulate, and analyse construction sequences and resource utilization over time. It provides a comprehensive understanding of the construction process, helps identify and mitigate schedule and resource conflicts, and improves project coordination and communication (Basu, 2007, pp. PS.12.1 - 12.2).

The next term is 4D BIM, which links time into the 3D model or objects for scheduling (Kjartansdóttir et al, 2017, p. 43). It can also be described as a form of development done on software which allows for the merging of scheduled information and 3D models (Vaai, 2014, p. 12). This process gives a clear understanding when calculating the cost of a space or an entire building. It identifies every required time and cost estimation for a project to be completed within a particular period, represented using a Gantt chart, as shown in Figure 8 below.

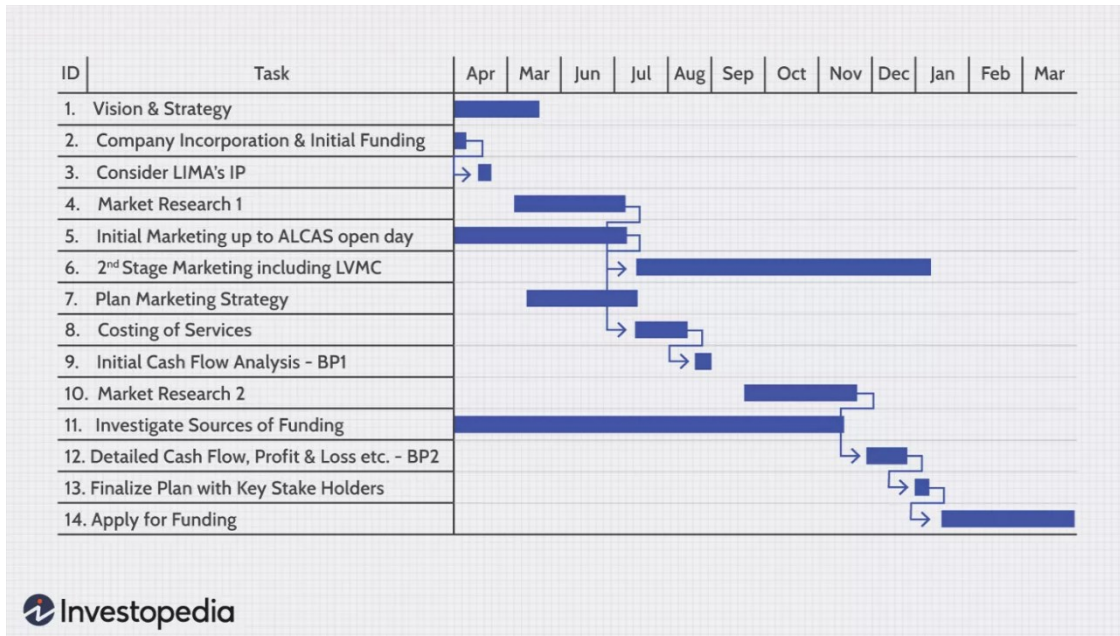


Figure 8: Illustration of scheduling on Gantt chart (Grant, 2022).

In summary, Figure 8 describes the graphical grant chart showing the task to be achieved concerning duration. These concepts and acronyms represent a change in basic assumptions in the construction industry towards a more integrated, collaborative, and data-driven approach to planning, designing, constructing, and operating a building.

Therefore, this approach to planning and designing sustainable buildings requires when an object utilizes time and space, allowing for participants or stakeholders to define and visualize the activities carried out during the project lifecycle and detecting conflicts that arise due to changes occurring within the construction period (Sheina et al, 2018, p. 2).

This method of planning and designing sustainable projects for construction thus represents an integral part of project management, involving the object modelled in 3D and the detailed representation of the network model. For example, the construction of a project addresses crucial areas of design conception and selection of technological methods, activities to be carried out, and estimation and management of different tasks (Zita, 2018, p. 23).

Research future describes the solution of planning by involving scheduling of information into 3D BIM as an act of generating comprehensive technique to define a model of a project that coordinate various uses cases of 4D BIM, which includes waste management in construction, detection and tracking issues, following up the progress of construction, analyzing the dynamics of the project site and logistics management.

Furthermore, 4D BIM simulation is significantly more efficient and resourceful than conventional planning procedures. Its capabilities have been described (see sub-chapter 2.3.3) with a reported increase in efficiency of up to 40%, demonstrating the level and value in improving planning, design, and construction project management as shown (see sub-chapter 2.3.4) (Doukari et al., 2022, p. 2) respectively.

2.3.3 The Capabilities of 4D BIM Adoption with Regards to Sustainable Building Design

4D BIM (Building Information Modelling) is a valuable tool for developing and improving sustainable building design in several ways. Based on four reviews of the literature (Tarar, 2012), (Montiel-Santiago et al, 2020), (Ahmad et al., 2020) and (Avvir, 2019) five advantages of 4D BIM that are specifically relevant to sustainable building design are identified below:

a). Efficient planning and lifecycle analysis: This plays a crucial role in projects to be sustainable. The success of a project amounts to adequate planning and utilization of 4D BIM to analyse the percentage of work from start to completion and determine the impact a building will have over its entire lifecycle, including construction, operation, and demolition (Tarar, 2012, pp. 38 - 39).

b). Optimization and detailing of the accurate work plan: 4D BIM enables proper generation of the work plan for the project team, and detection, mitigating potential conflicts that will arise from wastage of time, as in the case of the traditional planning

method, making execution of projects faster with less cost overrun (Tarar, 2012, pp. 37 - 38).

c). Simulation of energy usage: The wide adoption and acceptance of 4D BIM will help in simulating the energy consumption of a building within its lifetime, considering factors like climate, occupancy patterns, and building systems. These factors enable architects and designers to optimize the energy efficiency of the building thoroughly and further help reduce its carbon footprint (Montiel-Santiago et al, 2020).

d). Analysis of material and waste management: Material management over the years amounts to difficulties and environmental pollution. The introduction of 4D BIM further helped analyse the environmental impact of different building materials and construction methods. For example, efficient utilization of surplus materials like shipping containers added value to the sustainability of building with recycling and achieving minimum waste on environmental pollution (Ahmad et al., 2020, p. 6).

e). Integration of sustainability tools and tracking project progress: The process quickly identifies the progress and improvement of planned work among project stakeholders; with the sustainable tools and approach, visual representation of project setbacks can easily be detected, as illustrated in Figure 9 below (Avvir, 2019, p. 7).

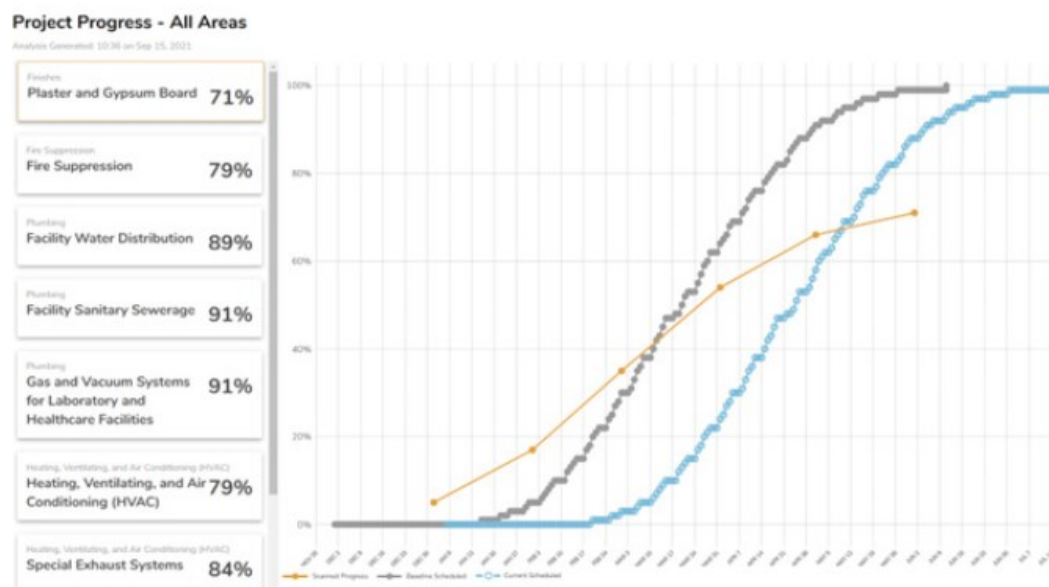


Figure 9: Progress report using visual expression of 4D schedule for a sustainable project (Avvir, 2019, p. 7).

Figure 9 above shows the utilization of 4D BIM progress of work already accomplished in percentage against the schedule plan for the entire project. Thus, 4D BIM is given a good review and must complete a specific project within the predefined duration, as illustrated above.

Thus, using BIM is essential for the construction time schedule for the research and the management of residential and commercial sustainable building design methods, especially regarding 4D BIM, because it helps checkmate the construction time, construction cost, and general management of the building life cycle, respectively.

2.3.4 Level of Adoption of 4D BIM Usage in Sustainable Building Design

Adopting 4D BIM (Building Information Modelling) in sustainable building design depends on the region and its specific project utilization. The growing development of 4D BIM and sustainable building design allows for better visualization and analysis of the building performance over time. For example, it is assumed that in the United States and Europe, the level of adoption of 4D BIM in building design is growing as numerous firms and construction companies incorporate it into their design processes.

However, research has yet to identify the level of usage in sustainable building design, but further research has been developed to show the level of adoption of 4D BIM in the construction sector in the United state, as shown in Figure 10 (Statista, 2023).

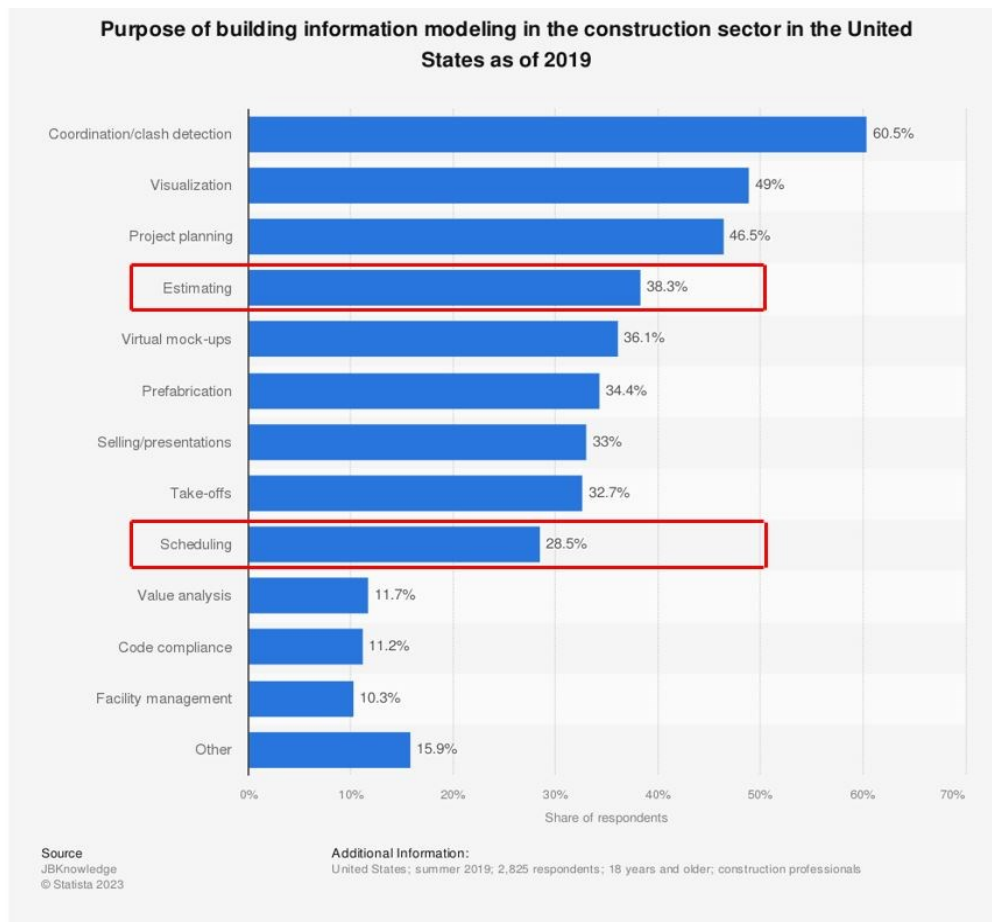


Figure 10: Statistical information on estimating and scheduling carried out in 2019 (Statista, 2023).

The above figure 10 shows that estimating and scheduling, two vital aspects of project management, has a joint percentage of 38.3% and 28.5% usage as adopted using BIM in the United state. Estimating is a procedure of computing tasks and calculating different quantities like materials, labour and other anticipated expenditure or resources incurred within a project (Sekhar, 2019, p. 1). While scheduling involves developing a plan that outlines the sequence of activities or milestones, as shown in Figure 8 and the timeline or start-to-end dates of the activities developed against their dependencies for completing them (Hutchings, 2004, pp. 39 - 41).

Therefore, estimating, and scheduling work together, because accurate estimates are essential for developing a proper schedule and underestimating project prolonged or cost delays and budget overruns respectively.

Summary of Sub-Chapter 2.3

The findings in sub-chapter 2.3 summarize building information modelling as a digital method, which, when adopted, improves the sustainable representation of the physical and functional characteristics of buildings highlighting its ten dimensions, focusing on 4D BIM and discussing potentials relevant to sustainable building design and level of adoption which is increasingly growing around the United States and Europe respectively.

2.4 Main Summary of Chapter 2.0

The review of Chapter 2.0 summarizes the use of literature, which is vital for generating knowledge about sustainable buildings and their innovative ideas, with crucial principles highlighted and adopted in residential and commercial buildings over the building's life cycle (see sub-chapter 2.1).

The findings further summarize container architecture as a sustainable building method. The word container architecture has been used at this point of the master thesis, and going forward in the following Chapters means a sustainable building or sustainable container architecture because container architecture can only be sustainable, defining *steel* as a critical factor to sustainable material. After all, it is 100% recyclable. In utilizing steel potentials, the principles and types of the shipping container are discussed with its use for residential and commercial buildings, giving a breakdown of the advantages, construction schedule and the problems facing the constructability (see sub-chapter 2.2).

In conclusion, the Chapter summarizes the meaning of building information modelling (see sub-chapter 2.3) as an essential digital method for sustainable building, highlighting the ten dimensions it possesses with a focus on 4D BIM as a relevant dimension for design, construction time, cost, and management of buildings, with a question of how to utilize it for container architecture especially for design, sustainable building, and construction time scheduling as major problem respectively.

3. Research Methodology

The essential module of this Chapter develops the method and framework on how to solve the problem of utilizing 4D BIM potentials for container architecture, especially for the design, sustainable building methods, and construction time schedule. In addressing the importance of this framework, construction professionals and researchers can fully use the potential by improving the construction industry and project outputs and developing more sustainable and well-planned projects. During this chapter, the workflow will be discussed under the following sub-chapters.

The first part (see sub-chapter 3.1) gives a general description of the research hypothesis and the objectives that must be addressed during the research resulting in two critical methodologies chosen with the design approach and knowledge of the key stakeholders involved in the study.

The second part (see sub-chapter 3.2) highlights five case studies discussed based on the utilization of 4D BIM, describing the opportunities available for professionals and the type of software (s) used in the utilization phase to make buildings sustainable and conforming to the construction time and cost designed for the building.

The final and third part (see sub-chapter 3.3) provides a straightforward procedure for utilizing 4D BIM for container architecture, especially for the design, sustainable building methods, and construction time schedules. The sub-part further discusses the limitations of this container architecture, the essential steps in developing a building information model that supports the container architecture during the planning and design phases, and the extraction of quantities that are useful for the construction time schedule, respectively.

3.1 Research Development

The vital part of this module provides an overview of the specific research hypothesis and objectives (see sub-chapter 3.1.1) to address the purpose of the study. In addressing the hypothesis, the need to align the methodology is of crucial importance, and the design approach and techniques for the research are discussed (see sub-chapter 3.1.2).

The approach selected, which is the qualitative and quantitative method, will further give a clear direction for the researcher on developing areas of solving the research question and objective, putting in mind the knowledge of the stakeholders (see sub-chapter 3.1.3) who are integral beneficiaries involved in this project to understand the procedures adopted for the research before a summary of 3.1 respectively.

3.1.1 Research Hypothesis

The fundamental hypothesis of the research is how to utilize 4D BIM for container architecture, especially for design, sustainable building methods, and construction time schedules. The hypothesis aims to give the outer reader and the researcher sufficient knowledge and understanding of the research and validation to be applied (see Chapter 4) following the procedures developed in this Chapter 3.0.

Other objectives of the research, as it relates to (see chapter 1.3) are as follows.

- a). What is the level of adoption of 4D BIM usage in sustainable building design?

- b). What are the potential capabilities of 4D BIM adoption concerning sustainable building design?

c). What training and education opportunities are available for construction professionals regarding 4D BIM use in sustainable Building design?

d). What are the ways to promote 4D BIM in sustainable building design?

In testing some of the capabilities identified using 4D BIM (see sub-chapter 2.3.3), the hypothesis will enhance and define the following critical points based on the efficiency of construction planning, improving possible clashes that can lead to construction cost or time overrun, identifying how resource optimization can be achieved during the project life cycle and ways in which visualization and communication can be achieved using 4D BIM.

The hypothesis procedure will involve different approaches and techniques that will make the research feasible as described (See sub-chapter 3.1.2).

3.1.2 Research Approach and Techniques

The targeted approach for utilization of the 4D BIM problem for container architecture, especially for the design, sustainable building methods and construction time schedules, is adopting two essential research methods as qualitative and quantitative methods. This approach and technique allow for detailed investigation on implementing and finding results on the stated problem above.

Based on the established literature review, which serves as a quantitative method, it attempts to clearly explain objective questions one and two of sustainable buildings, BIM, 4D BIM and the construction problems involved during utilization. The framework describes the argumentation (see sub-chapter 2.3.4) of exploring the potentials in the United States and Europe and the benefits of construction projects. In most cases, this evolution is only partially in use with the barriers described (see

sub-chapter 2.2.5) compared to the best practices used thus far (see sub-chapter 3.2).

In further developing the approach, the research will describe the available knowledge of 4D BIM for construction professionals (see sub-chapter 3.1.3) and case study techniques as a qualitative method selected based on container architecture as a form of sustainable design methods to be utilized for renovation and scheduling using BIM and 4D BIM.

Furthermore, the findings (see Chapter 4) will be validated with a case study of the BRLO craft beer warehouse, which is an excellent example of sustainable building design using shipping containers for comparative analysis when compared to the conventional buildings for renovation purposes and encourage owners and users of establishments to adopt sustainable building approach which is less expensive in construction cost, construction time, sustainable and eco-friendly to help meet the European Union goal of zero carbon-neutrality plan of 2050 respectively (Oettinger, 2012, p. 3).

3.1.3 Stakeholders' and Professional Knowledge of 4D BIM

Stakeholders in a project can be defined as individuals or teams of organizations involved in project delivery (Duncan, 1996, p. 15). Every project requires stakeholders, and their knowledge influences the result generated through 4D BIM. In the project development phase and construction time schedule for this research, the following vital stakeholders are technically the beneficiaries being selected in the development of the framework (see sub-chapter 3.3); Client, Architects, engineers, cost managers, quality control, project managers, document managers and data security (Duncan, 1996, pp. 15-83). And one of the complicating issues is the approach and technique to connect the stakeholders in understanding the BIM process for effective project management (Kensek, 2014, pp. 36-38).

Thus, the professional idea of 4D BIM among stakeholders is crucial and beneficial in decision-making for a successful planning, design, and construction time schedule

for these projects. Table 3 describes the stakeholder’s involvement in project planning and 4D BIM knowledge for proper utilization and management.

4D BIM use		Stakeholders														
		Role type	Client	Construction man.	BIM manager	Architect	Civil/Structural eng.	MEP Engineer	Contractor	Safety manager	Workers	Manufactures suppl.	Building surveyor	Quantity surveyor	Facility Manager	
Design-Approximate	4D Scheduling	Forecast construction phases & sequencing	R	RV	RC	RV	RV	RV	RV	PE		PE	PE			
		Optimize the construction schedule	P	PR	PE	RC	RV	RV	RV	PP	PE					
	4D Clash Detection	Detect spatio-temporal conflicts	R		PE	RC	RV	RV	RV	PP	PE					
		Detect static and dynamic conflicts	P		PE	RC	RV	RV	RV	PP	PE					
	Pre-construction phase - Precise	4D Scheduling	Forecast construction phases and sequencing	R	<i>RV</i>	RC	RC	RV	RV	RV	RC	PR	<i>PR</i>	PR	PR	PE
			Optimize the construction schedule	P		RC	RC	RV	RV	RV	RC	PP	<i>PR</i>	<i>PR</i>	PR	PR
		4D Clash Detection	Detect spatio-temporal conflicts	R		PE	RC	RV	RV	RV	PP					
			Detect static and dynamic conflicts	P		PE	RC	RV	RV	RV	PP	<i>PR</i>			PE	
		4D Safety Management	Analyze structural safety issues	R	<i>RV</i>	PE	RC	PE	PE	PE	RV	RC				
			Identify safety issues	P	<i>RV</i>	PE	RC	PR	<i>PR</i>	<i>PR</i>	RV	RC				
4D Constructability Management		Design temporary works	R		RC	RC	PE	PE	PE	RV	<i>RV</i>		PE	PE		
		Test different construction alternatives	P		PE	RC	RC	RV	RV	RV	RV				PE	
Construction phase - Detailed		4D Site Lay-out & Environment Management	Anticipate environment conflicts	R		RC	RC	PE	PE	PE	RV					
			Forecast onsite conflicts & coordination	P		RC	RC	PE	PE	PE	RV					
	4D Safety Management	Analyze structural safety issues	R	<i>RV</i>	PE	RC		<i>PE</i>	<i>PE</i>	<i>RV</i>	RC	<i>PR</i>				
		Identify safety issues	P	<i>RV</i>	PE	RC		<i>PE</i>	<i>PE</i>	<i>RV</i>	RC	<i>PR</i>				
	4D Constructability Management	Design temporary works	R		RC	RC	PE	PE	PE	RC	<i>RV</i>		PE	<i>PR</i>		
		Test different construction alternatives	P		PE	RC	RC	PE	PE	RC	<i>RV</i>			PE		
	4D Site Lay-out & Environment Management	Anticipate environment conflicts	R		RC	RC	PP	PP	PP	RC						
		Forecast onsite conflicts & coordination	P		RC	RC	PP	PP	PP	RC						
	4D Monitoring	Give short term goals to construction team	R	RV	RC	RC	PE	PE	PE	RC						
		Record real progress & compare to schedule	P	PC	RC	RC	PE	PE	PE	RC						
4D Monitoring	Adjust the schedule during the construction	R	PC	RC	RC	PE	PE	PE	RC							
	Adjust the schedule during the construction	P	PE	PP	PE	PP	PP	PP	PP	PR	PR	PR	PR			

R : RV – Responsible Validator, RC – Responsible Coordinator, P: PP – Participant Production, PE – Participant Expert, PR – Participant Reader, *Italic – background influence*

Table 3: Illustration of stakeholders (beneficiaries) and knowledge of 4D BIM utilization (Bolshakova et al., 2018).

As shown in Table 3, three key phases in project management describe the design, pre-construction, and construction phases (Bolshakova et al., 2018). The role of key stakeholders is to understand the utilization of 4D BIM for proper project coordination. The role of the client under RV is to be responsible for validation and forecasting the involvement of construction cash flow and short-term goals to the construction team. Architect has the possibility of detecting static and dynamic

conflicts and participating in the production of the design. The quantity surveyor prepares the cost estimation and records the accurate schedule developed to keep the project feasible before the engineers involved handle structural safety analysis, optimizing the construction schedule to meet the design time and the quality check.

Accordingly, the stakeholders and their knowledge of 4D BIM are highly required for any successful sustainable design project to meet the required time and cost designed to accomplish the project as described respectively.

Summary of Chapter 3.1

The findings in this chapter summarize the fundamental hypothesis on how to utilize 4D BIM for container architecture, especially for design, sustainable building methods, and construction time schedules. The hypothesis gives the researcher the knowledge to develop the research approach with two methods adopted, qualitative and quantitative methods, to find solutions to the research question with the understanding of stakeholders, which is integral for utilizing the 4D BIM respectively.

3.2 Case Studies Using Fourth-Dimensional Building Information

Modelling as a Sustainable Process

The module of this Chapter gives the outer reader a detailed process of developing the research framework. Before developing the framework, introducing BIM containing five case studies are selected and discussed based on the application of 4D BIM as a sustainable building process. Thus, the highlighted case study is helpful in preparing the research framework (see sub-chapter 3.3), analyzing the general deductions that will be adopted for the research framework as described as a

summary deduction is shown in Table 4 to give the outer reader the vital information deducted from the five-case study selected respectively.

3.2.1 Case Study 1- London Housing Project, London, United Kingdom

In analyzing sustainable design opportunities using 4D BIM, Case Study One, located at Canada Garden or plot E03, and plot E05 or Quebec in London, United Kingdom, will be discussed.

The sustainable London housing projects designed and developed from digital mapping are also known as digital containers, integrated the use of a 4D BIM environment and drone technology for data capturing (GW Prime, 2021). The leading investment company “Quintain” awarded the contract to John Sisk and Son as contractors for the development of the housing project, utilizing the digitized process BIM for the design and construction.

The development of the efficient and effective asset (project) utilizes the DPD (digital project delivery) approach of the model referred to as “digital container”, linked to the 4D planning tool in BIM 360 for extracting and estimating the cost of the project. The digital containers supported the connection of QR code, enabling the development of an unlimited quantity of information for the asset and further saving time of development to 35% as compared to a manual system of cost estimation which will possibly take two weeks to develop. This system of digitization of the container enables the integration of a 4D model highlighting the potential of the project workflow, resolving issues of potential hazard with clash detection and safety throughout the planning, design and construction stage, saving about 90,000 pounds of the cost of the project as shown in Figure 11 (GW Prime, 2021).



Figure 11: Digital containers designed and developed using 4D planning (GW Prime, 2021).

The generated information from Figure 11 illustrates the adoption of a digital container project using 4D planning to effectively reduce the number of delays for the project and shift focus towards project optimization with the drone technologies adopted to eliminate the need for scaffolding based on proper 4D planning and simulation delivery handled by BIM professionals respectively (GW Prime, 2021).

3.2.2 Case Study 2- Istanbul Grand Airport, Istanbul, Turkey

Building information modelling is an integral component of the planning and construction of one of the notable and most significant airports in the world. The airport began operation in 2018 with a target to accommodate 150 million passengers annually (BIMCommunity, 2018).

The project involves four phases of planning and construction due to the scope and complexity, as shown in Figure 12.



Figure 12: Aerial view of Istanbul Grand Airport, Istanbul, Turkey (BIMCommunity, 2018).

The illustration of Figure 12 describes the complexity of the Istanbul Grand Airport with a strategic goal of utilization of 4D BIM to keep control of the time, outstanding standards, and management according to the baseline schedule on the milestones set for the start of operations in 2018.

The integration of the 4D plan and BIM plan by designers allowed for the interface management process for a 30-month development plan, design, and stages of construction to accomplish the sustainable style of architecture with the aim of decrease in environmental effects during the life cycle of the airport. In achieving the management plan, IGA company generated a 30,000-activity plan on Synchro Pro as the most prominent 4D model in the world today for daily, weekly, and monthly progress of the project (BIMCommunity, 2018).

The methodology allows for operation and maintenance using BIM as a significant component set to solve any arising problems during the life cycle of the airport. Based on the maintenance capabilities, facility managers, engineers, and architects can easily collaborate to support the building life effectively, which further saves cost for the maintenance of the building respectively.

3.2.3 Case Study 3 – Museum of the Future, Dubai, United

Arab Emirates

The museum, located in Dubai, United Arab Emirates, is designed by a Killa design symbolizing a silver oval form and an open Centre, which defines the innovative concept, futuristic concept and technology applied to the building. The museum, which began operations in February 2022, adopted BIM as an enabler for the art and metaphor of the driven concept and utilized 4D building information modelling as a component managing the complexity of the building, as shown in Figure 13 (BIM community, 2018).



Figure 13: Aerial view of Museum of the Future, Dubai (BIM community, 2018).

Based on Figure 13, the illustration of the graphical image represents the knowledge and futuristic concept that evolves in the building requiring BIM as a tool for computation and development of ideas. To ensure the ideas are being constructed and meet LEED platinum standards, parametric scripting allowed for building performance simulation and reduced the cost of water usage by 45%. BAM International, a construction company, employed 4D BIM sequencing and reality capture enabling visualization and efficient construction processes.

The models developed by Burohappold, an engineering services company, identify the weights and constraints the construction could face. In achieving the construction of the building, 4D BIM generated data enabled daily updating of information into the

model to cut construction cost, construction wastage, and construction risks. The idea was achieved within 14 months duration of the project through a collaborative process among the team of architects and engineers making decisions and achieving more than fifty sustainable ideas adopted, including recycled products, photovoltaics for energy conversation of about 25% and internal-air recovery system creating a sense of architecture for the museum respectively (BIM community, 2018).

3.2.4 Case Study 4- RNEST Refinery, Sao Paulo, Brazil

RNEST refinery is another excellent example of a 4D BIM application. The modern refinery is in Sao Paulo, Brazil, with a carrying capacity of 240 thousand barrels of oil daily. The planning and design of the refinery being accomplished by the renowned Camargo Corrêa company developed the innovation and technology of implementing 4D planning using Synchro Pro for results generation in all project phases (Gonçalves, 2019).

In the first implementation and planning phase, a detailed design was released by Petrobras, an employer company with the problem of elaborating in detail the planning of the project alongside the duration. The involvement of Camargo Corrêa enabled interaction with all professionals in the project to develop a proper simulation schedule using Synchro Pro for the execution plan, as shown in Figure 14 (Gonçalves, 2019).



Figure 14: Planned view of RNEST refinery using synchro pro (Gonçalves, 2019).

The use of Synchro Pro in Figure 14 describes the considerable improvement in the quality of communication and collaboration among the construction professionals involved in the project to share information and update the progress of work done weekly in the database to avoid delays in the scheduled activities shown in the Figure 15 timetable.

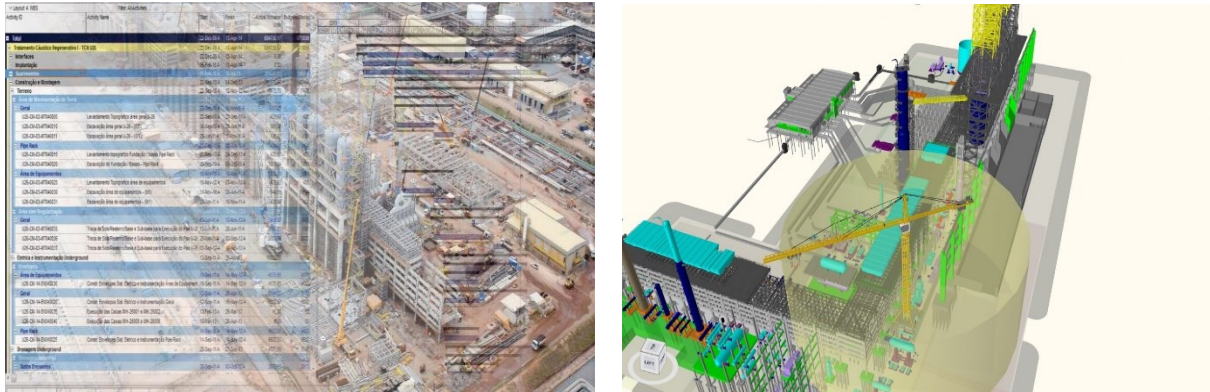


Figure 15: Activity table of RNEST refinery using synchro pro (Gonçalves, 2019).

As shown in Figure 15, all activities generated provided a sequence and analysis for execution time developed between the BIM models, SAP and coordinating professionals to reduce wastage of time and labour costs and make the project sustainable for use. The project was fully developed, providing a sequence of activities carried out for efficient building management, respectively.

3.2.5 Case Study 5 – Twin Tower, Dubai, United Arab

Emirates

Twin Tower is known to be Dubai's new landmark of a mega mixed-use building with construction in progress. Sources from government authorities of the United Arab Emirates and developer Emaar Properties confirm the building to be the world's largest cantilever building when completed, using 4D BIM due to the complexity and size of the building.

The complexity gave way for ALEC Engineering and Contracting LLC to develop a new concept from the traditional method initially developed using tables, charts and graphs to Bentley's Synchro Pro for 4D modelling saving time of about 70days due to clash detection, \$16m in value for a clearer picture of the structure, and schedule as shown in Figure 16 (CIOB, 2019).

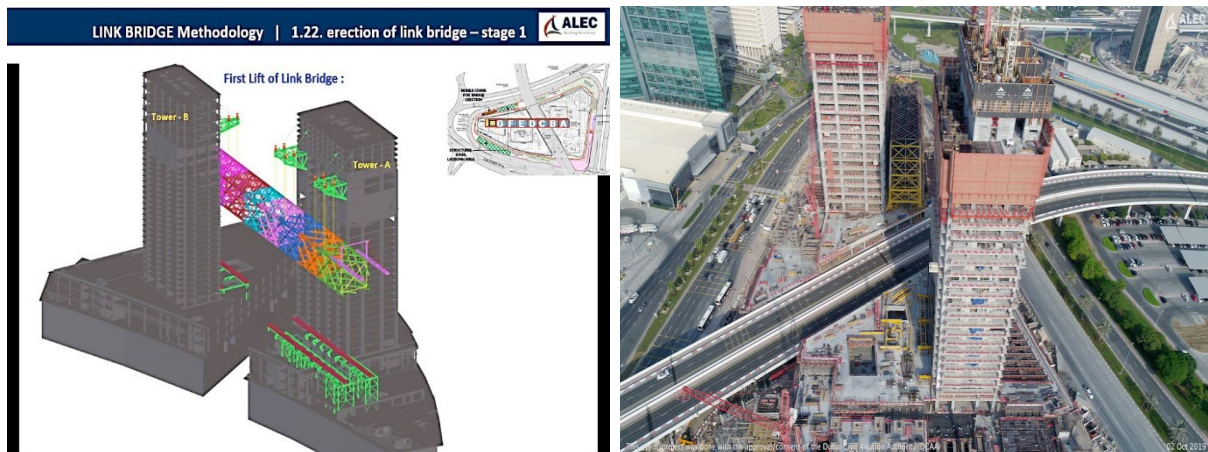


Figure 16: ALEC developed a 4D BIM model of the structure and schedule of the Twin Tower (CIOB, 2019).

The output of the illustration of Figure 16 shows two mounted podiums of building towers on both sides next to Dubai's World Trade Centre. The steel bridge structures are linked to 105m and 66m high, making it the world's largest cantilever building.

The design and construction of the building using 4D BIM identifies sections of the most significant lift in the middle east being fixed. Clashes of cranes within tower A caused the building delays, which amounted to shifting the tower crane below the opening and allowing for the steel structure to be used on a timesaving 40-day delay and \$12m in cash value (CIOB, 2019).

Another benefit of 4D BIM on the building is the steel link bridge erected and configured in six segments compared to the initial seven segments. This operation cut down 30 days in construction and \$4m in value, convincing the Dubai authorities that the cost and duration of the project could be saved from unforeseen risk and help increase the possible return on investment within a short duration (CIOB, 2019).

The usage of 4D BIM for the building is already a vital tool in coordinating the construction design of the building, which as well has been beneficial for the rest of the case studies discussed respectively.

Summary of Sub-Chapter 3.2

Based on the findings in sub-chapter 3.2, a summarized deduction of the five case studies selected based on the adoption of different 4D BIM types, which help develop the research framework (see sub-chapter 3.3), is discussed as shown in Table 4 respectively.

Number of Cases Selected	Location	4D BIM Adoption	Type of 4D BIM Used
Case study 1	London Housing Project, London, United	Yes	BIM 360 enabled for extraction of data and cost estimation
Case study 2	Istanbul Grand Airport, Istanbul, Turkey	Yes	Synchro Pro for Planning and cost estimation
Case study 3	Museum of the Future, Dubai, United Arab, Emirates	Yes	4D BIM sequencing for cost analysis and visualization (Microsoft project)
Case study 4	RNEST Refinery, Sao Paulo, Brazil	Yes	Synchro Pro for Planning and cost estimation

Case study 5	Twin Tower, Dubai, United Arab Emirates	Yes	Synchro Pro for Planning and cost estimation
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Table 4: Summary of Case studies using 4D BIM types (Source: Author's work, 2023).

The general connection of Table 4 to the designed framework (see sub-chapter 3.3) is the possibility of a framework that utilizes the different 4D BIM software applications highlighted above. Based on the knowledge of BIM, the researcher, therefore, adopts 4D BIM sequencing for cost analysis and visualization (Microsoft project), which is a valuable tool for the construction time schedule (see sub-chapter 4.3.4) respectively.

3.3 Utilization Process of 4D BIM for Container Architecture

The module of this chapter explains the procedures to utilize 4D BIM for container architecture, especially for the design, sustainable building methods, and construction time schedules, as described in Figure 17, showing all the significant steps and sub-steps.

The essence is to give the outer reader a clear understanding of the numerous benefits and ways to achieve improved planning that involves less construction cost and time for these container buildings.

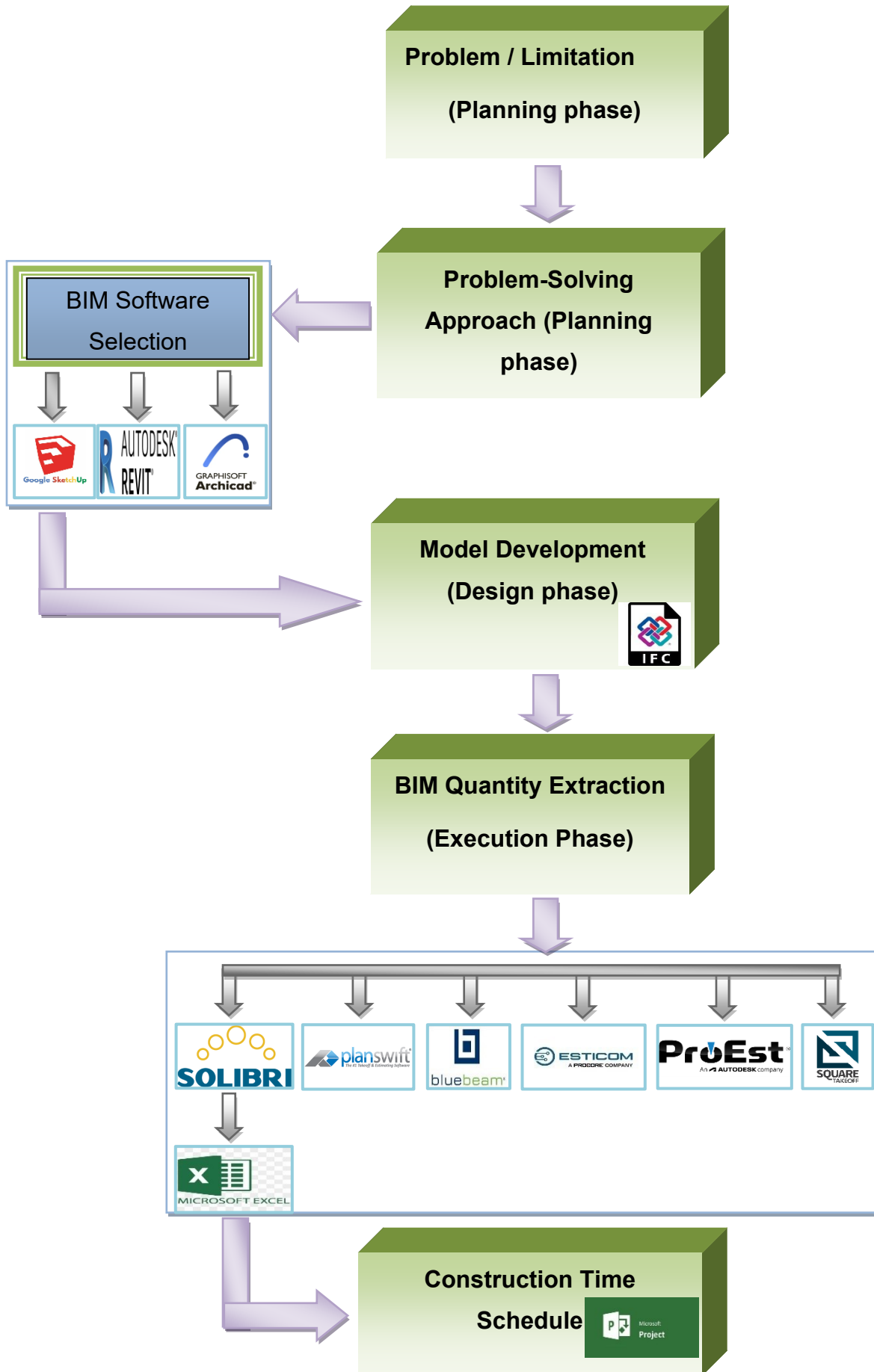


Figure 17: Framework of the research (Source: Author's work, 2023).

Figure 17 shows a graphical representation of the research framework involving five significant steps, including sub-steps, for a clear understanding of the outer reader.

The module covers the various parts for the researcher and outer reader to know the critical process required in developing the construction time schedule for this container architecture under the following: figuring the container limitations during the planning phase (see sub-chapter 3.3.1), which is an essential step in developing a building information modelling procedure and execution of the container architecture (see sub-chapter 3.3.2). The following process is creating a required strategy during the design phase (see sub-chapter 3.3.3), thereby extracting the quantities (see sub-chapter 3.3.4) that support the preparation and vital process of developing the construction time schedule (see sub-chapter 3.3.5).

3.3.1 Figure Out the Container Limitations – Planning Phase

Familiarizing the container constraints is the first crucial stage when adopting its use because the knowledge gained can improve the construction time, labour cost and safety when constructed. In utilizing the container architecture, significant constraints are based on sizes (see sub-chapter 2.2.3); identifying various standard container sizes is the first step to eliminating construction costs.

Secondly, consider the structural stability or integrity, for example, when having more than two containers stacked together. The recommended approach uses spread footing, mat foundation, and piles. This foundation is recommended because spread footings involve reinforced concrete that is enlarged from the bottom of a structural column which is best for small to medium size buildings like container residential and commercial buildings. The mat foundation is closely enlarged spread footings that cover about 50% footprint or more of the building before piles help support the depth of stability of the structure in soft soil areas (Giriunas, 2012, pp. 48-50).

Thirdly, limiting connections and compatibility among other building systems requires vast knowledge. If cutting, welding and installation are not done correctly, it will amount to construction costs and longer construction time. Also, MEP systems are

essential areas that need to be figured out because of the height and thickness of the containers described (see sub-chapter 2.2.3).

Therefore, the suggested way of handling the issue of electrical wiring and installation is to embed the cabling within horizontal and vertical raceways to the laminated insulation provided internally for the container layers, as shown in Figure 18.

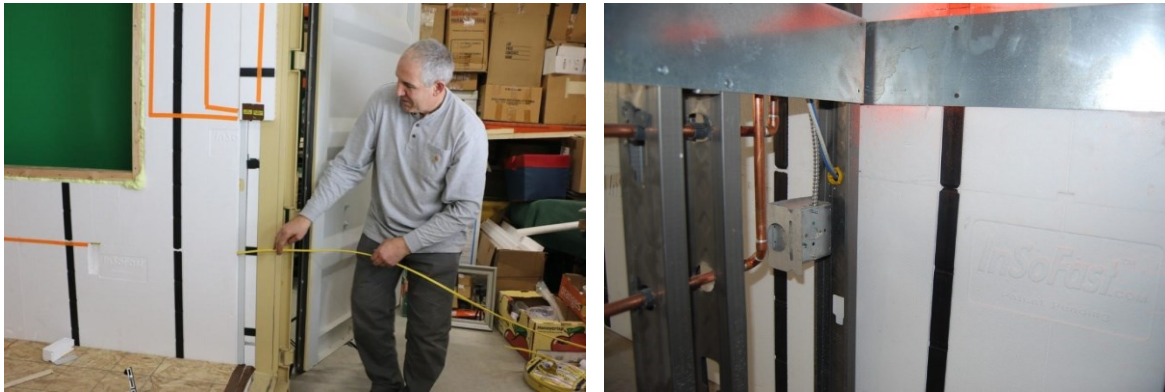


Figure 18: Installation of electrical services of container architecture (InSoFast, 2023)

The illustration in Figure 18 shows the connection lines (horizontal and vertical raceways) locating all the support joints before laminated boards are used to cover the surfaces. For MEP connections, the systems are open surface connections for double-volume container buildings because of the height of the container and easy maintenance.

Thus, figuring out these steps or procedures provides accurate knowledge in the selection, model or design and stimulation of the container-based architecture using 4D BIM to avoid unnecessary costs in construction and time respectively.

3.3.2 BIM Procedure and Execution – Planning Phase

The following crucial procedure to develop an efficient construction cost estimation is selecting a BIM software that supports the design and stimulation for container residential and commercial buildings. The concept is essential for project teams

(architects or designers) to create a detailed implementation plan in the early stage for project stakeholders or team participants to have the overall scope and flow of the project.

In achieving this objective, the selection of design software such as Revit, ArchiCAD or Google sketch-up can support in developing of the model of the container building effectively and allowing for an accurate representation of containers, including all necessary features like dimensions, structural elements, and the interrelated connections of the container (Messner et al., 2020, pp. 8-9).

The software(s) can interoperate and update all forms of information designed, constructed, and maintained throughout the project's lifecycle. The flexibility within the software(s) enables the project stakeholders to highlight project feasibility in terms of cost, time, and visual cash detection during the project and facility management period.

Therefore, the selection of the software gives a clear roadmap for effective design and identifies the specific requirements, roles, and information to be exchanged throughout the project's life cycle. In determining the conditions, the data specified requires a detailed level of modelling, components, or elements of the building, which can be understood by various stakeholders in the project because the information being computed and designed will be translated into cost analysis for a sustainable building design.

With the procedure in hand, an architect or designer can fully implement the required design of the container project as described (see sub-chapter 3.3.3).

3.3.3 Strategy for Model Development - Design Phase

The design phase involves the project team (the designer or architect) outlining the goal of developing and implementing the building model for the specific container BIM software highlighted (see sub-chapter 3.3.2). In developing the model, the next important step is to create a comprehensive and detailed library of the container components that includes the type of containers, sizes, windows, doors, insulation

elements, electrical systems, mechanical systems, and MEP systems, among other necessary features like furniture. The generated library efficiently assembles the container structure with the modelling environment of the BIM software for a detailed, visual, and accurate representation of the container building.

Another essential task in the design phase is setting a goal after the BIM library has been created to focus on the general project performance involving the projected project duration, schedule, and overall design quality. Following the guideline, the generated model and application can fully meet efficient documentation, quantity takeoffs, and data maintenance management.

The step in the development or mapping process is modelling the container building; the idea of modelling the structure is to give the project team and the users a visual understanding of several added pieces of information from the selected BIM use and data attributes carried out by the architect. After the development of the model, identifying each phase of the model used is an integral part, for example, the generated plans; the author developed design coordination models, which includes structural models, MEP models, mechanical model, electrical model, specifications sequence and deliverable tasks.

After all necessary information about the BIM model has been generated, the next feature is reviewing all the plans and designs done by various stakeholders in the project for possible additions and corrections of the information generated before all files are collated and saved as IFC supported or 4D BIM supported software for cost analysis.


Therefore, all the highlighted information must be established and coordinated by the project head with the collaboration of the key stakeholders for the effectiveness and utilization of the 4D BIM, especially for sustainable design, cost, and time management. The coordinated information among key stakeholders will be extracted for cost estimation and analysis as described (see sub-chapter 3.3.4).

3.3.4 Extraction of BIM Quantities – Execution Phase

Construction estimators traditionally use 2D plan sheets and blueprints to estimate project costs and time schedules. The process, which involves manual computation and review of every single sheet of plans and specifications based on material and details to be calculated, amounts to a waste of construction time, mistakes in cost calculations, and large numbers of unnecessary variables being developed (Olsen et al, 2017, p. 1098).

However, the recent development of 3D software like Autodesk Revit, ArchiCAD, and Google SketchUp, which serves the purpose of modelling, gave an advantage for more technological advancement and development of software around quantity takeoff for generating a bill of quantity or estimating, cash detection and development of schedules to meet the construction cost and time frame with the ability to link all the developed plans represented in the model.

In the construction field, numerous quantity takeoff software is available to support different levels of projects based on their complexity. For container buildings, the appropriate software to generate quantity takeoff is using essential and detailed software listed, for example, solibri office, Plan swift, Bluebeam, Esticom, Proest and square takeoff, as described in Table 5.

List of BIM and quantity take-off software	Uses
	<p>With the use of the Solibri office, quantity take-off is much easier to handle because of the flexibility to interoperate and extract data through generated IFC files from the 3D BIM software highlighted (see sub-chapter 3.3.2). All data related to the container building can be classified based on the components, labels and the classified components being able to test the quantity of the information modelled by the designer and communicate to various stakeholders in the project.</p>

	<p>Plan Swift is rated as one of the outstanding quantities generated take-off software for its suitability for commercial and residential buildings (OTO Estimating, 2023). It can support dwg format files, pdf, and TIF based on the information developed, including container building. When quantities are generated, the capacity to export data to Excel format is available based on the unit computed as the bill of quantities.</p>
	<p>Blue beam is another highly rated quantity take-off software supported for container architecture. It is advanced software compared to plan swift because of the capability to review information from an end-user during utilization and directly import PDF files from the design software highlighted (see sub-chapter 3.3.2). Overlaying two different files over each other is entirely possible for quick completion of tasks if changes arise due to computation or errors (OTO Estimating, 2023).</p>
	<p>Esticom is a notable BIM estimating software for container building and MEP projects like plumbing, HVAC, and electrical systems (OTO Estimating, 2023). The software is a cloud-based application for quantity take-off and estimating, which does not require a download before achieving a few clicks of quantity take-off. Based on its capacity, it is an excellent fit for residential and commercial business operators to generate all data within the shortest possible time to minimize cost and make the project sustainable.</p>
	<p>ProEst is known as collaborative software capable of operating with all stakeholders in a project at the same time to save construction time among stakeholders (OTO Estimating, 2023). The software demonstrates its user-friendly environment for stakeholders and even</p>



	<p>subcontractors to have a vast knowledge of possible project cost and material quantities to be utilized based on the built-in templates available for all requirements or components of a project with minimal or no errors to be detected, operating as a cloud base software like Esticom.</p>
	<p>Square takeoff is a unique web-based software for quantity takeoff and estimating with potential users through mobile devices and computers, depending on the stakeholder's choice of use (OTO Estimating, 2023).</p> <p>It supports residential and commercial container building with a customized template for cost preparation and time depending on your location for efficient management of time within the project.</p>

Table 5: Container building supported BIM and quantity take-off software (Source: Author's work, 2023).

The data in Table 5 gives a detailed description of the supported software available for container building, especially for residential and commercial buildings, for quantity take-off. To be able to check the quantity of the model generated by all stakeholders, the use of Solibri has been selected based on the researcher's knowledge of the project before the quantities generated can be developed as the bill of quantities for planning the construction schedule for a sustainable design, cost, time, and maintenance of the overall building life cycle to be described (see sub-chapter 3.3.5).

3.3.5 Preparation for Construction Time Schedule

Construction time schedule also referred to as the fourth-dimensional method of scheduling in project management, is one of the key foci for the successful execution of a project, as explained (see sub-chapter 2.3.2). For a successful project, there are many important reasons why a construction time schedule is utilized for the avoidance of failures which have continued to emanate within the construction industry in the form of complexity or lack of proper planning of projects.

Thus, the construction industry's complexity or lack of proper planning has seen notable project failures in Germany, for instance, the Berlin international airport and the opera house roof in Cologne, among others, across the world. The experience and expertise of stakeholders involved in any project are essential in planning and developing the construction time schedule to meet the project timeline and completion.

As such, preparing an efficient construction time schedule, especially for container architecture projects, requires necessary guidelines and procedures due to its recent innovation in the construction industry. For this reason, the effective use of the container architecture requires the following planning, development, and adoption procedures for the construction time schedule.

a). Understanding the project scope: Having a broad idea of the project is highly important when utilizing container architecture as a sustainable method (see sub-chapter 3.3.1, 3.3.2, and 3.3.4). Understanding the project gives the scheduler a general idea of the project, the technique, the tools used, and the form of the approach developed for efficient planning during the construction time scheduling or estimation. The basis of the knowledge provides the scheduler or estimator with the type of construction schedule required for the project.

b). Selecting a method: In project management, there are various types of construction schedules, for example, network analysis, critical path method (CPM), program evaluation and review techniques (PERT), Gantt chart method, line of

balance (LOB), quantitative scheduling and resource scheduling (R.Neale and D.Neale , 1994, pp. 22-83).

For container architecture, the Gantt chart method holistically describes all the stages in a project from project start, project completion, milestones, project cost, project duration and resource allocation, which is visually accessible, allowing for a quick level of assessment of the overall project and possible delays which might have occurred during the planning.

Thus, understanding the method or approach gives directions of the type of building information modelling software available to generate the schedule.

c). Selecting a building information modelling tool: In the construction market, various software developers have contributed to developing BIM software for scheduling in recent years. For container building, the most efficient BIM tool adopted from case study research (see sub-chapter 3.2) is widely Synchro Pro for more complex projects because of the excellent features and templates available to speed up the estimation and accuracy of the project.

Another efficient tool for container architecture is the use of a spreadsheet in Microsoft project supporting the quantity take-off generated (see sub-chapter 3.3.4). This process is helpful for small and medium-scale container projects like residential and commercial buildings utilized for this research because of the vast knowledge of stakeholders and utilization compared to Synchro Pro. After selecting the tool, the next aspect is preparing and distributing the project's work breakdown structure.

d). Determine and break down the project work: The understanding of the project gives a clear concept of how to distribute the tasks and components. For instance, a new container building construction has its mission and part of achieving differently as described (see sub-chapter 2.2.4), as compared to the proposed renovation concept to be developed for this research.

Therefore, the work breakdown structure should be comprehensive to cover all aspects of the project, including each milestone achieved, for example, new residential or commercial development which involves the development of plans,

getting the building permit, foundation works, completion of the building structure, installation of fixtures, up to handing over of the project, likewise with different milestones for the renovation of buildings.

e). Arrangement of task and duration: The generated bill of quantities is fully utilized at this stage by logical procedures in which jobs will be accomplished as distributed following their dependencies and duration. In achieving the designs, the knowledge of stakeholders and historical information is essential considering all factors (negative and positive) conditions in a project which can be the procurement of the container or demolition of the container, the construction materials, the techniques, and the available labour to handle the project.

f). Resource allocation and creating a Gantt chart: Gantt chart defines the visual management of a project which is represented as a fourth-dimensional model, developed either in Microsoft Project or Synchro Pro as building information software displaying all the task, their dependencies, and the duration of the overall timeline of the project. The critical aspect of estimating is understanding the workforce, material and equipment allocated and utilized in a project.

The importance is avoiding project conflicts amounting to delays based on the schedule developed using the Gantt chart. Using the Gantt chart clearly explains the representation of all stakeholders and their activities in a project to avoid project delays and run-over costs, which can quickly arise when management is not followed correctly based on the milestone allocated.

g). Milestone identification: The project work phase is essential to a successful project. Following the allocated milestone based on duration and cost improves the sustainability of the container project because it helps tracks the progress and quality of performance by stakeholders, which is one of the basic ideas of the construction time schedule.

h). Check and incorporate all necessary contingencies: Contingency incorporation, also known as unforeseen delays or changes, is an essential step to creating a flexible and balanced schedule. The buffer in contingency helps reduce the possible risk that can be involved in a container project. Mitigating this risk makes the project more feasible when design and construction are being reviewed.

i). The final step is to review, monitor and update regularly: Reviewing the construction time schedule developed for the container architecture is highly recommended by project stakeholders. Any concern or issue that will cause project delays must be addressed at this stage and updated in the schedule. The regular input of the stakeholders regarding the project also requires monitoring, including the construction progress as the schedule developed for a feasible, accurate and sustainable project maintained within the project's timeline.

Therefore, considering the utilization of a fourth-dimensional building information model for container architecture requires all the procedures highlighted above to be duly followed and adopted throughout the project's planning, design, construction, and maintenance management phase of the project among stakeholders.

Even though the utilization is slimly in place in the construction industry, recent research, and case studies (see sub-chapter 3.2) describe notable projects developed and adopted with fourth-dimensional models using building information tools like Synchro Pro 4D BIM sequencing to achieve smooth and effective coordination of the projects. And continuous adoption in mega and small-medium scale projects will further boost the sustainability of projects completed on time with minimal construction cost respectively.

Summary of Chapter 3.3

The findings in this Chapter summarize the utilization of 4D BIM for container architecture, especially for the design, sustainable building methods, and construction time schedule.

The Chapter further explains the various procedures to achieve construction time scheduling involving formularization of container limitations based on the planning phase (see sub-chapter 3.3.1), having the best idea in developing a building information modelling procedure and execution for the container architecture (see sub-chapter 3.3.2). The methods created using BIM are essentially required on the strategy used for modelling during the design phase (see sub-chapter 3.3.3), resulting in extracting the quantities (see sub-chapter 3.3.4) for proper development of the construction time schedule (see sub-chapter 3.3.5).

3.4 Main Summary of Chapter 3.0

The findings of Chapter 3.0 summarize the method and framework on how to solve the problem of utilizing 4D BIM potentials for container architecture, especially for the design, sustainable building methods, and construction time schedule. The research hypothesis and the objectives are being addressed in the research resulting in two methodologies chosen, addressing the design approach and knowledge of the key stakeholders involved (see sub-chapter 3.1).

The findings further review and provide five necessary case studies discussing using 4D BIM opportunities in the construction industry. Extensively, the recent development has made the projects sustainable and conforming to the construction time and cost designed for the buildings (see sub-chapter 3.2).

In conclusion, the Chapter summarizes and provides the procedures for utilizing 4D BIM for container architecture, especially for the design, sustainable building method, and construction time schedule, discussing the limitations, the steps in developing a building information model during the planning phase, design phase, extraction of quantities from the developed model that is useful for the construction time schedule of the container architecture (see sub-chapter 3.3) respectively.

4. Case Study Finding

The essential module of this Chapter validates the developed method and framework on how to solve the problem of utilizing 4D BIM potentials for container architecture, especially for the design, sustainable building methods, and construction time schedules. In addressing the importance of this Chapter, a single case study is selected for renovation purposes using a shipping container located in Berlin, Germany.

4.1 Information on the Selected Building

This section selects a case study based on existing information (see sub-chapter 3.1.2). A single case study of the BRLO craft beer warehouse is selected for renovation based on the design and construction with shipping container architecture located in Berlin, Germany. The case study selection is related to the research topic and literature review conducted. Therefore, the section highlights existing information about the building at the planning stage and existing knowledge about the structure at the design stage respectively.

4.1.1 Existing Information About the Building – Planning Stage

BRLO craft beer warehouse built in 2016 on a site area of 1,821 sqm is located at Schöneberger Straße 16, Berlin, Germany. The building is developed from the planning concept and construction of modular composition of 38 reuse shipping containers on a floor area of about 892 sqm measuring about 2.5m width by 12.192m length for a single module of European type shipping container (see sub-chapter

2.2.3), and an overall measurement of 12.5m width by 48.76m length in size of the containers (Graft Architects, 2023).

The two stories container building shown in Figure 19 established the unique and innovative concept of Graft Architect with a team of directors Franconian, Mecklenburger, Michael Lembke and Ben Pommer, all Berliners bringing the ideas and funding of the notable beer factory to Lamplight (BRLO GmbH, 2023).



Figure 19: Google Earth aerial view of the BRLO craft beer warehouse.

Figure 19 illustrates the BRLO craft beer warehouse at Schöneberger Straße 16, Berlin. The Graft architect, responsible for the innovative concept of the building, planned and designed the warehouse as a production factory for beer and as a restaurant or relaxation spot for users, primarily glazed within the interior space (BRLO GmbH, 2023) Its planning highlights the creative interior design handled by Novono Interior Design and Dieholzkoepfe GmbH for the interior fittings with an adequate connection of U-Bahnhof Gleisdreieck, U1, U2 & U3 for easy accessibility (BRLO GmbH, 2023).

4.1.2 Existing Information About the Building – Design Stage

The two-story container building consists of a production warehouse, restaurant, events, gallery, office space and conveniences. On the ground floor, the building is zoned based on the busy areas, for example, the production warehouse, the restaurants, the preparation area, conveniences, and bars, as shown in Figure 20 (Graft Architects, 2023).



Figure 20: The aerial and interior ground view of the BRLO craft beer warehouse (Graft Architects, 2023).

Figure 20 illustrates the aerial view and ground floor view of the BRLO craft beer warehouse in detail. The first-floor office spaces, galleries, and conveniences are designed as quiet zones, as shown in Figure 21 (BRLO GmbH, 2023).

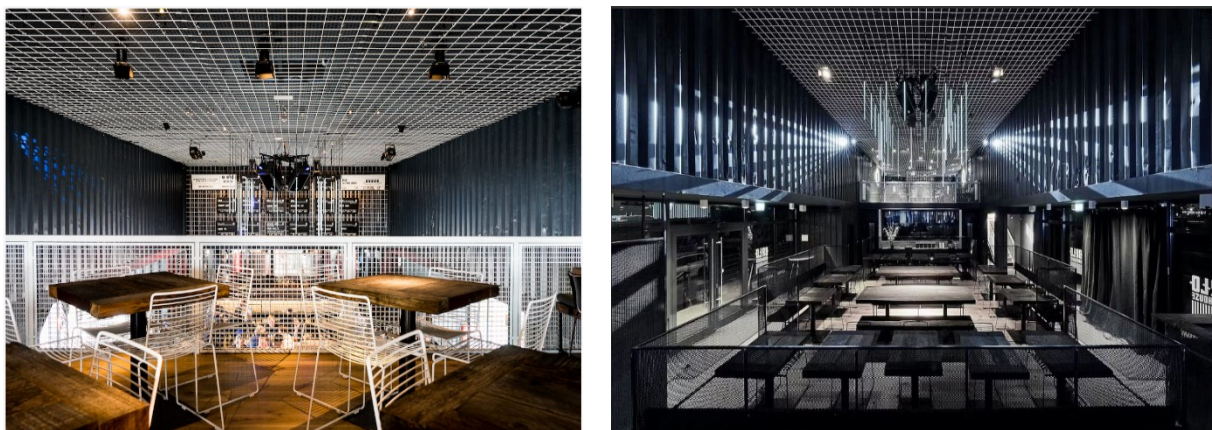


Figure 21: First floor gallery and office space of the BRLO craft beer warehouse (BRLO GmbH, 2023).

Figure 21 shows the connection of the quiet zone on the first floor consisting of an open gallery to have a view below the ground floor and serves as an office area for administration and meetings for the building. The design and construction of the building also accommodate a vertical and inclined staircase placed on the west side of the building serving as the entrance to the office spaces and gallery level, and two horizontal staircases on the east side, as shown in Figure 22 (Graft Architects, 2023).



Figure 22: Pictorial view of the vertical, horizontal, and inclined staircase of the BRLO craft beer warehouse (Graft Architects, 2023).

Figure 22 illustrates the visual image of the building and the external staircases built to connect the offices on the first floor of the building. The image also depicts the balcony area showing the seating arrangement around the building during the summer and when it is filled to its capacity respectively.

Summary of Chapter 4.1

The findings in this Chapter summarize the background knowledge of the BRLO craft beer warehouse used as a case study for the research, discussing the current information of the building based on planning and design approaches, respectively.

4.2 Developed Data for the Building Information Model

Before introducing the Chapter in detail, this module focuses on the data information generated from the BRLO craft warehouse (see sub-chapter 4.2.1); likewise, Tables 6 and 7 describe all the available spaces in the building, which are helpful for the bill of quantities. The generated information gives an overview of possible problems the building faces (see sub-chapter 4.2.2) and developing a problem-solving approach explained respectively (see sub-chapter 4.2.3).

4.2.1 Data Collection of the Building Model

The BRLO craft beer warehouse is a commercial building with two floors describing each space allocated for use. For developing the data collection of the building, Autodesk BIM software enabled drafting easier generating information as described in Appendix A and B.

On the ground floor, the following data collection of space quantity is shown in Appendix A and identified in Table 6 below.

Space Allocation	Quantity (sqm)	Remarks
Technology room	10.38	The data was collected for two number technology rooms.
Kitchenette	12.0	Data collection for two space numbers of the kitchenette.
Collection area	11.4	The space links with the kitchen space for easy accessibility.

Kitchen	54.6	Major kitchen space.
Entrance Terrace	20.7	Entrance areas are located at the front, rear, and left side of the building.
Storage	10	It is located close to the collection area.
Bar	225.08	Appendix A shows that data collection includes the counter area and adjoining stair hall linking the first floor.
Stair hall	16.4	The space links with the first-floor slab from the bar area.
HMS	5.7	An extension from the bar area to the technology room.
Technology hall	34.3	It is located directly to the bar on both sides.
Storage hall	54.8	Both halls on the right and left directly link with the production hall to store the already-made beers for distribution.
Production hall	80.4	The production hall serves as the main space for producing the beer being sold from the warehouse.
Toilets	24.5	All space quantity for convenience is highlighted in four numbers.

Table 6: Ground floor space and quantity data of the BRLO Craft Beer Warehouse (BRLO GmbH, 2023).

Table 6 illustrates all the available space and extracted quantity distribution in sqm, which is helpful for a cost analysis for the research.

Furthermore, Table 7 shows the available space allocation for the first-floor plan of the BRLO craft beer warehouse and a pictorial draft shown in Appendix B, which are helpful for the cost data analysis of the research.

Space Allocation	Quantity (sqm)	Remarks
Restaurant and Bar	295	The two-space allocation serves both the restaurant and bar and is linked with an internal and external stair hall from the front and rear elevation of the building, as shown in appendix b.
Office	11.7	The space is directly connected to the restaurant and bar on the right side with an external staircase for escape users of the building, as shown in appendix b.
Balcony	30.8	Two balconies are located on this floor connecting both the restaurant and bar.
Stair hall	67.8	Four external staircases are identified at this level, two from the front and two from the rear part of the building. Furthermore, one staircase is located internally, linking the restaurant users.
Storage	27.7	One storage space is located at this level.

Toilet	15.4	At this level, the convenience is located on the right part of the building linking the restaurant and bar.
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Table 7: First floor space and quantity data of the BRLO Craft Beer Warehouse (BRLO GmbH, 2023).

Based on the data in Table 7, an illustration of all the space and extracted quantity in sqm is needed and will be utilized for cost estimates. The usable floor area includes the highlighted space defined above, and the unusable space is void directly from the ground floor area, as shown in Appendix B.

Thus, the floor area in Tables 6 and 7 highlighted above gives essential data useful for cost estimation and building analysis, respectively.

4.2.2 Understanding and Figuring Out the Problem(s)

The development and understanding of various spaces of the BRLO craft building gives information necessary for renovation. In 2021 the BRLO craft building management began to develop the concept of calculating the CO2 footprint of the building with Klimatech start-up Planetly GmbH to measure and determine the reduction of emissions generated from the building via the selected climate protection projects. Regrettably, Planetly was shockingly shut down in November 2022 without accessing and establishing the calculation to determine critical issues of the building.

Given that, the goal of BRLO craft is to conduct a sustainable analysis of the building to measure accurately a long-term reduction plan of emissions which could be generated within the building. The information received concerning the building so far focuses on a few components that require renovation to reduce emissions further and make the building sustainable.

In determining the components, the following areas require renovation, for example, the windows, doors, changing lighting fittings, toilet fittings, changing of refrigerator system and maintenance of areas that have defects, which construction time schedule is a significant factor in checkmating the renovation time frame of the building because of its use.

The problems highlighted above are crucial to reducing emissions because changing the systems to a more sustainable one can further reduce the CO₂ emissions generated from the building, which affects the environment and users of space. Understanding the problems gives a clear idea of the approach and necessary materials to solve the problem, as described in sub-chapter 4.2.3 below.

4.2.3 Developing a Problem-Solving Approach

In developing a solution to the highlighted information (see sub-chapter 4.2.2), the type of material selection which meets sustainable building standards is considered for the research. For the research, the following sustainable building materials are selected for renovation example, replacing the existing doors and windows with uPVC doors, uPVC windows because it is known as a recyclable material with long durability, energy efficient, low maintenance requirements, flexible and affordable to set up (Neuffer Fenster, 2023).

Other building materials considered sustainable for renovation include automatic wash hand basins with sensor taps and automatic showers with sensor taps as described (see sub-chapter 2.1.2), paragraph two. Furthermore, dual flush toilets and HFC refrigerators described (see sub-chapter 2.1.3) paragraph five, halogen and fluorescent lighting are vital, which helps reduce emissions and conserve energy in the building.

The itemized building materials above give an idea of generating a holistic bill of quantities for the research by developing a cost survey, as shown in Table 8, based on the present market value of material and labour costs in Berlin.

RENOVATION DATA FOR BRLO CRAFT WAREHOUSE, BERLIN, GERMANY						
PRICE OF MATERIALS	Unit	Price (euro)	Total amount(euro)	PRICE OF LABOUR	Unit	Price (euro)
UPVC Windows (800mm x 1200mm)	1piece	350	350	Painting (average)	per sqm	10,00
UPVC Windows (1465mm x 1200mm)	1piece	450	450	Cement Mason	per hour	25,00
UPVC curtain wall (1465mm x 1200mm)	1piece	450	450	Replacing window	1window	150,00
UPVC curtain wall (2210mm x 2590mm)	1piece	900	900	Replacing door	1door	150,00
UPVC curtain wall (2820mm x 2590mm)	1piece	1200	1200	Screeding	per sqm	10,00
UPVC curtain wall (3210mm x 1200mm)	1piece	1500	1500	Tiler (Tile setter)	per sqm	23,00
UPVC curtain wall (6020mm x 2100mm)	1piece	4000	4000	Demolition of window	per hour	12,00
UPVC Doors (750mm x 2100mm)	1piece	694.77	694.77	Demolition of door	per hour	12,00
UPVC Doors (900mm x 2100mm)	1piece	780	780	Repair of cracks	per hour	12,00
UPVC roller shutter door (2500mm x 2590mm)	1piece	2047	2047	Electrician	per hour	27,00
Toilet Tiles (20x20cm)	1 Carton	28,75	28,75	Unskilled worker	per hour	12,00
Automatic Wash hand basin sensor tap	1piece	279,99	279,99	Crane	Per day	322,00
Automatic shower and sensor tap	1piece	4435	4435	Plumber	per hour	27,00
Dual flush toilets	1set	1349	1349			
HFC refrigerator	1set	2999	2999			
Halogen lighting	1set	89.3	89.3			
Fluorescent lighting	1set	66.52	66.52			
Wire (1.5mm)	Roll	59.55	59.55			
Wire (2.5mm)	Roll	84.23	84.23			

Table 8: Material and Labour cost in Berlin, Germany (Source: Author's work, 2023).

The illustrated data in Table 8 presents the current market value for 2023 based on material and labour costs in Berlin. In generating the Table, data for materials and labour are obtained from survey analysis as shown in the Table. Therefore, the generated information is valuable and sufficient for the bill of quantities to be developed for renovating the BRLO craft warehouse.

Summary of Chapter 4.2

The findings in this Chapter summarize the generated data information in Tables 6 and 7, describing the spaces and quantity in units of the BRLO craft warehouse. The importance of the data is to have an overview of the required spaces during cost analysis and schedule. In developing the data, the findings show the problems faced by the building in carrying out analysis to determine the reduction procedure of CO2 emissions, which resulted in setbacks, requiring a new driving approach to solve the issue of emissions as discussed respectively.

4.3 As-built Design Model

Before explaining the as-built model in detail, this section of the Chapter describes an overview content of the design model of the BRLO craft warehouse (see sub-chapter 4.3.1) developed using Google SketchUp. The model developed involves necessary components and spaces which are helpful for quantity takeoff (see sub-chapter 4.3.2) coordinated and utilized for construction cost estimation developed (see sub-chapter 4.3.3) respectively.

4.3.1 Model of the Building

Modelling of the building is a crucial aspect in generating the overall quantity for the renovation. Building information modelling is an integral part of developing the quality and quantity takeoff of the building. In that regard, the model was developed using Google sketch-up, adopting the parameters and measurement of shipping containers (see sub-chapter 2.2.3) to produce the model of the building, as shown in Figure 23.

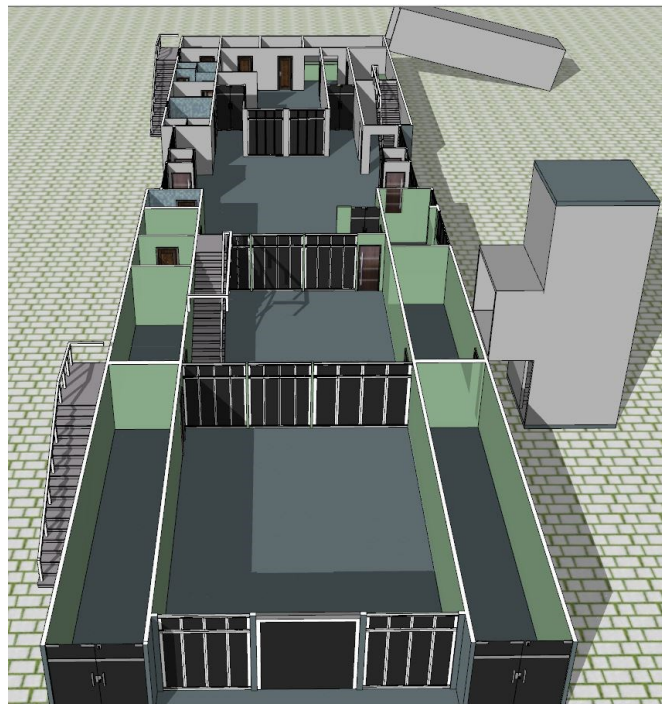


Figure 23: Google sketch-up model of the BRLO craft beer warehouse (Source: Author's work, 2023).

Based on the graphical illustration of Figure 23, the modelled spaces of the BRLO craft beer warehouse are fully replicated. The generated BIM model contains all the available details for quantity takeoff, which will be utilized for cost estimation based on the areas to be renovated within the building.

The model will pass through the quality test during quantity takeoff to ascertain any need for correction before proceeding with the quantity for cost analysis, as shown (see sub-chapter 4.3.2) respectively.

4.3.2 Accessing the Design Model and Quantity Take-off

The familiarization of the design model, which involves different components, spaces and levels shown in Figure 23, enabled direct understanding, and checking of all the necessary data required to generate quantity takeoff. In generating the quantity takeoff, Figure 24 shows the use of Solibri, a BIM software (see sub-chapter 3.2.4), allowing for the extraction of quantities useful for cost estimation.

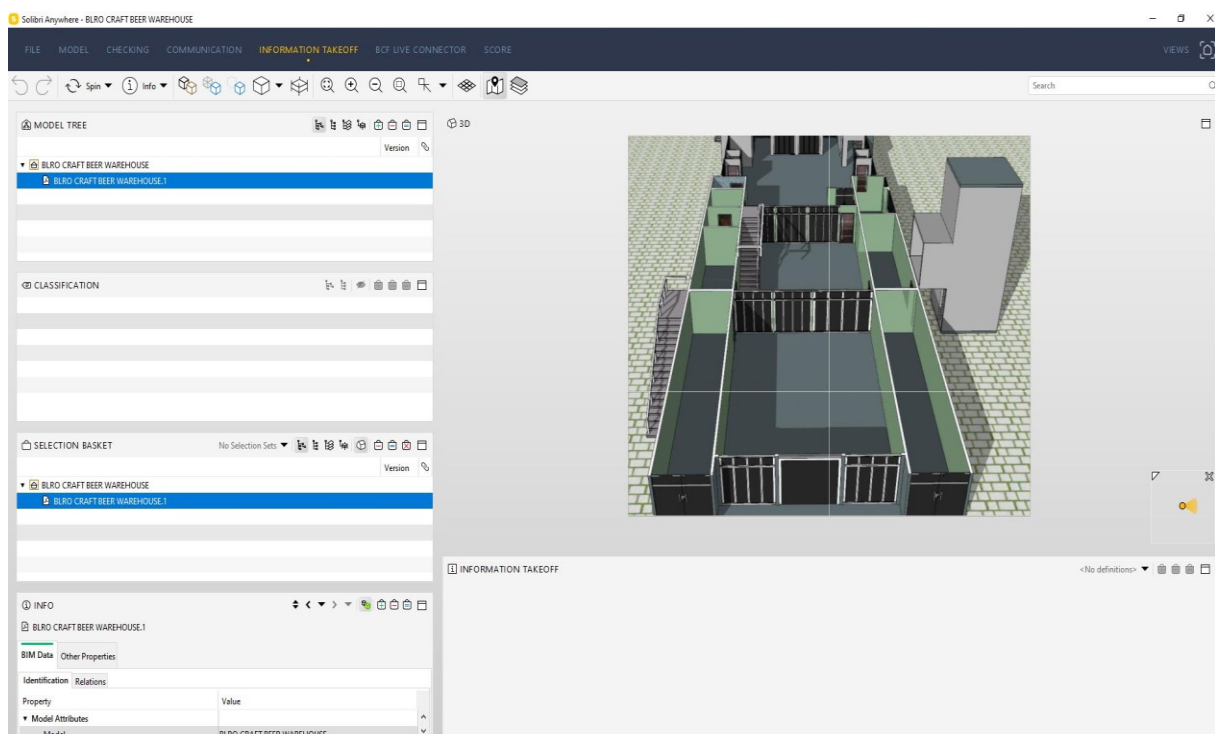


Figure 24: The use of Solibri for quantity take-off of the BRLO craft beer warehouse

(Source: Author's work, 2023).

The illustration of Solibri in Figure 24 further describes how the quantity of the building model was entirely generated. After completing the model with Google Sketch-up, the design model was saved as an IFC file, a compatible file format for Solibri. The IFC file was further imported into Solibri, allowing for checks concerning clashes and necessary amendments from Google sketch-up before importation was done again to generate the quantities saved as Microsoft Excel.

The Excel shows all the detailed cost analyses necessary for the renovation of the BRLO craft beer warehouse, as shown (see sub-chapter 4.3.3) respectively.

4.3.3 Construction Cost Estimation

Based on the generated information from Solibri saved in Microsoft Excel, a renovation cost estimation for the BRLO craft beer warehouse is being developed from the highlighted data (see sub-chapter 4.2.3) and described in Figure 25 below.

Item	Description	Qty	Unit	Rate	Amount
	DEMOLITION :				
A	Cearfully remove existing Doors and keep for client reuse	38	Nr	39.00	1,482.00
B	Cearfully remove existing Windows and keep for client reuse	6	Nr	19.20	115.20
C	Hack out existing interlocking tiles in toilet and remove debris away from site	13	sq.m	14.00	182.00
D	Remove existing toilet fittings and keep for Client reuse	2	day	216.00	432.00
	REPLACEMENT:				
	L20: Metal doors/shutters/hatches				
	<u>Supply and fix UPVC doors complete with frame, architrave and accessories from approved manufacturers.</u>				
E	1200x2100mm high	2	Nr	1,250.00	2,500.00
F	900x2100mm high	22	Nr	930.00	20,460.00
G	750x2100mm high	7	Nr	844.77	5,913.39
H	UPVC roller shutter door 2000x2100mm high	1	Nr	2,197.00	2,197.00
	<u>Supply and fix UPVC windows from approved manufacturers.</u>				
J	UPVC Windows (800mm x 1200mm)	1	Nr	350.00	350.00
K	UPVC Windows (1465mm x 1200mm)	1	Nr	450.00	450.00
L	UPVC curtain wall (2210mm x 2590mm)	1	Nr	900.00	900.00
M	UPVC curtain wall (2820mm x 2590mm)	1	Nr	1,200.00	1,200.00
N	UPVC curtain wall (3210mm x 1200mm)	1	Nr	1,500.00	1,500.00
P	UPVC curtain wall (6020mm x 2100mm)	1	Nr	4,000.00	4,000.00
	CARRIED TO COLLECTION				€ 41,681.59

M40: Stone/Concrete Quarry/Ceramic tilling/Mosaic					
	<u>Ceramic floor tiles of approved colour, bedded and jointed in cement and sand (1:3) mix floated bed</u>				
A	20 x20cm toilet tiles	13	m2	65.00	845.00
	<u>Sanitary Appliances</u> <u>Supply, assemble and fix the following sanitary appliances and accessories, including all joints to cold water supply and discharge pipes.</u>				
B	Automatic Wash hand basin sensor tap	5	pcs	279.99	1,399.95
C	Automatic shower and sensor tap	2	pcs	4,435.00	8,870.00
D	Dual flush toilets	5	set	1,349.00	6,745.00
E	Kitchen/Kitchennette Touchless Kitchen Faucet with Pull Down Sprayer, High Arc Single Handle Motion Sensor Smart Activated Hands-Free Kitchen Sink Faucet	4	Nr	129.00	516.00
F	Labour for Mechanical installation	5	day	312.00	1,560.00
	<u>Supply and lay the following cables for connection of electrical fittings</u>				
G	Wire (1.5mm) Roll	1	roll	59.55	59.55
H	Wire (2.5mm) Roll	1	roll	84.23	84.23
	Fittings and accessories				
J	Fluorescent lighting 1set 66.52	1	set	66.52	66.52
K	Halogen lighting 1set 89.3	1	set	89.30	89.30
L	HFC refrigerator	1	set	2,999.00	2,999.00
M	Labour for inspection and installation	2	day	312.00	624.00
	<u>CARRIED TO COLLECTION</u>				€ 23,858.55

	M31: Fibrous Plaster of Paris				
	Prepare and apply ''aduplan'' or other equal and approved wall floating material on rendered walls				
A	Rendered surfaces	756	m2	45.00	34,038.00
B	Rendered surfaces, width not exceeding 300mm	189	m	13.50	2,552.85
	M60: Painting/Clear finishing				
	Prepare and apply two finishing coats of emulsion paint on:				
C	Walls	756	m2	30.00	22,692.00
D	Ditto not exceeding 300mm girth	189	m	9.00	1,701.90
	<u>CARRIED TO COLLECTION</u>				€ 59,282.85
	COLLECTION				
	PAGE 1			€ 41,681.59	
	PAGE 2			€ 23,858.55	
	PAGE 3			€ 59,282.85	
	GRAND TOTAL				€ 124,822.99

Figure 25: Bill of quantities for the renovation of the BRLO craft beer warehouse

(Source: Author's work, 2023).

The calculation in Figure 25 shows the level of work to be performed to meet a more sustainable building using shipping containers. In addition, from the bill of quantities, several changes will be made to spaces that amount to high emissions, using sustainable materials to reconstruct and remodel the building for a cost of 124,822.99 euros.

Based on the bill of quantities developed above, the generated data will be further determined and developed into a construction time schedule to be represented in the Microsoft project, as shown in Chapter 5 respectively.

4.3.4 Construction Time Schedule

Developing the construction time schedule (4D BIM) forms the final and integral utilization phase as described (see subchapter 3.3.5). In determining the construction time schedule, the generated bill of quantities (see subchapter 4.3.3) is one of the significant factors utilized to achieve a flexible and less construction time schedule in this subchapter.

Based on the selected case study of the BRLO craft warehouse, the construction time schedule serves as the schedule for the renovation of the building, identifying significant components defined (see subchapter 4.2.2), which are vital areas involving the renovation. In achieving the construction time schedule, the bill of quantities enabled to plan of the activities (task) that will be accomplished concerning time, as shown in Figure 26 and Appendix C in detail.

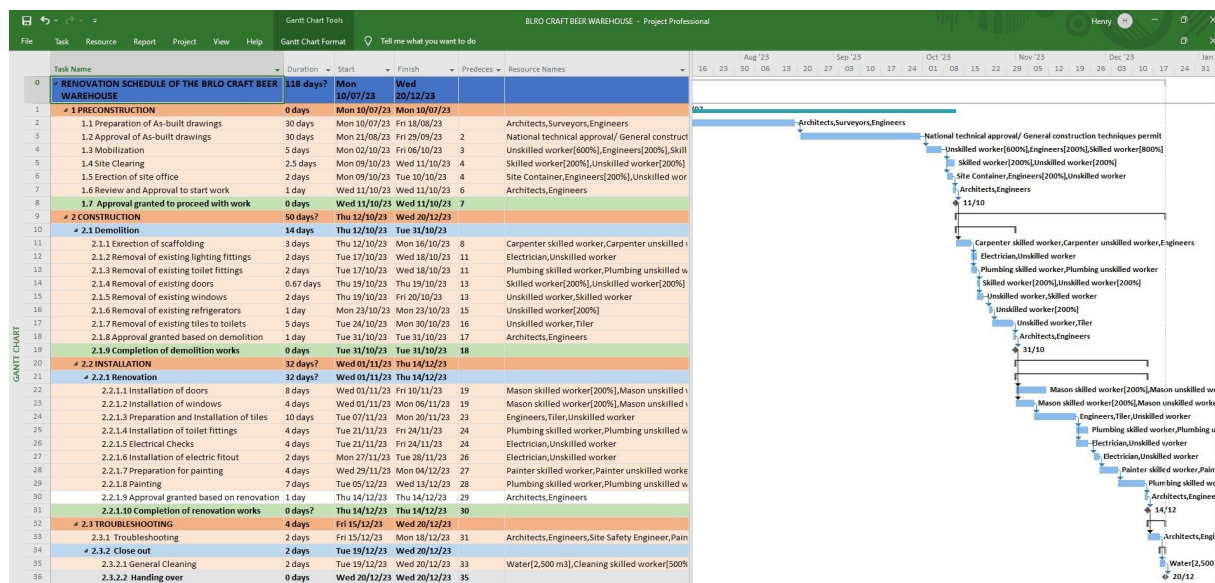


Figure 26: Construction time schedule for the renovation of the BRLO craft beer warehouse

(Source: Author's work, 2023).

Based on the illustration in Figure 26, the construction time schedule for renovating the BRLO craft beer warehouse is generated. The schedule developed using the Microsoft project identifies all the necessary activities to be carried out to renovate the state building.

The activities further show the duration of works, the predecessors and resource names that will be used to achieve the allocated activities or tasks. The planned renovation will begin from 10/07/2023 to 12/12/2023 for a cost of 124,822.99 euros involving all necessary details planned to be achieved in approximately six months to minimize construction costs and time which is an essential factor for the research.

In achieving this timeline, milestones are set based on start dates and finish dates identified in Figure 26, likewise combining activities which can be achieved at the same time as site clearing, erection of site office, and demolition of doors and windows, among others are described in Appendix C. Thus, with the developed construction time schedule above, the procedures defined (see subchapter 3.3) has been fully established making the research relevant, especially for shipping container (sustainable building) involving renovation based on little knowledge found from previous research respectively.

4.4 Evaluation of the Results and Analysis

Considering the validation of the results based on the research, the construction time schedule developed (see subchapter 4.3.4) follows the research framework providing all the necessary information and steps to accomplish the BRLO craft beer warehouse schedule.

First, the research has been able to define the background information of the case study selected, highlighting all the necessary information related to the existing planning of the container building and further defining the usage of the building as a commercial building meant to produce beer, restaurant, and relaxation spot for users.

Secondly, the planning information delivers more holistic information for the design stage with helpful information on spaces within the building amounting to the quantities in square meters as extracted (see subchapter 4.2.1), justifying that the developed schedule is fully recognized and authentic to achieve the purpose of the research.

Thirdly, based on the design information of the building, an adopted process of utilizing BIM for modelling the selected case study was fully achieved from the design phase utilizing Google Sketchup as powerful software to define the quantity and visual image of the building. As a result of modelling the building, Solibri BIM software further functions following the modelled building for quantity takeoff figuring out the main concerns of the building being identified and enabling for integration of the given areas to be renovated as defined (see subchapter 4.3.2).

Fourthly, identifying costs presents the financial reflection and overall cost objective of executing the works. Given that, construction cost estimation was accomplished after the quantity takeoff focusing on the defined works and amount to be utilized for the renovation process with necessary materials. The cost for labour shown (see subchapter 4.3.3) further define the fees for execution of work, involving architect's and engineer's fees, which are subject to the DIN 276 and HOAI chargeable cost and fee band as shown in Appendix D (Deutsche Norm, 2008), (HOAI, 2013). The fees also apply to repairs and maintenance, referred to as the renovation of the BRLO craft beer warehouse.

Lastly, because of the cost analysis generated, the construction time schedule was developed successfully (see subchapter 4.3.4), showing the renovation of the building being planned to be achieved within six months at 2,658.67 hours as shown in Appendix E for work done, at the cost of 124,822.99 euros, which is economical and feasible for the project to minimize cost and time that is key for the research respectively.

5. Discussion

The research's definition of how to utilize the construction time schedule for sustainable buildings using shipping containers was a significant concern. The evaluated results (see sub-chapter 4.4) explain the study's relevance following adopting procedures to accomplish the construction time schedule.

In achieving the procedures, the knowledge of sustainable building design, which are environmentally friendly buildings involving residential and commercial buildings, was an essential factor from the literature review, especially for shipping containers. The idea summarizes the guiding principles that make buildings more sustainable, following the reusability of material and economic advantage when constructed due to the different types and sizes available in the market for purchase and construction.

The findings from the literature review further generated more relevant information for the construction of new development for shipping containers without having access to the case of renovated buildings because of the recent innovation of shipping containers which was a focus for validation of the research in Chapter 4. Therefore, the argumentation that BIM is a functional tool for solving the problem of construction time schedule was developed, explaining building information modelling as a representation of physical and operational processes involving collaborative stakeholders to understand the design, construction, and operation of the building through its lifecycle (Besenyői, 2023, pp. 7 - 8).

The results demonstrate the relevance of BIM, which was further adopted in analysing the research framework in Chapter 3, making the validated result more precise in Chapter 4, following all the necessary guidelines to achieve a successful construction time schedule. Concerning the development, the project's duration is to be completed within a feasible six-month construction time at the cost of 124,822.99 euros construction cost. When duly maintained, the time frame controls high construction costs in relation to the time spent to accomplish the renovation, which successfully answers the problem of how to utilize the construction time schedule, especially for sustainable building and design.

Furthermore, the discussion and utilization of the design model are described (see subchapter 5.1), identifying the process involved in selecting the case study, including the problem and action plan taken to solve the problem. In solving the problem, the limitation encountered are being discussed (see subchapter 5.2) and explaining the way forward in further research (see subchapter 5.3), respectively.

5.1 Discussion of the Design Model

Based on the analysis done on the design model, the BRLO Craft beer warehouse is a commercial building located in Berlin, Germany. The location and accessibility of the building made the design model much easier to handle because of the first-class information about the selected structure.

As mentioned in Chapter 4, before the design model was considered, the identified problem was how to reduce generated emissions with a considerable construction time and cost by the elements described (see sub-chapter 4.2.2). In developing a problem-solving approach, certain sustainable building materials were further highlighted for renovation (see subchapter 4.2.3), in which BIM performed an integral function in the development of the as-built model, which forms the primary data for the refurbishment of the building. The creation of base models was utilized fully on BIM software following all the procedures developed in the framework.

In achieving the target of the construction time schedule, the bill of quantities further helped develop the cost analysis. The cost analysis gave the researcher a successful flow through the framework created in Chapter 3, making the outer reader understand the various procedures to take when determining the construction time schedule for the renovation of shipping containers.

The overall research was supported and successful due to the practical usage of BIM, even though limitation is considered inevitable in most cases, as reflected, and discussed (see subchapter 5.2) respectively.

5.2 Limitation of the Design Model Selected as Case Study

Every research always has a limitation because of the subject matter. This research is not an exception because of its recent development of shipping containers in the construction industry. The development has continued to meet up with the popularity of cost-effective and sustainable building solutions, which also applies to the renovation of buildings. Thus, consideration limitation applies to this form of the shipping container is highlighted based on the following.

The first constraints are based on the standard sizes available, which have minimal possibilities of structural modification (cutting and welding). Any attempted professional mistakes in modification amount to a loss of structural strength and therefore weaken the container building from standing for a given lifecycle.

Secondly, the constraint of building codes and forms of regulation guiding the renovation of the shipping container. This constraint forms a challenging factor during the renovation (modification) of the structural elements of the shipping container.

Thirdly, the constraint on the award of permits; the lack of available building codes and consistent regulations has amounted to fewer permits being given out yearly for shipping containers.

Therefore, the study requires measures that professionals can adopt to smoothly solve the limitations highlighted above for efficient and more reliable reconstruction of the building using shipping containers and given more opportunity for further study to be carried out respectively.

5.3 Further Study Regarding the Research

For further research works, the researcher highlights the importance of developing solutions related to the limitations, which explains the recommendations regarding the analysis suggested by this research.

Regarding the problem of modifications concerning shipping containers, it is recommended that further researchers should investigate the area of structural strength when modification is to be taken place to ascertain the professionals required to handle modification works.

Another key recommendation is the area of building codes, regulations and permits; due to the recent development of shipping containers, the research recommends that building codes and permit templates be developed and generated to guide and oversee shortcomings that arise due to approvals of drawings.

Thus, the recommendation given above, if duly researched on, the development and motivation of professionals and users of shipping containers will be improved and highly adopted for the construction and reconstruction of buildings irrespective of their sizes, volume, and complexity, which in turn will further reduce the generated carbon emissions and making buildings more sustainable utilizing feasible time for construction and managing cost adequately.

6. Conclusion

The general focus of the present research is how to utilize 4D BIM for container architecture, especially for design, sustainable building, and construction time schedule, using a case study of the BRLO craft beer warehouse for the renovation process. To properly understand the problem statement, literature reviews (see Chapter 2) were carried out in the sustainable building, container architecture and BIM to expand the knowledge of utilizing the 4D BIM for the selected case.

After expanding the knowledge through literature reviews, the following procedure was the framework (See Chapter 3), the developed framework acted as the integral measure to solve the problem of how 4D BIM can be utilized. In developing the framework, two important methodologies were adopted, which involved qualitative and quantitative research methods. The concept was the key driver of how to utilize 4D BIM, demonstrating the knowledge of stakeholders involved in a project before developing the utilization process of 4D BIM, which was carried out in Chapter 4.

The validation of the framework duly followed the adopted case study of a commercial shipping container (BRLO Craft beer warehouse), stating all the necessary information related to the building's existing planning and design stage. The information derived from the building is translated into data collection of all the required spaces, which is being used to generate computed data of the areas that need renovation. Building information modelling made it possible to develop the model in Google Sketch-up and save it as an IFC file for other use. The saved IFC file, being imported into Solibri (BIM software), enabled the development of quantity takeoff and bill of quantities used for the construction time schedule.

The findings from the generated result (See Subchapter 4.4) analyzed a constructive and practical template validated (see Chapter 4) testing the utilization of 4D BIM, especially for sustainable shipping containers. The construction time schedule was designed to be achieved within the shortest duration of six months at the cost of 124,822.99 euros involving the as-built, approval and reconstruction of the building. The fulfilment of the shortest duration allows for minimal construction costs for the client and the operation of the building.

Overall, the research solved the problem of 4D BIM for sustainable building design, even with limitations highlighted (See Chapter 5), allowing for further research to encourage users to adopt more usability of the shipping container irrespective of the purpose of the building when developed.

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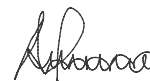
Declaration of Authorship

I hereby declare that the attached master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

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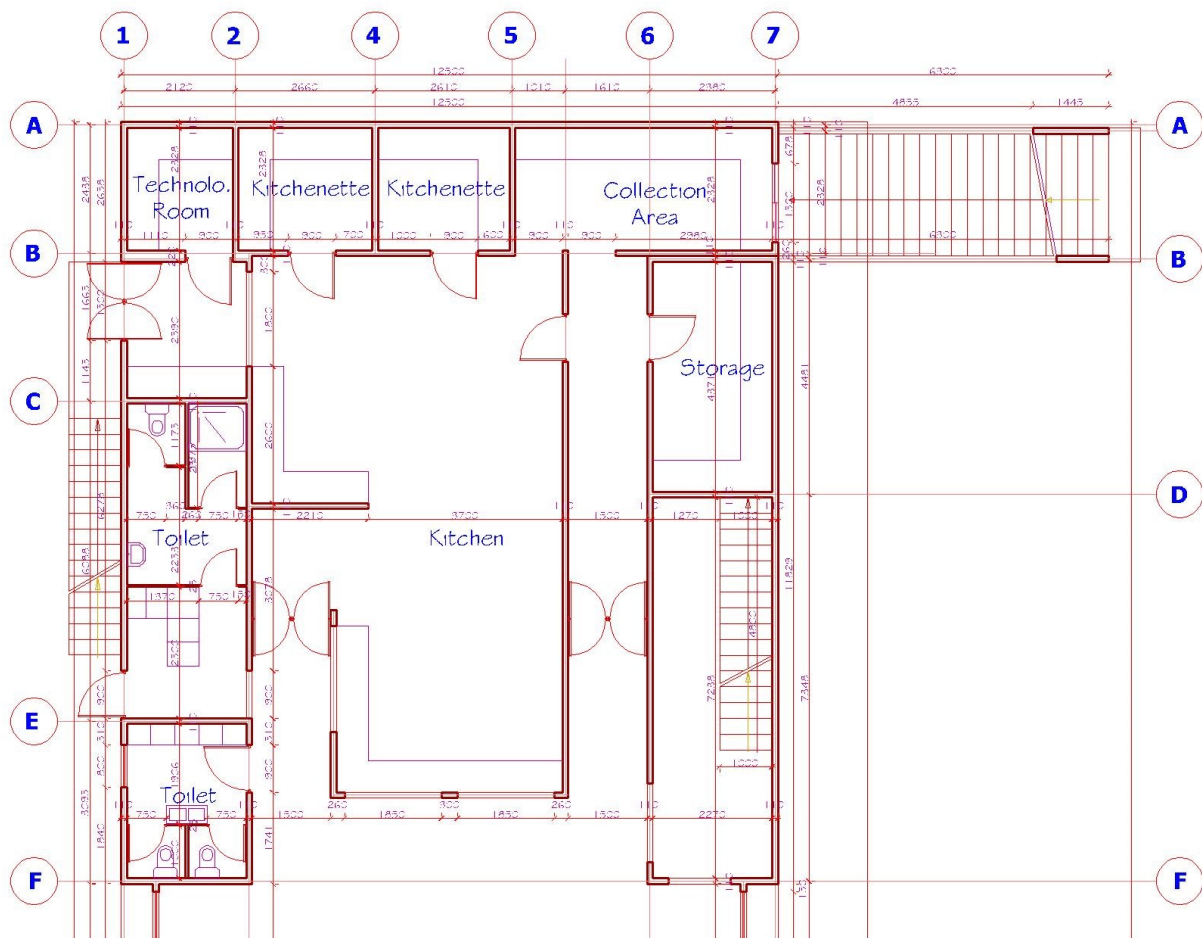
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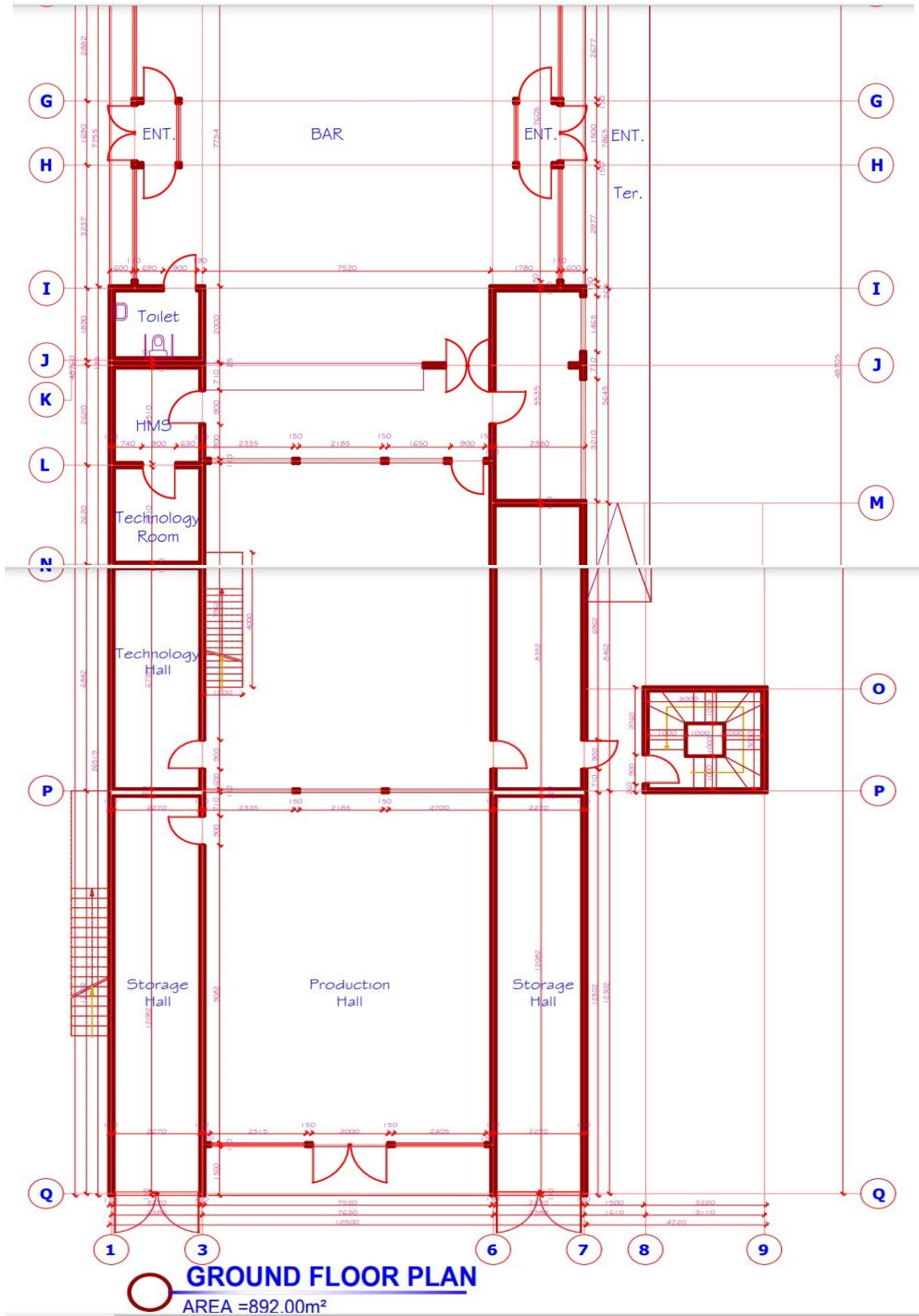
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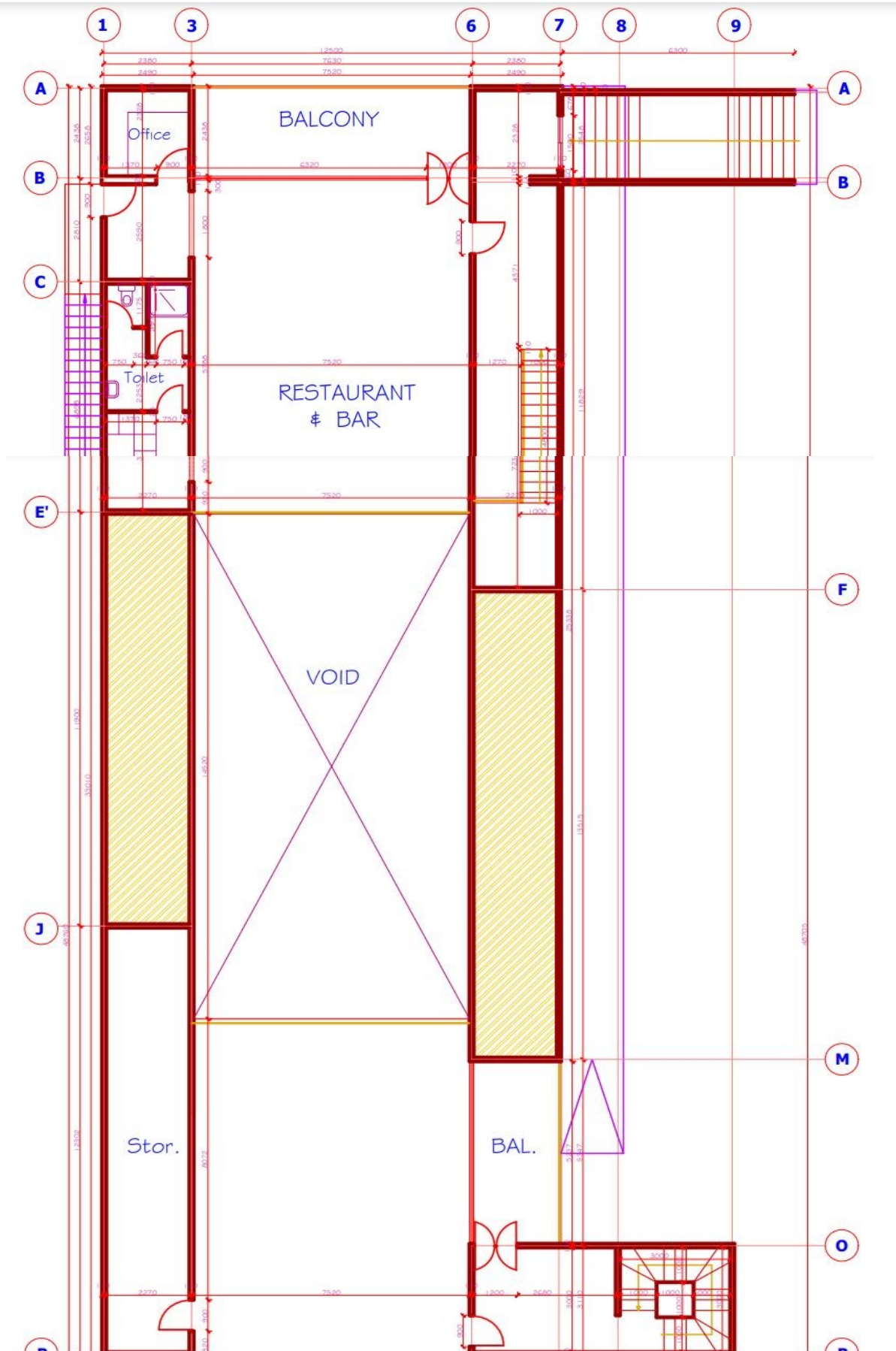
Appendices

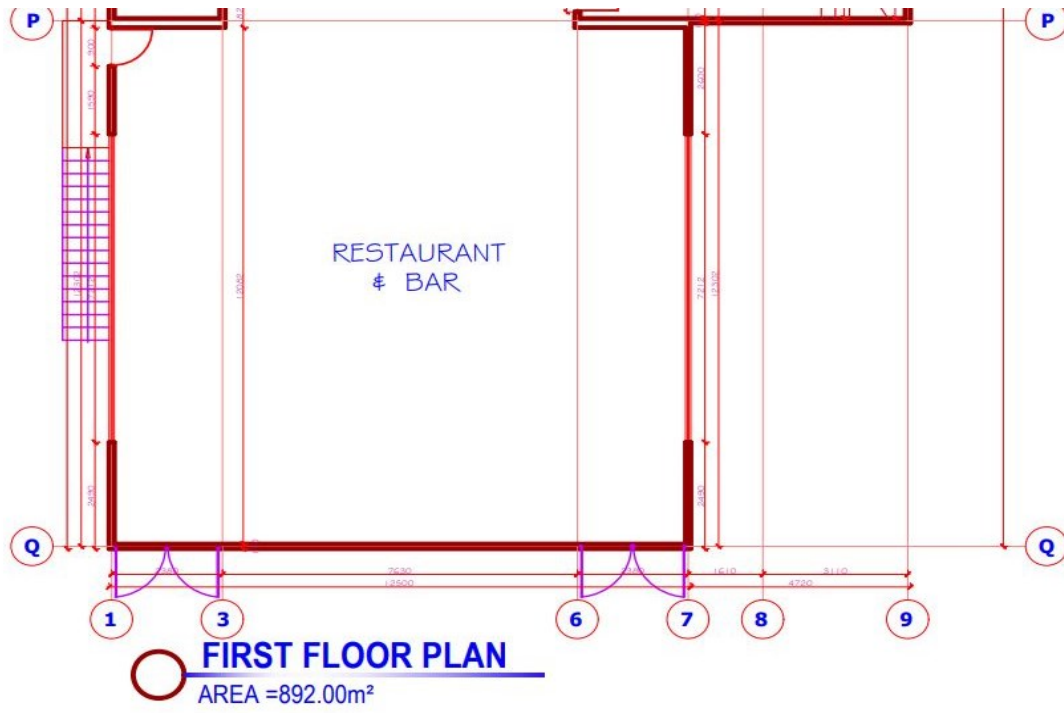
Appendix A



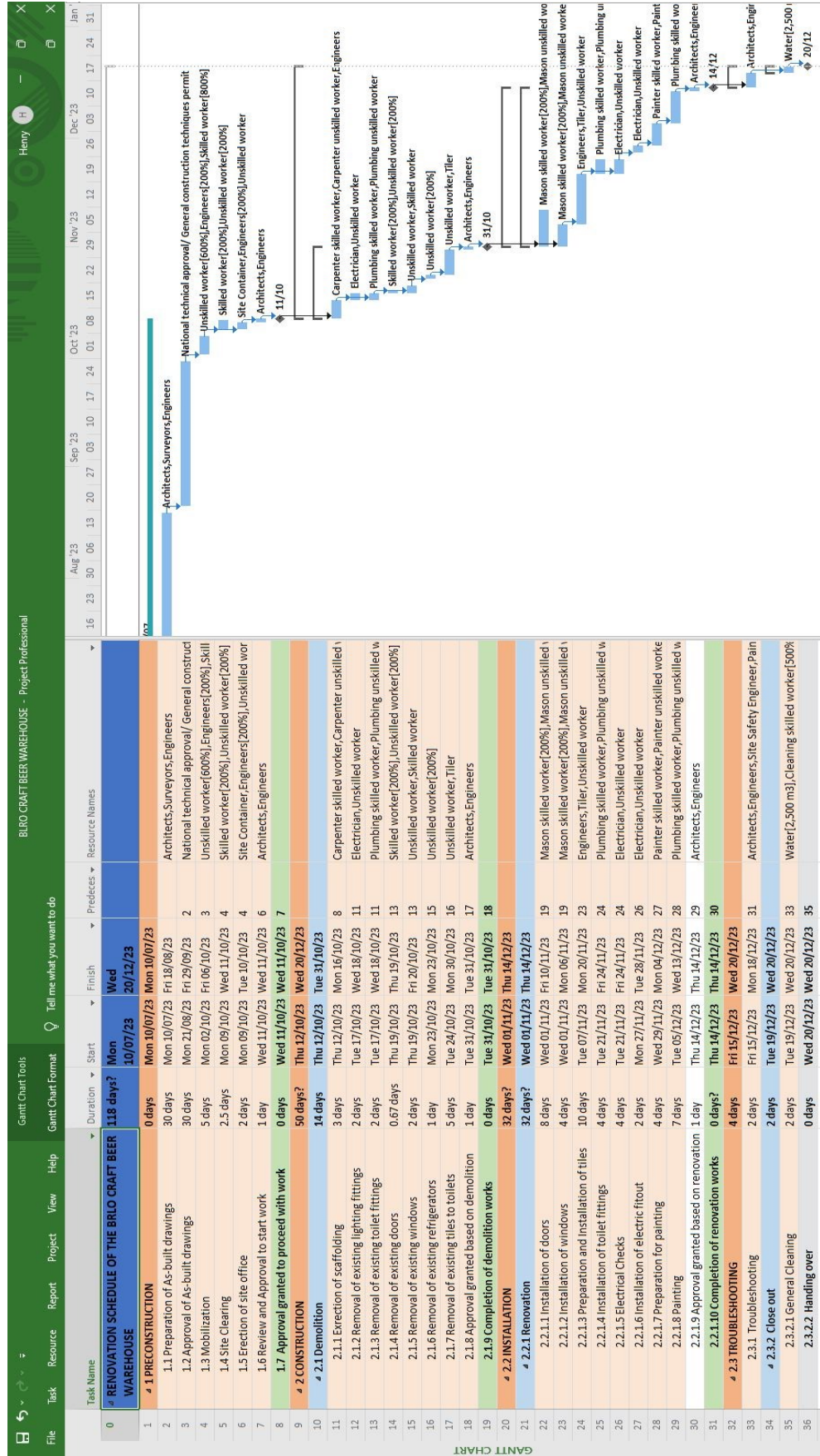


Appendix B





Appendix C



Appendix D

§ 21 Fees for services pertaining to building plans

- (1) The minimum and maximum rates for the basic services listed in § 19 and Appendix 3 for building plans, are listed in the following fee table:

Area in hectares	Fee band I low requirements		Fee band II average requirements		Fee band III high requirements	
	from Euro	to Euro	from Euro	to Euro	from Euro	to Euro
0,5	5.000	5.335	5.335	7.838	7.838	10.341
1	5.000	8.799	8.799	12.926	12.926	17.054
2	7.699	14.502	14.502	21.305	21.305	28.109
3	10.306	19.413	19.413	28.521	28.521	37.628
4	12.669	23.866	23.866	35.062	35.062	46.258
5	14.864	28.000	28.000	41.135	41.135	54.271
6	16.931	31.893	31.893	46.856	46.856	61.818
7	18.896	35.595	35.595	52.294	52.294	68.992
8	20.776	39.137	39.137	57.497	57.497	75.857

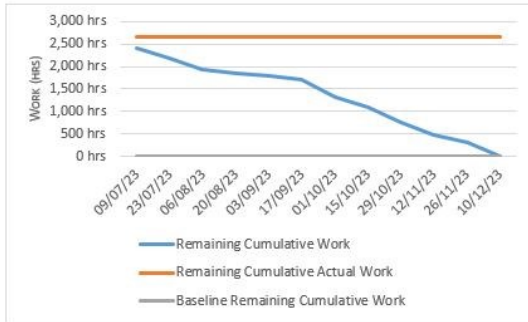
§ 27 Service profile of the maintenance and development plan

- (1) The basic services pertaining to the maintenance and development plans are summarized to form four service phases and should be valued with the following percentages of the fees of § 32 as follows:
1. with 3 percent for service phase 1 (compilation of the initial conditions),
 2. with 37 percent for service phase 2 (ascertainment of planning basics),
 3. with 50 percent for service phase 3 (preliminary version) and
 4. with 10 percent for service phase 4 (agreed version).
- (2) Appendix 8 regulates the basic services of each service phase. Appendix 9 contains examples for special services.

Appendix E

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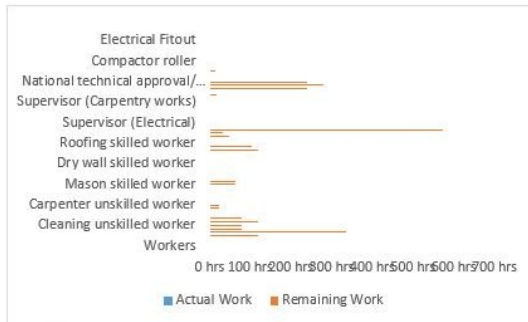
WORK OVERVIEW



Is your baseline work zero?
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WORK STATS
Shows work stats for all top level tasks.

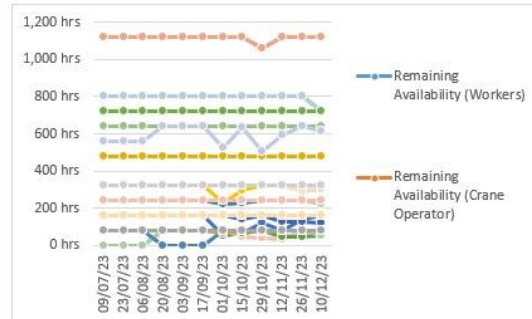


RESOURCE STATS
Shows work stats for all your resources.



WORK OVERVIEW

Mon 10/07/23 - Wed 20/12/23



REMAINING AVAILABILITY
Shows remaining availability for all work resources.