QATAR UNIVERSITY

COLLEGE OF ENGINEERING

BUILDING INFORMATION MODELING (BIM) TOWARDS FOSTERING CIRCULAR AND SUSTAINABLE CONSTRUCTION (CIRCULAR BIM)

BY

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ABSTRACT

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Title:Building Information Modeling (BIM) Towards Fostering Circular and Sustainable Construction (Circular BIM)

Supervisor of Thesis: Dr. Nuri Cihat. Onat.

The aim of this thesis is to study the circular economy (CE) model in construction, sustainability, and the utilization of building information modeling (BIM) to support decision making on building component circularity and sustainability based on their ranking by the use the power of BIM software and management workflow. An analysis of a real-world project with requirements of BIM implementation, the circular economy concept of design for disassembly, and sustainability requirements in Qatar. Developed BIM model and management documents were created to experience the findings and results of the analysis of the real project. In addition to a well-structure survey designed to identify the gaps in practice of sustainability, CE, and BIM utilization in the construction industry. The observations, analysis results, BIM developed project model and survey results were used to develop a recommended best practice workflow model; to utilize BIM management and modeling software and workflow in supporting the measurement and record of the circularity of the designed and constructed asset. This was studied to help decision makers to make better sustainable and circular economy decision during the design and construction stages of the project. The results show that following a developed BIM utilization workflow and the addition of circularity and sustainability parameters within the BIM management documents and models of the project from the early stages of the project, would have huge impact on the circularity and sustainability decisions by the stakeholders.

Consequently, this will lead to building better assets aligned to the circular economy and sustainability development goals in construction industry projects.

DEDICATION

I dedicate this thesis to my beloved parents, “Amnah al Sayyed and Mohammad Mustafa”, my beloved siblings “Murad & Mary”,

Who have supported me during the past years of my academic, professional, and personal life journey.

I have no way to express my gratitude to them, for the love and prayers to me along the whole journey.

It is with genuine gratitude and warm regard that I dedicate this work to my beloved wife “Rand Al Asir”, and extend my huge gratitude to her, for the emotions, love, support, and motivation she has showed to me during the whole duration of my journey.

To all my friends, colleagues, and supporters, who supported me and helped me to be stronger, more committed and dedicated than I could be or imagine to be.

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I do also wish to mention that this thesis would not have been possible without the valuable feedback of Dr. Murat Gunduz support and feedback, and the valuable comments provided to enhance the writing of the proposal.

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CHAPTER 1: INTRODUCTION

1.1. Overview

Due to Being the largest Gas producer in the world and the first country to vaccinate more than 70% of its people, Qatar has gained the world's largest attention in the last decade, and as a result of hosting the FIFA world cup 2022 and many other sports events; which will have a strategic long term impact on the country and the region, Qatar has involved sustainable construction in its strategy and country vision and has involved all the sustainable and technology economical tools within its construction strategy complying to the FIFA strategy in minimizing the environmental, social, cultural and economic Impact of FIFA world cup pre & post-event phases' activities from stadium construction projects, beautification projects, travel plans, material consumptions, and many other human activities (Death, 2011; Kucukvar et al., 2021a).

According to (Gold & Gold, 2013; Talavera et al., 2019; Al-Hamrani et al., 2021), environmentalists and policymakers have given growing attention to sports mega-events starting 1994 in Lillehammer Winter Olympic games, followed by the 1996 declaration of the life cycle of the future Olympic Games and it's mandatory environmental impact analysis by the International Olympic Committee, afterward the environmental concerns addressed under the areas of: water, waste, energy, transportation and climate change in Germany in 2006, followed by the green goal initiative 2010 in South Africa, the same experience in Brazil 2014, later in 2013 the triple bottom line sustainability strategy of social, economy and environment was established to cover the strategy needed to be followed for the FIFA World Cup – Russia 2018, reaching Qatar Sustainability and construction economy vision and strategy being the hosting country for FIFA World Cup 2022.

Qatar Government has launched a comprehensive socio-cultural, economic and environmental vision to be the leading criteria towards enhancing all sectors in the country to make them green and sustainable, and has paid great attention towards the use of the latest technology tools, specifically in construction projects and especially in FIFA world cup 2022 projects; it is clearly spotted that Qatar Supreme Committee for Delivery & Legacy (SC), the responsible committee for FIFA world cup 2022 event and preparation of construction and beautification projects in Qatar, has followed strictly a clear sustainable and technological plan with Four main pillars namely, Human, Environment, Economic and Social to deliver the best sustainable and green solution, using the latest construction technologies available, as a result it was clearly mentioned in all FIFA world cup 2022 related projects to mandate the use of Building Information Modeling (BIM), with a strictly secured Common Data Environment (CDE); to guarantee smooth and sustainable progress of the projects in line with Sustainability and Green building requirements and latest trends, which is a requirement of Qatar Construction Specification (QCS 2014); that mandates governmental projects to achieve at least 3 stars Global Sustainability Assessment System certification “GSAS” (Access et al., 2014; *Qatar National Vision 2030 General Secretariat For Development Planning*, 2008; Sustainability & Report, 2022;Murat Kucukvar 1*, Adeeb A. Kutty 1, Nuri C. Onat 2 & Noora Al-Abdulmalek4, 2021).

1.2. Construction in Qatar

Developing countries consider construction as a vital sector and an essential growth booster and motivator, but they are facing the challenge of making their construction procedures more sustainable and environment friendly, through the use of the latest up to date tools, and techniques, this orientation and mindset is considered to be one of the most common measurement tools on the county's development pace and an impacting factor on the citizens prosperity (Kucukvar & Tatari, 2013; Reffat, 2004)

Qatar; the FIFA world cup 2022 hosting country is experiencing a huge economic growth boom while preparing to this significant event; where the country has planned to invest more than 40 billion USD in infrastructure and construction projects (Senouci et al., 2015) from the Airport to a metro system, Speed Rail, hotels and accommodations, and many other beautification and public parks projects.

Such an exponential construction growth and a large number of mega and giga projects have brought the environmental concerns to the main frame of the picture, and the extensive studies and research amount has been made to observe the country's construction behavior through the years, especially on the topics of sustainability, environmental impact, waste generation and waste management, circular economy, and many other environmental and sustainability aspects, as well as the used technology, software driven methodologies, building information modeling and management approach and methodologies (Ding, 2008; Mavi et al., 2021).

Qatar has invented the Qatar sustainability Assessment System "QSAS" as a guide for the sustainability and green environmental practices in the construction industry; which was on a later stage upgraded to be Global Sustainability Assessment System "GSAS", and has mandated a minimum of a 3-stars GSAS rate on most of the governmental infrastructure and construction projects all over the country (Ayoub et al., 2014).

1.3. Sustainability

In the last few decades, the concern towards sustainability and healthy environmental practices in the construction industry has raised exponentially due to the significant increment in the CO_2 and GHG emissions, and the construction industry has had a vital impact on gas emissions and environmental violations (*2021 GLOBAL STATUS REPORT FOR BUILDINGS AND CONSTRUCTION Towards a Zero-Emissions, Efficient and Resilient Buildings and Construction Sector*, 2021.; Wong & Zhou, 2015).

With the large scale, number, and complexity of construction projects in the major cities over the world, cities have committed to develop and apply the sustainability regulations, concepts, and protocols, covering environmental and economical pillars (Ferwati et al., 2019). In line with this trend and to serve the sustainability and environmental and human being needs, the United Nations "UN" has extensively studied the causes and effects of the sustainability violations and has developed 17 Sustainability Development Goals "SDG's", which have emerged in the sustainability practice, where many institutes and entities have developed sustainability codes of practice, like but limited to the Leadership in Energy and Environmental Design "LEED" system and Global Sustainability Assessment System "GSAS" (Council, 2021; Sezer & Fredriksson, 2021; "SUSTAINABLE DEVELOPMENT GOALS," 2020).

1.4. Sustainability Practice and Qatar's Vision

Qatar has a rapid growing industry in all sectors, especially in the infrastructure and construction field, particularly after winning the host of the first FIFA world cup 2022, which will be the first FIFA world cup to be hosted and organized in the Arabs region, therefore all relevant authorities and institutes have worked together and still; to ensure the delivery of the best FIFA World Cup event with the highest sustainability and environmental practices, and to generate sustainable infrastructures and buildings; to serve the event and the country on the post-event stage; where the mission and the vision were aligned to the purpose of achieving the required micro and macro sustainable development without compromising the countries environment (*FIFA World Cup Qatar 2022 TM First Sustainability Progress Report*, 2020;Al-Yafei et al., 2021).

The green building concept and standards are a vital foundation stone of sustainability practices in construction sector (Kotkar et al, 2017) , which according to (Ferwati et al., 2019) is defined as a set of strategies and design standards working with each other to enhance the quality of users' life, simultaneously, protect the environment of communities by reducing the construction rate of natural resource consumption.

Early in 2000's Qatar has started to understand the importance of sustainability and green building practices and their impact on the country's and citizens' development and growth, therefore in 2008 Qatar has developed the first comprehensive sustainability framework by Qatar National Vision "QNV" and Qatar Development Strategies "QDS"(*Qatar National Vision 2030 General Secretariat For Development Planning*, 2008); while four years before, Qatari Diar company has announced the first green building rating system "QSAS", which stands for Qatar Sustainability Assessment System, which has later changed to "GSAS" referring to Global Sustainability Assessment System (A.M., 2011).

1.5. Circular Economy & Qatar Practice in FIFA World Cup Stadiums

Circular Economy (CE) is the model based on the take, make, use, reuse\recycle\reproduce\remanufacture, which is being the area of interest for the majority of the architecture, engineering and construction (AEC) practitioners and researchers; due to its ability to control the use of raw material, waste production, gas emissions, and many other sustainability aspects, which is considered to be the model to replace the current linear methodology of take, make, use, dispose (Hukoomi, 2021 accessed on December 2021.;Kirchherr et al., 2017; Köhler et al., 2022); in Qatar, the CE model has been taken a significant notice of the government and decision-makers in the field to align the practice in the construction field with Qatar National Vision 2030, and FIFA sustainability considerations and measures to more sustainable mega event.

In order to fulfill the mega event of FIFA world cup 2022, Qatar has constructed Eight World Cup stadiums namely, Al Janoub Stadium, Alkhor (AlBayt) Stadium, Lusail Stadium, Qatar Foundation (Education City) Stadium, Ahmad Bin Ali Stadium, Khalifa International Stadium, Al Thumama Stadium and Ras Abu Aboud Stadium "RAAS" which was later renamed to be 974-stadium.

974-stadium has been built in Al Corniche, Doha, Qatar, with a gross capacity of 40,000 spectator (Hukoomi, 2021 accessed on December 2021), the stadium is promoting the idea and concepts of the Circular Economy model in an innovative way (*Ras Abu Aboud Stadium (A Pioneer in Stadium Development) | FIFA World Cup*, 2021; *Turning Old into New: Al Rayyan Venue's Sustainability Experience | See You In 2022*, 2020.), considering the use of shipping containers, and the concepts of the Design for Disassembly, where the whole stadium will be dismantled, transferred and reused for other purposes after the end of the FIFA world cup 2022 event (Kucukvar et al., 2021a; Kucukvar et al., 2021b), and the material used in the construction of the stadium will be re-utilized.

This thesis proposed a comprehensive case study that will be used to utilize the practical concepts and methods used to achieve this CE concepts; and understand the whole information management cycle followed and implemented by the appointed parties worked in the design and construction phases of the project, considering the valuable utilization and use of Building Information Modeling\Management technology to help achieving the purpose.

The design and construction concepts and methodology pillars of the case study project can be summarized as follows:

1. Circular Economy Model Considerations.
2. Design for Disassembly for decreased waste
3. Design for Disassembly for a maximum reuse
4. Steel Structure use
5. BIM technology and information management
6. Material Passports
7. Sustainability Measures
8. Project Life Cycle Stages.

1.6. Building Information Modeling

BIM is a process for creating and managing information on a construction project throughout its whole life cycle. As part of this process, a coordinated digital description of every aspect of the built asset is developed, using a set of appropriate technologies. It is likely that this digital description includes a combination of information-rich 3D models and associated structured data such as product, execution and handover information; Internationally, the BIM process and associated data structures are best defined in the ISO 19650 and 12006 series of standards (*What Is BIM? | NBS*, n.d.)

To ensure that the information produced throughout the project life cycle stages, BIM is built on a well-structured information management cycle considering all the objects and methodologies that will bring the maximum value and benefits to all project teams and stakeholders involved in the Design, Construction and in use (operation) phases of the project, by building a well-coordinated and structured information production platform, environment, and information exchange procedure (*What Is BIM | Building Information Modeling | Autodesk*, n.d.; *What is BIM? | NBS*, n.d.) .

1.7. BIM Standards

Like other industry subdivisions, authorities and standards authors have recognized the importance of developing the underlying ground roles; to support teams and stakeholders working in the construction field who aim to utilize BIM in their process, and have established, authored, published and maintained a set of important BIM related standards, like but not limited to the following set of standards mentioned in THE National BIM Standards (*Building Information Modelling (BIM) | Information Management | BSI Middle East and Africa*, n.d.-a; *What Is BIM | Building Information Modeling | Autodesk*, n.d.):

1. ISO 16739-1:2018 concerned of data sharing,
2. ISO 12006-2:2015 which is a framework for classification.
3. Uniclass 2015, the UK BIM classification system
4. ISO 23386:2020, focuses on BIM and other digital process used in construction.
5. ISO 19650 series in consideration of BIM processes, with a basis of PAS pack of standards.

With other BIM standards followed worldwide the above set of standards are among the most famous ones followed and are being followed in Qatar.

1.8. BIM in Practice

BIM industry is being developed rapidly with additions and amendments of the standards, requirements and methodologies involved in the process, including the vocabs and glossary to be known and clear for the participants in the industry as a solid base to build on (Kensek, 2014).

According to (Groh & Dubik, 2018), The construction industry is widely fragmented, and the information production is built on the production of the traditional two-dimensional (2D) drawings, which usually results in errors and clashes among the building disciplines, which causes huge amount or rework, costs overruns and delays, while the solution for such a serious gap in practice; is to use a comprehensive collaborative process offered by using BIM.

In order to utilize BIM in its ultimate benefits procedures and concepts, practitioners need to familiarize themselves with BIM glossary and vocabulary, to mention few, BIM dimensions, BIM Levels of Maturity model, Level of Definition/Development LOD, Level of Details LoD, Level of Information LOI, BIM Object, Common Data Environment CDE, BIM Preliminaries, BIM Execution Plan BEP, BIM Exchange Information Requirements EIR, BIM Protocol, Model Element Definition Matrix MED, and many other Vocabs (*22 Terms in BIM You Should Know – Bim Corner*, 2019).

1.9. BIM Uses in Mega Projects in Qatar

Most of the governmental Projects in Qatar are being managed through Qatar Public Works Authority "PWA" ASHGHAL, which has developed their standards and procedures regarding the best practices and the Exchange Information Requirements in the projects they manage or build as a client; to get the most value out of using BIM among their projects.

ASHGHAL is the highest construction authority in Qatar when it comes to public projects, whom has already shifted their projects to be built as per the most updated and beneficial international standards, including building information modeling “BIM” requirements, through providing the employer/exchange information requirements “EIR” documents with the tender stage documents; for the information and consideration of the consultants and contractors working on their projects, PWA is also mentioning all the objectives and BIM uses they want to achieve in their projects or project phases (Public works authority, ASGHAL, Qatar, Employer Information Requiremets (EIR), 2022), which are mentioned in the table 1 below:

Table 1 BIM uses in Qatar construction projects

No.	BIM use	G1	G2	G3	G5	G6
1.	Existing Site Conditions Modelling	☑			☑	
2.	Design Reviews					
2.a	Site Analysis	☑				
2.b	Design Options		☑			
2.c	Accessibility Studies			☑	☑	
3.	Design Coordination					
3.a	3D Coordination, & Clash Analysis			☑	☑	
3.b	Interface Coordination				☑	
3.c	Virtual Mock- Up				☑	
3.d	Visual Method Statements				☑	
3.e	Sustainability Compliance (GSAS)			☑	☑	
4.	Drawing Production			☑	☑	☑
5.	Measurement					
5.a	Quantity Takeoff			☑	☑	

Table 1 BIM uses in Qatar construction projects

5.b	Material Inventory & Procurement Management			☑	
6.	Construction Planning				
6.a	Phase Planning	☑			
6.b	Schedule Compliance (4D)			☑	
6.c	Progress Monitoring			☑	
6.d	Constructability Review			☑	
6.e	Logistics Planning			☑	
6.f	Health & Safety Support			☑	
7.	Cost Management				
7.a	Cost Estimation (5D)		☑	☑	
7.b	Value Engineering		☑	☑	
8.	Engineering Analysis				
8.a	Structural Analysis		☑	☑	
8.b	Lighting Analysis		☑	☑	
8.c	Energy Analysis		☑	☑	
8.d	Mechanical Analysis		☑	☑	
8.e	Other Engineering Analysis		☑	☑	
9.	Asset Handover				
9.a	As- Built BIM			☑	☑
9.b	Laser Scan Verification			☑	☑
9.c	Field BIM (Site Forms & Asset Tagging)			☑	☑
10.	Emergency Response				☑

Table 1 BIM uses in Qatar construction projects

11.	Asset Management			
11.a	Asset Information Modelling			☑
11.b	COBie (V2.4) Integration	☑	☑	☑

G1 Initiation, G2 Pre-design, G3 Design, G5 Construction, G6 Project closure.

Source: **BUILDING INFORMATION MODELLING (BIM) ASHGHAL EXCHANGE INFORMATION REQUIREMENTS** - 08c Volume 2 Schedule A Part 2 Appendix 3 - PWA EIR CONSTRUCTION-V3.0

Considering the above-mentioned BIM uses, the project owner can guarantee an efficient BIM process throughout the well-structured BIM execution plan BEP, and BIM management plan.

From the above list, user can figure out the BIM uses which can support the purposes of circular economy and sustainability practices, like but not limited to Existing Site Conditions Modelling, Site Analysis, 3D Coordination, & Clash Analysis, Virtual Mock- Up, Visual Method Statements, Sustainability Compliance “GSAS”, Quantity Takeoff, Material Inventory & Procurement Management, Constructability Review, Cost Estimation (5D), Value Engineering, Engineering Analysis, As- Built BIM, Laser Scan Verification, Field BIM (Site Forms & Asset Tagging), Asset Information Modelling, COBie (V2.4) Integration.

1.10. FIFA World Cup Stadium as a Case Study

As mentioned in the above sections 974-stadium is one of the most important projects among the Eight FIFA world cup 2022 stadiums that Qatar has built considering the CE, Material Passports (MP) and the use of BIM technology, as it has been built to be dismantled, transferred, and reused; using shipping containers and steel structure as the main element of design.

The owner has developed their own BIM standards, procedures, BIM management Plans, Exchange Information Requirements and many other BIM management Documents, Procedures, workflows and road maps in line with the international BIM standards, sustainability measures and CE concepts and requirements; to ensure the achievement of the sustainable practice and goals, while constructing all the projects in relation with the mega event of FIFA world cup 2022, which will be used as a case study to support the objectives discussed in this thesis, and to develop a comprehensive workflow and model that serves the purpose of CE in maximizing the ability to reuse, manufacture, and recycle of building construction material (Prabhakaran et al., 2021).

In this thesis, the author decided to thoroughly study and analyze the case of FIFA world cup stadiums program, its information management model, BIM procedures, objectives, and achievement.

1.11. Problem Statement.

While studying construction industry effect on the international economy, environment and sustainability development goals factors and main pillars, as well as the negative impact of the resources consumptions caused by the construction sector activities and computer aided design “CAD” traditional information management and exchange methodologies, it was found that the construction industry is one of the top sectors involved in the high resource consumption level, waste generation, time, and human resource consumption activities; when it comes to the current linear construction model, it failed to solve the problems of consumptions of resources, environment and the generation of waste, therefore industry practitioners and researches has noticed the importance of using a new sustainable model that can solve the problem, namely the circular economy model, built on the idea of take, make, use, reuse\recycle\remanufacture; through the use of the latest design and construction technologies, which can work effectively in all the project lifecycle stages, starting from initiation, brief, concept design, preliminary design, technical design, construction and manufacturing, hand over, and the use stage, and due to the booming spread of the effective use of building information modeling technology in the industry; it was found that it is the efficient management system that can serve the purpose of authoring, recording and measuring the desired circular design and construction of an asset.

The research proposal will be focusing on studying a real project case study that has been considered as an iconic mega project; built to achieve circular economy objectives through the use of design for dismantling concepts, material passports and building information modeling, in the second part of this thesis the author will be building and developing a model of a construction project using the finding and results of analyzing the real project data, and will be designing and using a survey which will be distributed to specific industry professional practitioners with various experience and backgrounds in the field of:

1- Construction
2- Design
3- Building information modeling and management
4- Circular economy
5- sustainability
6- Academia

The built model will be developed and authored based on the analysis of the huge amount of data, information, management documents, and BIM models collected from a real project in Qatar, and the literature reviewed, in addition to the survey recommendations and results, trying to find the ideal and best practice workflow that might be beneficial and supportive when it comes to achieving, authoring, recording, and measuring the circularity of design, construction and project digital modeling.

1.11.1. Research Question

There were many problems that have been identified as a result of the literature of this proposal; namely:

1- Most of the literature papers and research reviewed, did not analyze real world scenario case studies, and did not propose a practical model on how to use building information modeling in a practical way to implement, measure and record circularity of the built asset.

2- The literature did not identify a well-structured analytical framework and roadmap to clearly record and track the percentage of circularity of the design and construction of an asset.

3- It was difficult to find a real case study in the real practice where the practitioners have implemented the requirements of CE parameters to produce circular construction.

4- To the best knowledge of the author there is a huge gap between the circular economy basic components requirements and what is being done in real projects, to name some:

   a. Material passports

   b. Design for disassembly

c. The use of BIM management proper workflow, management documents and methodology.

d. Clear employer and exchange information requirements.

5- It was clearly identified that communication and integration is not being done in a proper efficient way, specifically in a project where circular economy and building information modeling and management are required.

1.11.2. Research Goals and Objectives

Investigating on the most appropriate workflow model in a real-world scenario and fining the steps of achieving circularity of built components of a project, or record and measure the circularity of the asset, and then build an enhanced BIM workflow model and road map that will support the authoring, recording, and measuring the circularity of built assets. Therefore, the research goals and objectives might be summarized as follow:

1- Identify the gaps in literature and practice about the connection between the circular economy practice in construction industry, sustainability, and the utilization of BIM workflow.

2- Involving professional industry practitioners in identifying the gap in the practice and finding the best workflow recommendations to utilize building information modeling in supporting the decision making of sustainability and circularity of built assets.

3- Analyze a real-world project BIM management documents and BIM models and find the strengths and weakness to identify the gaps, and suggest a developed work frame model to support the utilization of BIM in an efficient way to support sustainability and circular economy decisions.

4- Building a best practice model and workflow supported with findings and results from analyzing real-world projects and a special model developed for the purpose of supporting the objectives and findings of this proposal.

1.11.3. Research Scope.

To accomplish the research's goals, the author will gather data, analyze a real-world project BIM management documents and models, develop a project BIM model, and build valuable work frame results; that will assist decision-makers in making better judgments and decisions on circularity and sustainability of project components in both design and construction project stages, then developing new model and workflow based on the research's findings. (See methodology structure in methodology section of the proposal).

Following are the details for each phase:

- Collect BIM management and employer information requirements documents from real-world project case study in Qatar, international industry standards, and available literature.
- Read the collected data and analyze the collected international standards documents, management documents and BIM models.
- Develop a project model and management documents based on the findings and observations of the analysis of the collected data, then create the needed circularity parameters and fill the collected information from the industry organizations and professionals, to create the supporting schedules which will be used to identify the circularity ranking to support decision making. AUTODESK Revit software will be used to develop the built model.
- Design a well-structured survey and distribute it among specific construction professional practitioners to support the thesis results and recommendations by a real professional construction engineer and specialist’s input.

- Build and provide a best practice work frame and methodology to help the construction professionals in the utilization of BIM to support the analysis, measurement, record, enhancement of sustainability and circularity ranking of construction projects.

CHAPTER 2: LITERATURE REVIEW

2.1.Environment and Emissions

Qatar Vision 2030 fourth Pillar “environmental development” has put the country on the track of raising its sustainability requirements and ranking system and the way should be followed to achieve the vision goals and objectives, (The State of Qatar seeks to preserve and protect its unique environment and nurture, the abundance of nature granted by God. Accordingly, the development will be carried out with responsibility and respect, balancing the needs of economic growth and social development with the conditions for environmental protection),(*QATAR NATIONAL VISION 2030 ADVANCING SUSTAINABLE DEVELOPMENT QATAR’S SECOND HUMAN DEVELOPMENT REPORT GENERAL SECRETARIAT fOR DEVELOPMENT PLANNING*, 2009).

Being a growing country in the last 10 years and winning the hosting of FIFA world cup 2022 event, Qatar has increasingly invested in the construction sector which is among the most prominent industry fields that contributes to a vital environmental impact share (Moubaydeen et al., 2013).

According to (Al-Hamrani et al., 2021; Marie & Quiasrawi, 2012; Tafheem et al., 2011), Concrete is the most used material in construction in which 6 million metric tons are produced worldwide; resulting in huge raw materials consumption, needless to mention the resulting production of CO_2 and Green House Gas (GHG) emission, the second largest emitter and 1/3 emitter respectively (Ürge-Vorsatz & Novikova, 2008).

2.2.Construction resource consumption and building sector CO_2 emissions

According to Breene, Formative Content article on weforume.org (*Can the Circular Economy Transform the World’s Number One Consumer of Raw Materials? | World Economic Forum*, 2016); the construction industry is the largest material consuming sector with about 50% of steel annual production globally, and around 3 billion of raw materials usage, while a 40% of solid waste is generated from construction and demolition activities.

Referring to the GLOBAL alliance for buildings and construction and the UN environment program – 2020 (UN Environment Programme, 2020), global status report for buildings and construction towards a zero-emissions, efficient and resilient buildings and construction sector in order to achieve the 2050 target of a net-zero carbon building stock, we need a reduction of 50% and 60% of the direct and indirect CO2 emissions from the buildings and buildings sector in emissions of power generation respectively by 2030, as per the international energy agency "IEA". in other words, we need to reduce 6% of building's sector emissions annually from 2020 to 2030, but it is clear to the observers that the CO2 emissions from the building operation has reached its highest level of 28% of total energy-related CO2 emissions globally, but when it comes to the buildings sector only it increases to touch the 38% level of the global CO2 emission in 2019.

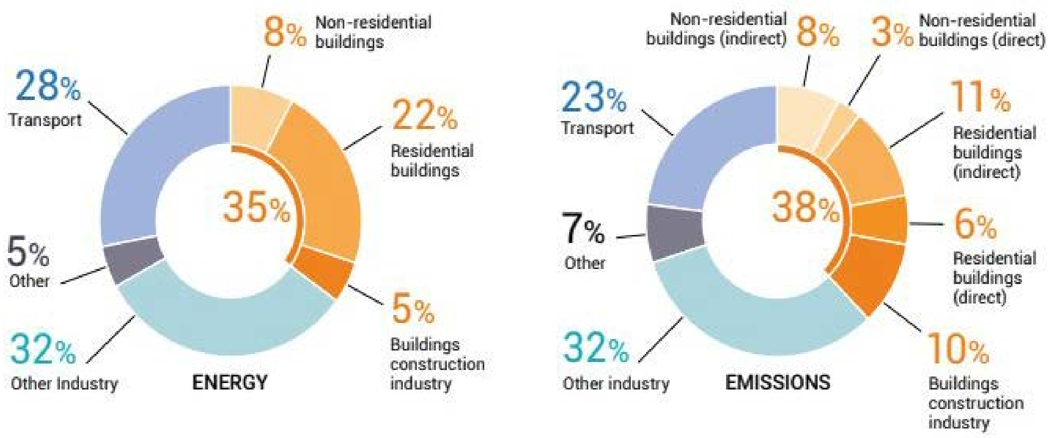


Figure 1 Global share of buildings and construction final energy emissions 2019

2.3.Material Waste

Due to hosting the FIFA world cup 2022 in Qatar and the development vision 2030, Qatar has become a construction booming country since the last decade; resulting in a noticeable record in raw material consumption and waste generation, Qatar Development Bank “QDB” in their report (MATRIALS RECOVERY) released in 2017 has highlighted the percentage of material waste generated in Qatar in 2016 by segments namely, Metals, Plastic, Paper, Rubber, E-waste, Glass, Waste oil with percentages of 86.9%, 8%, 1.6%, 2.1%, 0.2%, 0.4%, 0.4%, 0.4%, and amounts of 8.870, 0.819, 0.165, 0.213, 0.020, 0.042,0.038, 0.037 Million tons respectively.

According to Gulf Organization for Research & Development “GORD” and the Supreme Committee for Delivery and Legacy (SC) in Qatar report; waste management best practices for construction – case studies from FIFA world cup Qatar 2022 stadiums, April 2021, in the most developing countries waste generation can reach up to 70% of the total generated waste, with many types like but not limited to, organic waste, paper, word, plastic, soil, steel, and concrete (*FIFA World Cup Qatar 2022 TM | Sustainability strategy* , 2019).

In Qatar, there is a huge attention to the construction sector waste and waste management, especially with the release of Qatar National Vision 2030, Qatar National Development Strategy 2018-2022, and the FIFA world cup 2022 sustainability requirements. Where a huge attention to the same started to take place from the very early project stages from the initiation, briefing, conceptual design, technical design, design development and project construction to the closing, commissioning and handing over, and the project operation phase and the end of life decision, which has brought to construction gurus attention to the technologies which will help in sorting this issue out and boosting the productivity and efficiency towards achieving this sustainable target, therefore the majority of governmental projects, FIFA world cup 2022 projects have mandatory requirements of using building information modeling BIM from the early stages of the project.

According to (GORD and Qatar construction records) waste is estimated in many approaches, one of them is the BY STREAM ESTIMATES, which estimates waste amounts by stream, which shows that Concrete has the highest percentage of waste among all other streams, with a 70.00% and 45.50% for weight and volume respectively in Qatar in FIFA world cup stadiums, which shows a main concern either on using Concrete in construction or recycling concrete if used; in order to increase the amount of material recycling and achieve more sustainability goals (*WASTE MANAGEMENT BEST PRACTICES FOR CONSTRUCTION SITES Case Studies from FIFA World Cup Qatar 2022TM Stadiums*, 2021).

2.4.Material Waste Management in Qatar

To achieve high sustainability standards in the FIFA world cup 2022 stadiums, SC has followed GSAS-CM guidelines and best practices, which has involved all the project stakeholders in the process from zero to hero.

The client, the designer, and the contractor in all the project stages, from planning, to subcontracting, construction, site audits, and handover, SC has also mandated the waste segregation, following a strict strategy that guarantees achieving the waste management and construction management plan, namely, Selecting Waste Segregation Areas, Labeling Waste Stream Containers, Covering Light Waste Skips, Storing Hazardous Waste Separately, Collecting Waste from High Floors, Hiring Authorized Waste Haulers, Disposing Waste at Authorized Recycling Facilities, and Waste Tracking System (Manzoor et al., 2021).

Through their project requirements files shared with the tenderers Qatar Free Zones Authority QFZA has highlighted clearly their objectives towards waste materials in their projects like but not limited to; (a) Minimizing the generation of construction waste at the site, (b) Maximizing the re-use and recycling of construction waste on site, (c) Adopting appropriate ways and means for handling the generated construction waste on site and (d) Solid waste generated during the construction or operation should be collected, segregated and disposed in coordination with the concerned department (QFZA, Construction manual, 2009).

The goals and objectives mentioned above can be achieved by:

1. Minimizing the generation of construction waste at the site by:
    a. Considering the waste issue during the design and planning stage,
    b. Designing with a view to minimizing the need for excavations,
    c. Adopting construction methods that generate little waste,
    d. Avoiding placing too large orders of construction materials that might result in generation of waste.
2. Maximizing the re-use and recycling of construction waste on site
    a. Using excavated materials as fill material.
    b. Building systems to separate storage and collection of waste that can be recycled.
    c. Establishing a system for recycling of construction waste on site.
3. Adopting appropriate ways and means for handling the generated construction waste.

2.5. Material Prevention in Qatar

According to ("Fire Prevention Department General Directorate of Civil Defence Ministry of Interior, State of Qatar," 2015; British Standards *BS 7121-5_2019*

Code of Practice for Safe Use of Cranes. Tower Cranes - CivilNode.Pdf, 2019;Qatar Construction Specifications, 2014; Rev, 2021) Qatar Construction Practice is mainly evolving around the concept of avoiding waste generation in construction projects, and reducing the amount of waste generated in the first place, i.e. reduce the job needed resources, Qatar has followed a successful criteria and concept principles to achieve the target through the following measures:

1. Maintaining a tidy site that can minimize waste generation.
2. Storing construction material at site in a safe manner minimize waste.
3. Using locally available material wherever possible.
4. Order materials in bulk – to reduce packaging.
5. Purchase materials with minimum of packaging waste to dispose of.
6. Plastic drums, empty plastic bottles, scrap metal, batteries, wastepaper, and waste oil will be segregated on site and sent to recycling.
7. Contractor should re-use as much material on site if practicable.

2.6.Sustainability Development Goals SDGs

The continuous population growth and it's impacts and influences on the natural and environmental resources, as well as the quality of life and human well-being; the orientation to finding solutions and methodologies to reduce the reduction in life quality, environmental and natural resources, equality and inequality, and many other aspects has raised and came to the field of concern of environmentalists and sustainability activists; where 17 Sustainable Development Goals (SDGs) for the year of 2030 have been implemented by the United Nations (UN) in 2015, in respect to Food, Water, Energy, Climate Change, and Ecosystem (SDG 2, SDG 6, SDG 7, SDG 13, SDG 15 respectively) (Yue et al., 2021).

According to the United Nations (UN) the 2030 Agenda for Sustainable Development has fife main areas of critical importance for humanity and the planet namely, people, planet, prosperity, peace and partnership , which will take action over the coming fifteen years (*Transforming Our World: The 2030 Agenda for Sustainable Development | Department of Economic and Social Affairs*, 2015).

The Planet area main concern is to protect and safe our planet from degradation through the sustainable consumption of resources as well as their production, on the other hand taking care and pay attention to the sustainable management of the natural resources and taking actions towards the climate changes, while the prosperity area focuses on ensuring that all human beings can enjoy flourishing lives, and also focusing that the three main live aspect; economic, social and technological progress are harmonized with nature (Baeyens & Goffin, 2015).

As mentioned in the sections above, considering construction as a main sector for resource consumption, material waste, gas emissions, technology-based field, non-sustainable field, it came to the main frame of natural activists to utilize all the potential technologies to serve this sustainable goal, therefore the usage of BIM has become a booming field of interest, which will also be used in this study.

Out of the SDGs mentioned in Fig. 2 as per the United Nations agenda, there are Seven Main Goals shown in table 2.

Figure 2 United nations sustainability development goals

Table 2 Sustainability Development Goals related to this study

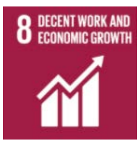
No.	Title	Icon	Goal
SDG 7	Affordable and clean energy		Ensure access to affordable, reliable, sustainable, and modern energy for all
SDG 8	Decent work and economic growth		Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all

Table 2 Sustainability Development Goals related to this study

SDG 9	Industry, innovation, and infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
SDG 11	Sustainable cities and communities	Make cities and human settlements inclusive, safe, resilient, and sustainable
SDG 12	Responsible consumption and production	Ensure sustainable consumption and production patterns
SDG 13	Climate action	Take urgent action to combat climate change and its impacts
SDG 17	Partnerships for the goals	Strengthen the means of implementation and revitalize the global partnership for sustainable development

2.7.Circular Economy, SDG's and Construction industry

Construction sector is a vital one which cannot be either stopped nor slowed down; due to the continuous growing demand on the sector by the continuous and fast increasing population worldwide; which has made this sector a main participant in the continuous environment pollution resulting from the Architecture, Engineering and Construction (AEC) industry and the built environment, and due to the finite available natural resources and raw materials that the industry absorbs, and the waste generated by the AEC activities, and the continuous extraction of raw materials to serve the sector, found in the Linear Economy and construction systems which is built around the concept of the take, make, use, dispose model, plus the little effort to minimize that, the industry experts have paid more attention to the transmission to a more sustainable and economical system that might serve to achieve the UN SDG's vision, and to be built around the concept of the minimization and reduction of the raw material extraction, less pollution, less cost, and faster grow, and they have started shifting to the take, make, use, reuse\reproduce\remanufacture, model in a circular loop based on the circular economy model (Eisfeldt & Ciroth, 2017; Ogunmakinde et al., 2022; Stason, n.d.).

According to (Ogunmakinde et al., 2022) there were about 137.8 million tons of construction and excavation waste generated in 2018. And the table 3 shows more insights on the construction waste scene, with the importance to note that less than one-third of the waste generated from the construction industry is being either reused or recycled.

Table 3 Amount of construction and demolition waste generated per year and region.

No.	year	Amount of construction waste generated (tons)	Country/region
1	2018	137.8 million	UK
2	2018-2019	12.7 million	Australia
3	2018	2.36 billion	China
	2018	600 million	USA
4	2017	5.4 million	South Africa
5	2016	12.7 million	Finland

2.8.BIM for Circular Economy concept in construction and sustainability

According to the British Standards Institution BSI group *(Building Information Modelling (BIM) | Information management | BSI Middle East and Africa*., n.d.) , BIM (is the management of information through the whole life cycle of a built asset, from initial design all the way through to construction, maintaining and finally de-commissioning, through the use of digital Modelling. It's all about collaboration - between engineers, owners, architects, and contractors in a three-dimensional virtual construction environment (common data environment), and it shares information across these disciplines).

With the wide range of benefits that BIM offers in the context of the AEC industry, especially in the construction phase and the facility management and the end of life decision; namely, fast and efficient process, increased productivity of resources, faster delivery, increased certainty, controlled whole-life costs, controlled environmental data, monitored and managed resource logs and BOQs, avoidance of rework, improved safety solutions and management, reduced waste, and prevention of errors and clashes, BIM is being the booming industry solution to be used throughout the whole project life cycle stages; to better manage the project processes, from initiation, planning, to executing, monitoring and controlling, handing over and closing and also in the operation and in use phase and the end of life decision; using the well-structured data and information base models, drawings, common data environment (CDE), reports, spread sheets, material passports and many other information based deliverables, which are valuable to be used for a decision making at the time needed, with wide range of information accessibility systems and permission levels (Kamyab, 2018).

The AEC industry experts are more open to more technological and sustainable solutions with specific industry standards that enhances the procedures, and guarantees the smooth authoring and production of information; therefore BIM is used due to being supported by a group of well-structured industry standards, like the ISO 19650, PAS 1192, BIM forum LOD specifications and the UK national BIM standards, and many other standards suites, that help the acceleration of BIM adoption on the international level with the same quality level; which can be applicable across the life cycle of any building and infrastructure project from design to handover, operation and maintenance phase, and the end of live decision making support (Manzoor et al., 2021)

In other words, BIM can be considered as the foundation of the digital transformation in the AEC industry to a better information management and production system, with its wide range of management, model authoring tools, clash detection and analysis tools, BOQ generation tools and much more.

According to Groh and Dubik (Groh & Dubik, 2018). in their Thesis Report, there are 4 pillars to orient construction projects to a more circular, sustainable, and technological approached, named in series: Circular economy “CE”, design for disassembly “DfD”, material passports, and BIM.

As long as the circular economy model promotes the maximum amount of reuse and\or recycling of materials and goods used in the life cycle of the project, and reduce the waste of the construction and demolition processes (considerably in the construction and end of life of the project); a high-end technological tool is needed to record all the information needed to serve and achieve the CE target ; which is BIM, through the more circular practices by the use of Material passports recorded and produced accurately from the project models, as well as using more sustainable design approach and intents through the use of the DfD techniques, tools and concept approach (Sassanelli et al., 2020).

In Qatar most of the governmental and mega investor entities have already shifted to mandate BIM in their projects by providing this obligation and required documents in their tender documents, so contractors and consultants be aware of the BIM requirements from the pre-tender phases of the project (Gerges et al., 2017), like but not limited to the Supreme Committee for Delivery & Legacy “SC” and public work authority ASHGHAL “PWA” in all their projects, Hamad international Airport “HIA”, Qatar Airways, Qutiefan Projects in their Quteifan Island Project in Lusail, Lusail City projects, United Development Company “UDC” in some of their projects in the Pearl in Qatar, Ministry of interior “MOI” in some of their projects, Hamad medical city in some of their projects, and many other entities; and all of them are following the international standards mentioned above as well as QCS 2014, GSAS requirements, Qatar Construction Standards and Global Sustainability Assessment System for their project BIM requirements and procedures and BIM uses on the projects.

2.9.Use of BIM Software to Achieve Circularity in Building Construction

As a result of the huge and wide range of abilities and powerful tools BIM has, like but not limited to Autodesk Revit, Autodesk Generative design tools, Autodesk Parametric Design solutions, Autodesk Navisworks, Autodesk solidworks, Autodesk Infraworks, Autodesk Civil 3Ds, Bentley products, Asset Lifecycle Information Management, SketchUP, BIM 360 Collaboration platform, Common Data Environment “CDE” platforms, and many other industry solutions, BIM has become the used concept, tool, and technique towards boosting the use of its procedures towards achieving construction circularity (*BIM Software Tools for all Occassions*, 2019).

To their point of view, Groh and Dubik (Groh & Dubik, 2018) in their Thesis Report, have concluded valuable results in this field, could be summarized in their conclusion section that the advantages of using BIM for Construction CE would be successful through the Design for Disassembly, due to its ability to orient the design efforts towards a more circular construction process during the design stage, and through the whole life cycle stages, which can easily happen through the process of storing the needed comprehensive information about the reusability of components, elements\assembly break down structure, disassembly methodology, and other needed information, which should be done through the use and production of accurate material passports as a cohesive whole\store for the CE data.

Practically the CE could be implemented and achieved successfully via the use of the cloud-based BIM authoring, collaboration, and management tools, which can support the ability to store data and information among the project elements, and within all the project trade and sub-trade models, namely, Architecture “AR”, Interior Design “ID”, Structure “STR”, Mechanical “Mech”, Electrical “Elec”, Plumbing “Plum”, Landscape “LS”, Infrastructure “Infra”, and any other utilized discipline, with the ability to add, remove, edit and develop any needed parameter, attribute or piece of Graphical or non-graphical information needed for the CE achievement (Charef & Emmitt, 2021; Xing et al., 2020).

These tools, software, and platform should involve the ability of accessing the information whenever needed, where ever needed, and by whom ever needs the information, covering all the stakeholder types, interests, influence and power towards the circulatory of the project and it’s components, which will automatically enhance the level of interest and engagement by the stakeholders themselves; to support the CE procedures and techniques confirmed in the project, through the whole building’s life cycle stages, this will allow the information storing process to be done gradually through the project phases, and to enhance the communication and stakeholder engagement among the process, as long as applying this concept of CE is a shared responsibility between all the project parties; starting from the clients to the designer, consultant, contractor in addition to the manufacturers and authorities (Salvioni & Almici, 2020).

Multi-advantages and positive results might be generated of using BIM tools and software to successfully achieve circularity in the construction projects ranging from boosting productivity, to simplifying and standardizing the information authoring and production procedures, reading information easily when needed, in addition to simplifying coordination and information communication procedures and making information more structured and more feasible to be used for the aim of circularity, which will result in decreasing landfill, improving material recycling as long as the engineering team has stored the recycling information within project elements, on the other hand it will enhance and increase the rate of the reuse of construction materials, and lower the waste generated either by construction or demolishing of a facility which will ensure cost reduction of the project (Charef, 2022; Xue et al., 2021).

2.10. Gaps in Literature

While reading enormous amount of papers and thesis proposals on the topic of circular economy in construction industry, and the contribution of BIM in supporting the circular approach in this sector, it was found that the majority of research papers has identified many areas of application of both CE and BIM to better produce circular buildings, as well as scratched the surface on how to use BIM to improve circularity of construction, but to the best of the author knowledge and efforts of analyzing the read literature, it was noticeably found that the majority of the literature did not analyze real world scenario case studies, and did not propose a practical model on how to use building information modeling in a practical way to implement circular economy practice and well-structured analytical framework and roadmap; to clearly record and track the percentage of circularity of the design and construction of an asset, even in the real practice it was difficult to find a real case study where the practitioners have implemented the requirements of CE parameters to produce circular construction, for example design for disassembly, material passports, and manufacturer manuals, and many other aspects were mentioned in the literature, but was not implemented in a real construction or design BIM model, as well as volume segregation, employer requirements, construction and BIM teams setup, communication and integration was not discussed deeply to get the best recommendations for the best practice recommended, especially from the real world professionals and practitioners.

Therefore the author decided to involve a real project case study in Qatar, and a real project built model for the purpose of this research thesis, as well as a well-structured survey which was distributed among specific design, architecture, engineering and construction professionals and real practitioners with various years of experience in the field, focusing on plus five years of experience practitioners in the fields of architecture, construction, building information modeling, sustainability, and circular economy.

CHAPTER 3: METHODOLOGY

3.1. Overview

This Chapter of the proposed thesis will clarify the methodology used to setup the structure of this thesis. It started with browsing the literature for gathering data from the relevant resources, authorities, and industry firms working in related fields of construction, BIM, CE and construction technologies. Then a related real project case study was studied; to understand the BIM management procedures. this is a vital part of the structure as it provides a real world accepted scenario, which proved its success in the areas related to the proposal problem. later in the next part of the methodology, the author applied the studied concepts and management procedure to a project case to study the resultant information, model, and BIM practice outcomes. The author used BIM management preliminaries documents collected; like but not limited to the BIM exchange information requirements (EIR), BIM execution plan (BEP) and BIM quality management plan; and used AUTODESK REVIT and AUTODESK BIM 360 collaboration platform. In the next part, the proposal conducts resulting outcomes of the model built and analyzes the observations and results. In parallel the author conducts a survey distributed among the industry experts; to get their input and feedback on the model built. Finally, the last part of the methodology; conducted a comprehensive analysis of the results of the gathered and analyzed data and information and the case study, along with an analysis of the built model case, and the survey's results factors and practice procedures. The purpose is to support the field practice to fostering BIM as a tool to be implemented in the Circular Economical Construction field (Circular BIM). Fig. 3 clarifies the proposal methodology components:

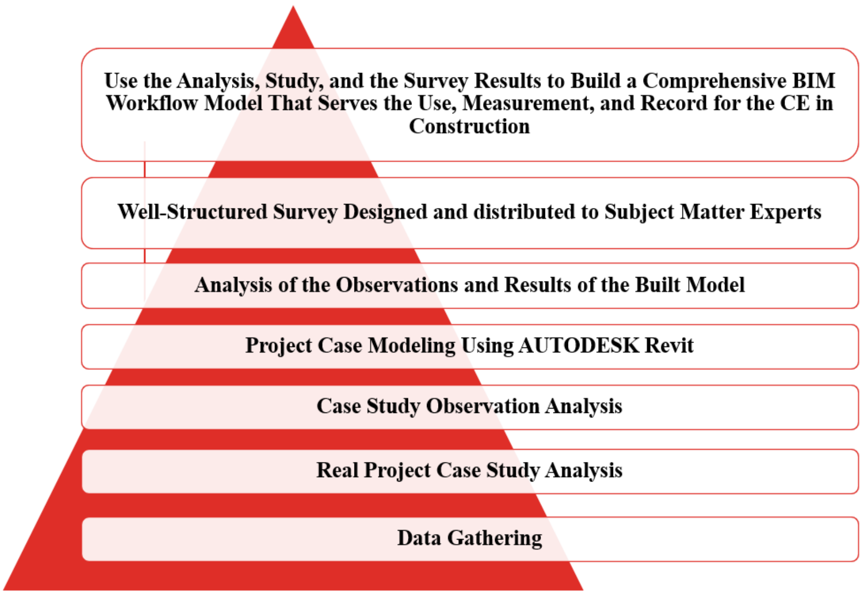


Figure 3 Methodology components and structure

3.2. BIM Management Preliminaries

Understanding the real proven practices starts with gathering the data, analysis of data collected and identifying assumptions. To find out the related best practice pillars; the author has collected all the possible documents and relevant information described as follows:

1- The information authored by the main contractor. Located in Qatar for the purpose of obtaining a comprehensive BIM management approach. The Project BIM standards and employer information requirements have guided the contractor in authoring and developing BIM deliverables. Table 4 shows information and documents gathered from the main contractor on real project case study “FIFA World Cup 2022 stadiums) for the purpose of this thesis:

Table 4 BIM information Gathered from the main contractor

No.	Document Title	Format
1	Element Interaction Matrix	PDF \ Excel
2	LOD Matrix	Excel
3		
4	LOD Specifications	Excel
5	BIM Document Registers	PDF \ Word \ Excel

Table 4 BIM information Gathered from the main contractor

6	BIM Manual	PDF
7	BIM Volume Strategy	PDF \ PPTX
8	BIM Organization Chart	PDF \ Word
9	Shop Drawings Sample	PDF
10	BIM management Plan	PDF \ Word
11	Design Validation Check Lists	PDF \ Word
12	Drawings Quality Check Lists	PDF \ Word
13	BIM Model & Sheet Quality Check Lists	PDF \ Word
14	Sample Audit List	PDF \ Word
15	BIM look Ahead Plan	PDF \ Excel
16	Weekly Progress Presentation	PDF
17	Design Team Interim Presentation	PDF
18	Functional Spaces and Installations Schedule	Excel
19	General BIM Audit Report	PDF \ Word
20	Virtual BIM 4D Audit Report	PDF \ Excel
21	Area Comparison Sheet	PDF \ Excel
22	RFI’s & Responses	Word \ PDF \ JPEG
23	Engineering BIM Training	Excel
24	Construction Execution Plan	PDF

2- The information and documents covering the BIM management preliminary documents, management plans, project BIM requirements related to real projects built by the Client, for the FIFA World Cup 2022 Stadiums; like, Al Thumama stadium, Al Janoub Stadium, Lusail Stadium, Al Bayt Stadium, Qatar Foundation Education City Stadium, and Ras Abu Abboud Stadium (RAAS) “974-Stadium. Table 5 shows the documents and information gathered from the client.

Table 5 BIM information Gathered from the client

No.	Document Title	Format
1	Model Element Definition Matrix	PDF \ Word \ JPEG
2	BIM Quality Assurance Plan	Word \ PDF
3	BIM Advisory Content	PDF \ Word
4	Asset Tagging & Coding	Excel
5	Client COBie Index	PDF \ Excel
6	GIS Management Plan	PDF
7	Building Information Management	PDF
8	BIM Content Standards	PDF
9	BIM Compliance Report	Word

Table 5 BIM information Gathered from the client

10	Client CDE protocols	PDF
11	Room Numbering Format	PDF
12	Master Deliverables Register – Advisory Content	Excel
13	Document Control Numbering - Collaborative	PDF
14	Maintainable Asset Standard Tagging and Coding Template	PDF
15	Project Handover Record Information	PDF
16	Asset Information Requirements	PDF
17	COBie Reference and Schema	PDF
18	Client Pick list for COBie	Excel
19	BIM Software and Hardware Specifications	PDF

3- The information and documents gathered from the consultants, subconsultants, subcontractors and the BIM consultant teams related to the scope of this thesis showing in table 6.

Table 6 BIM information Gathered From consultants, subconsultants and subcontractors

No.	Document	Format
1	BIM Manual	PDF
2	BIM Manual Report	PDF
3	Volume Strategy Comparison	PDF
4	BIM Quality Process Map	PPTX
5	Clash Detection Template	NWF
6	Minutes of Meeting Agenda Form	Word
7	Minutes of Meeting Form	Word
8	Kick-off Meeting Minutes	Word
9	BIM Submittal Form	Word
10	Submittal Response \ Comments Form	Word
11	GIS Management Plan	Word
12	RFI’s & Responses	Word \ PDF \ JPEG
13	BIM Team Roles, Responsibilities and Authorities on BIM Track	Excel
14	Rooms & Container Data Match - Dynamo	PDF

4- The information and documents gathered from other sources of international reliable firms, institutes and industry standards authorities related to the scope of this thesis showing in the table 7 below.

Table 7 BIM information Gathered other resources

No.	Author \ Owner	Type Of Organization	Country	Document	Format
1	BIM FORUM	Online Forum .org	US Chapter of buildingSMART international mission	LOD Specifications 2014	PDF
2	CSI, CSC	Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC)	US & Canada	Master Format	Excel \ PDF
3	AUTODESK	University and Software developer	US	AEC UK Protocol for Autodesk Revit Model Validation Checklist	PDF

3.3. BIM Revit Model Files

In order to comply to the technical practice requirements, BIM teams should be addressing project needs, challenges, opportunities, strengths and threats. They can find the guidance for the BIM process in the BIM employer information requirements (EIR) authored by the Client. The BIM team later should be implementing the needs in the BIM Revit Files. Therefore, the author of this proposal collected sample BIM Revit Files to understand the conversion to BIM models procedure. Table 8 shows the files gathered for the purpose of this study:

Table 8 BIM Revit Model Files Gathered

No.	Discipline	Software	Version	Format
1	STRUCTURE	Autodesk Revit	2019	.RVT
2	ARCHITECTURE	Autodesk Revit	2019	.RVT
3	FIRE ALARM	Autodesk Revit	2019	.RVT
4	ELECTRICAL	Autodesk Revit	2019	.RVT

3.4. BIM Relevant Standards

To align our research proposal and results to the international best practices and to the industry most common standards; the author of the thesis proposal has also gathered the most up to date related international BIM standard from its reliable sources. The purpose is to align the proposal-built BIM model to the reliable international standards. Table 9 mentions the collected standards documents and a description of each document content.

Table 9 BIM Relevant International Standards

No.	Document Title	Content description	Format
1	BS EN ISO 19650-1_2018	Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling – Part 1: concepts and principles	PDF
2	BS EN ISO 19650-2_2018	Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling - Part 2: Delivery phase of the assets	PDF
3	BS EN ISO 19650-3_2020	Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) -Information management using building information modelling -Part 3: Operational phase of the assets	PDF
4	BS EN ISO 19650-4_2020	Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling - Part 5: Security minded approach to information management	PDF

Table 9 BIM Relevant International Standards

5	PAS 1192-6:2018	Specification for collaborative sharing and use of structured Health and Safety information using BIM
6	PAS 91:2013+A1:2017	Construction prequalification questionnaires
7	PAS Series	Previous version of BIM standard which is withdrawn by the BS EN ISO standards series
8	UK BIM Framework Publication	Information-Protocol-to-support-BS-EN-ISO19650-2
9	RIBA PoW 2020	provide a framework for architects to use on projects with their clients, bringing greater clarity to the different stages of a project. It has evolved over the years to reflect changing trends in project approaches and has become an industry-wide tool.

3.5. BIM Application of the Gathered Data

In the next step, the author has read the data gathered and filtered the information mentioned in the stadium case study. The results are to be implemented in the built BIM project of the thesis, through applicable BIM process. Doing so; the author has concluded that the resultant model should have the following BIM management plan documents to maximize the process benefits on the proposal objectives, the documents needed to be authored are as follows:

1- BIM execution plan

2- BIM manual

3- BIM model element definition matrix

4- BIM quality checklist

5- BIM volume segregation strategy

6- BIM team organization chart

7- Design management plan

8- BIM standards benefit analysis and use road map

9- BIM LOD definition matrix

10- BIM clash detection matrix

11- BIM clash response management plan

12- BIM communication plan

13- BIM common data environment management plan

14- BIM acceptance criteria

15- BIM document control plan and trackers

16- BIM transmittal forms

17- BIM RFI forms

18- BIM transmittal response form

19- BIM RFI response form

20- BIM issue tracking and communication platform

21- BIM issue tracker form

22- BIM design and management tracker and schedule plan

3.6. BIM Revit Model Building Stage

In the next step, to build a reliable model, it has been identified that the model building procedure should be strictly aligned to the planned methodology, approved BIM management documents and procedures. The process should follow the BIM objectives, which in the stadium case presented by the project BIM management plan proposed by the client. In addition to that the model building procedure should be aligned to the confirmed BIM execution plan (BEP), BIM manual, BIM element definition matrix (MED) and other documents mentioned in the previous step.

To maximize the process outcomes; the model should be built in iterations and delivered incrementally. Each increment should be built in a specific level of development; combining the requirements of both the level of detail (LoD) (graphical representation) and the level of information (LOI) needed for each model stage as shown in Fig. 4:

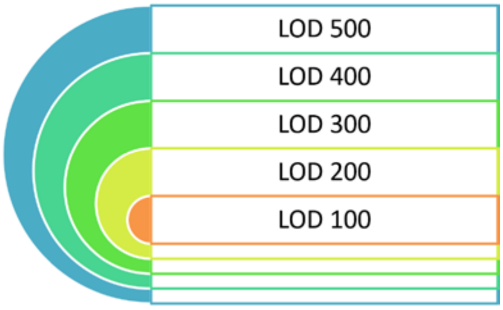


Figure 4 Level of development requirements

Where LOD stands for the level of development, which is processed incrementally in real. LOD 100 stands for the initial conceptual model with almost no information stored in the model. The Model might be showing the design intentions, the plot boundaries, and the volumetric representation of the design. LOD 200 is more developed model with minimal information known and represents the schematic design. LOD 300 is a sufficient model for tendering and estimation. Shows the exact design form, spatial organization and used components in the project. This model is used to extract design drawings, and it is sufficient for authority approvals prior the construction stage. LOD 400 is the construction is developed with the exact information needed for each single element in the model, exact dimensions, and fabrication and installation details needed to construct the model. In addition to the suppliers, specialists, subcontractors and subconsultants design development inputs. All information should be loaded into the project component families within the BIM Revit Models, and all the shop drawings and fabrication details are extracted from the built BIM model. LOD 500 model stands for the as built model with all the asset tagging and coding information loaded, COBie parameters, and asset information model (AIM) and facility management model (FM)information updated in the model. All the as built drawings are extracted from the upgraded LOD 500 model.

3.7. BIM Survey

In order to get the subject matter experts from the industry and construction field, a specific BIM survey was constructed using google forms to get a faster input. The survey was sent to specific subject matter experts with specific experience, background and BIM or construction field roles and position. Fig. 5 shows the areas covered in the Survey.

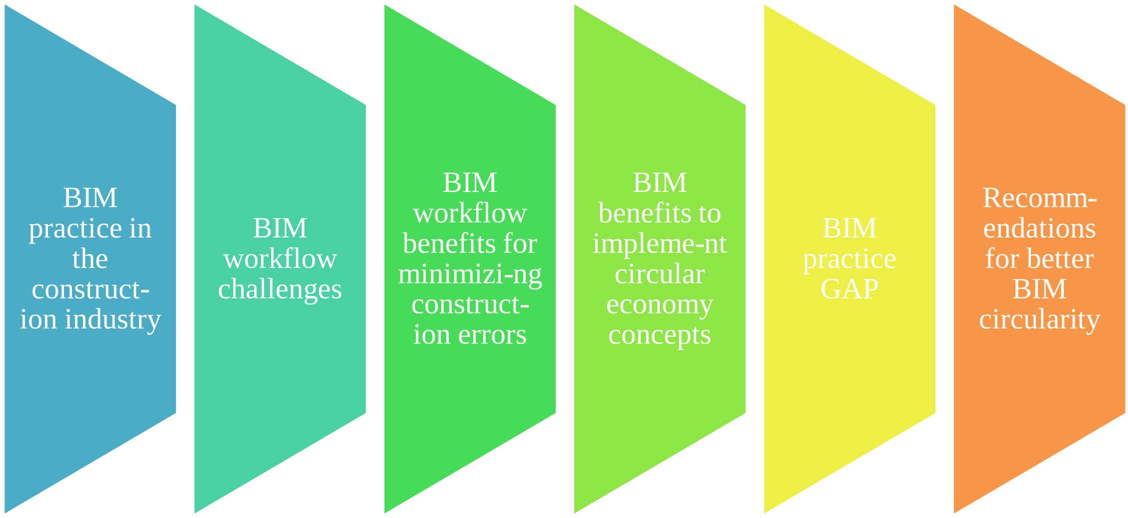


Figure 5 CE and BIM survey sections

CHAPTER 4: RESULTS AND DISCUSSION

To meet the goals and objectives of this thesis proposal, get the maximum out of the discussed topics and addressing the best results for the practice, the following pillars are addressed and discussed in this section:

1- Real stadium project BIM models analysis considering the EIR, BIM management plan BIM PMP, and BIM uses required to achieve the CE requirements, design for disassembly, and material passports requirements.

2- Built model practice, authored schedules and spreadsheets, and workflow to support the purpose of supporting the CE.

3- CE and BIM survey results and practitioners' recommendations for the best practice workflow.

4- Identifying the best practice model framework and roadmap to address and achieve the best results for measuring, recording, and tracking the built asset circularity.

4.1.Real Stadium Project Case Study Analysis

As discussed in the structure of the methodology of this thesis proposal, the author is going to start this discussion part of the research by the thorough study of a real stadium BIM management documents and BIM models gathered as a sample. The proposal will investigate more on the level of work done within the models at the stage the files gathered. Then will compare them to the BIM requirements issued in the BIM management documents gathered from the project teams during the information and document gathering part of this research.

As mentioned in the methodology section, the information and documents were gathered from multiple parties and stakeholders on the stadium project. The process of gathering the information has faced high level of resistance due to the confidentiality of the information on such mega projects. Due to the same reason this research will be presenting only a sample of the project files. The sample files selected should serve the purpose and objective of the study. This proposal will discuss other parts of confidential information explained verbally during personal meetings with the project team members.

The teams' members reached during the information gathering phase were from multiple organizations with diversity of backgrounds in the construction industry. Some of them were from the client organizations, others from the main contractor side, while some other members were from the design consultant team. On the other hand, the author of this proposal has met members from the BIM teams, Engineering teams, and construction engineers. The purpose is to gather as much valuable information as possible, which will be thoroughly discussed in this section.

Starting with the BIM management documents of the stadium, it is a top priority to discuss the content and orientation of BIM management plan, and the BIM manual documents. Due to time and resources constraints which is planned to be effectively used and utilized, the discussion was limited to these two BIM Documents. The remaining documents of the BIM management preliminaries and workflow documents are highly recommended to be studied for future work and expansion of this thesis scope and purpose. The documents with highest priority level among all others are:

1- Construction execution plan.
2- BIM model and sheet quality check lists.
3- Sample audit list.
4- BIM look ahead plan.
5- General BIM audit report.
6- Engineering BIM training.

7- BIM document registers.

8- Element Interaction Matrix.

9- BIM volume strategy.

10- BIM organization chart.

11- LOD matrix.

12- Design validation check lists.

13- Design team interim presentation.

14- Model element definition matrix.

15- BIM quality assurance plan.

16- Asset tagging and coding.

17- SC COBie index.

18- BIM content standards.

19- BIM compliance report.

20- Client CDE protocols.

21- Room numbering format.

22- Maintainable asset standard tagging and coding template.

23- Project handover record information.

24- Asset information requirements.

25- BIM software and hardware specifications.

26- BIM quality process map.

27- Kick-off meeting minutes.

28- BIM submittal form and BIM team roles.

The purpose of studying, investigating, and analysing the mentioned BIM & Design management documents is to find a real world practical successful framework to be used by the industry practitioners. Another target is to enhance the project execution workflow and measure the circularity of the designed building and the constructed asset.

4.1.1. BIM Management Plan

In this sub-section of the proposed research, the author had studied the BIM management plan of the Stadium. The following observations were found:

1- The BIM project management plan was prepared by the Main contractor team. The document was given a document reference number complying to the project naming convention, and the revision studied was revision 01.

2- The document owner is the BIM manager and his signature on the document is a must to be eligible to be officially submitted.

3- The document was prepared by the BIM manager, and checked by the QAQC manager, Design manager, and was approved by the project director, prior to the official submission by the main. This document is to be authored by the main contractor in the construction projects (construction phase of the design-build projects) or by the design consultant in the design phase of the project and by the contractor in the construction phase of the project in the design-bid-build projects.

In the BIM project management plan, the contractor has started by introducing the used Acronyms and abbreviations and the corresponding industry vocabs. The purpose is to ensure that any reader\user of this document understands all of them. Then the terms and definitions of the terminology used were introduce for the same reason. the BIM project management plan has included 5 main sections, namely; scope, project information, project BIM delivery plan, BIM outcomes delivery plan, and a references section.

Such a document should be authored to identify a unified approach and methodology of work to be followed by the participating teams, to be able to deliver the BIM requirements as required in the EIR. For the case of the stadium the document is named “BIM information Management” or “Client BIM Requirements”. Which was issued in the tender phase and prior to the project awarding\commencement. It is important to note that this is not the only management document to be authored and referred to while managing BIM projects, especially mega and complex ones. The document is always to be binding all the project teams and team members responsible for the production, authoring and the QAQC of the BIM models and produced data and information. Client BIM requirements is also to be thoroughly understood, and the team members should ensure that they are fully aware of all the mentioned BIM requirements within this management plan document. This needs all teams to comply with the points, clauses and requirements mentioned. In most of the projects this document is the only management document plan to be used by the project team members. All other relevant organizational or international standard and working methods and workflows shall follow this BIM project management plan (BIM PMP). It was clearly mentioned in the Stadium, that “For clarity, the BIM PMP supersedes any other BIM plan that may have previously existed at Project, Programme or Project Team Member’s organization level”.

It is important to be noted by any Project team leader, BIM manager and the project manager that the BIM project management plan or the BIM execution plan is a live document. This live document should always be updated and kept current and up to date with all the agreed amendments and changes.

The BIM project management plan should cover many areas under the project information section. This section purpose is to build a strong and comprehensive understanding and familiarize the team members with the project information. like but not limited to:

1- project details, (name, client, location, address, contract type & delivery method)
2- project description, (a comprehensive description about the project including all the information about the covering program of portfolio “if any”, underlying main standards document name, volume or size description, completion date, site plot area, and location description). This section may also mention a brief description of the design concept and intentions.
    a. Project milestones, (very high brief description of the main phases milestones, with name of the milestone, description, and date information)
    b. Project BIM team members, (this section should mention a high-level description of the main team members’ organization roles “client, construction manager, lead design consult … etc”, role code\abbreviation, company name, and the BIM role on the project “BIM Leader, BIM project Manager, BIM author and management for design … etc”).
    c. Project objectives, (project objectives should be specifically mentioned on this section, reference to other documents describing the objectives is acceptable, like but not limited to construction planning, tournament planning for security, developing and communicating coordinated and compliant design, asset information model & COBie parameters … etc”).

d. If there are subprojects, they should be mentioned in this section of the BIM project management plan, so all the users of this PMP will be aware of this dependency.
e. Delivery roles and responsibly (the project organization chart should be attached to this section).
f. BIM information (BIM team member roles requirements, skills, and competencies, where BIM key roles are mandatory to be mentioned, like but not limited to; BIM manager, trade BIM coordinator, trade BIM modeler, Information manager, task team manager, design manager, document controller, Quality assurance manager, trade project lead, managing planner, 4D coordinator\champion, 5D estimator\champion, construction manager, HSSE BIM champion, and others as needed)
g. If there are any intentions to outsource the BIM scope to a BIM consultant or firm, this should be mentioned in this section as well. The relationship to other organizational roles in the project should be clarified; through providing and extra organizational chart after adding the new BIM partner.

3- The very next section based on the stadium BIM project management plan is to discuss the Project BIM Delivery Plan. This is achieved by detailing the specifics of the project team's implementation plan for delivering project BIM through the topic headers mentioned in the following figure:

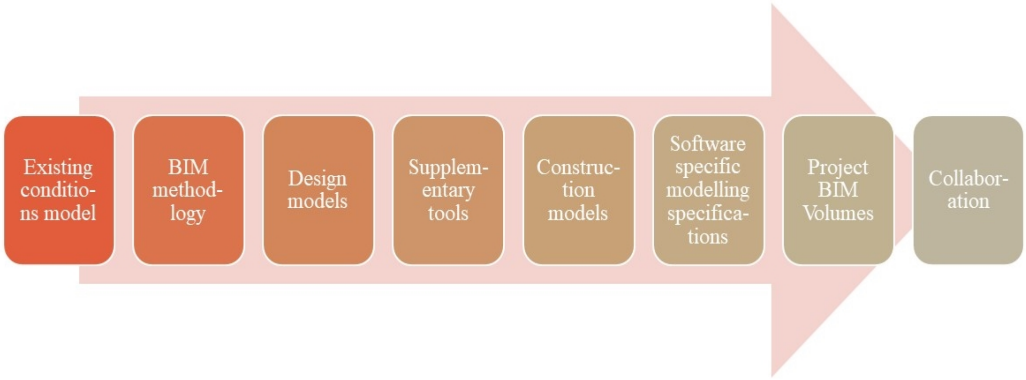


Figure 6 Project BIM delivery plan specifics

a. In the first subsection of this part of the BIM project management plan, the BIM management team should specify if there is any existing model categories or responsibilities; they might be creating a table like table 10 below.

Table 10 Existing Model Categories and associated responsibilities

Model Category	BIM AUTHOR	Software and version	Native file type and version	Exchange Format and version
Existing topography	Company name	Autodesk Revit	Revit	.RVT
02	02	Software 02	CAD	.DWG
03	03	Software 03	REVIT	.PDF
04	04	Software 04	04	04

It is important to note that the table above is not fixed and limited to 4 rows, it can be tailored and expanded to fit the project needs and requirements.

b. In the next subsection the approach for modeling and presentation of the existing conditions should be mentioned.

c. In the design models sections, it is vital that the BIM management team mention the agreed modeling tools and exchange formats used in the design model authoring and information production and exchange. where they can be guided by table 11.

Table 11 Existing Model Categories and associated responsibilities

BIM AUTHOR	Software and version	Native file type and version	Exchange Format and version
Architect	Autodesk Revit 2022	Revit	.RVT / 2022
Structural Engineer	02	CAD	.DWG
03	03	REVIT	.PDF
04	04	04	04

It is important to note that the table above is not fixed and limited to 4 rows, it can be tailored and expanded to fit the project needs and requirements.

d. In the following subsection team should discuss and mention any supplementary tools, coordination tools, software, native files type and version and the adopted modeling standards if any.

e. Jumping into the construction models the table used should at least mention the following information:

    i. BIM author
    ii. Discipline
    iii. Software and version
    iv. Native file type and version
    v. Exchange format

f. This subsection of the management plan may refer to the subcontractors, specialists, and temporary work models.

g. After mentioning all the software and versions will be used in implementing the project and complying to the project objectives and benefits management plan, the team should specify the software and modeling specifications using a table similar to table 11.

Table 12 Specific software and modeling specification

BIM AUTHOR	Software and version	Software specific modeling specification
Design Consultant	Autodesk Revit 2022	AEC (UK) Standards for Revit
Main Contractor	Autodesk Revit 2022	BIM Forum LOD specifications 2020
Subcontractor	Autodesk Revit 2022	AEC (UK) Standards for Revit
Specialist	Autodesk Revit 2022	BIM Forum LOD specifications 2020

h. Following the above mentioned, the management team should continue authoring the subsections that will help better managing the process through touching on the PROJECT BIM VOLUMES, and produce a proper model element definition matrix (MED), which has to define two aspects of the project BIM scope:

   i. Level of details of an element within a certain stage of the project
   ii. Level of information needed for an element within a certain stage of the project

   These two aspects form the Level of Development of the model elements and components will be implemented in the BIM models and used to produce project information and should be mentioned and referred to in the MED. the model element definition matrix is usually developed and submitted in a separate excel and PDF files as an attachment to the BIM management plan \ BIM execution plan.

i. If the project is large or complex like the status of the stadium and all World Cup 2022 stadium projects; Then the BIM manager and team jump into specifying the zoning strategy.

i. The zoning might be done, building wise and space usage wise
ii. Zoning and references of zoning might be added separately in the BIM manual and referred to in this section.
iii. Example of the stadium zoning plan showing in Fig. 7.
iv. If needed the team should go deeper and work on the part zoning strategy. The benefit of doing that is to be able to fill this information in the object\component parameters, which will serve the operation phase, maintenance requirements and circular economy parameters and the measurement within the BIM models. an example of the stadium is showing Fig 8 and Fig 9.

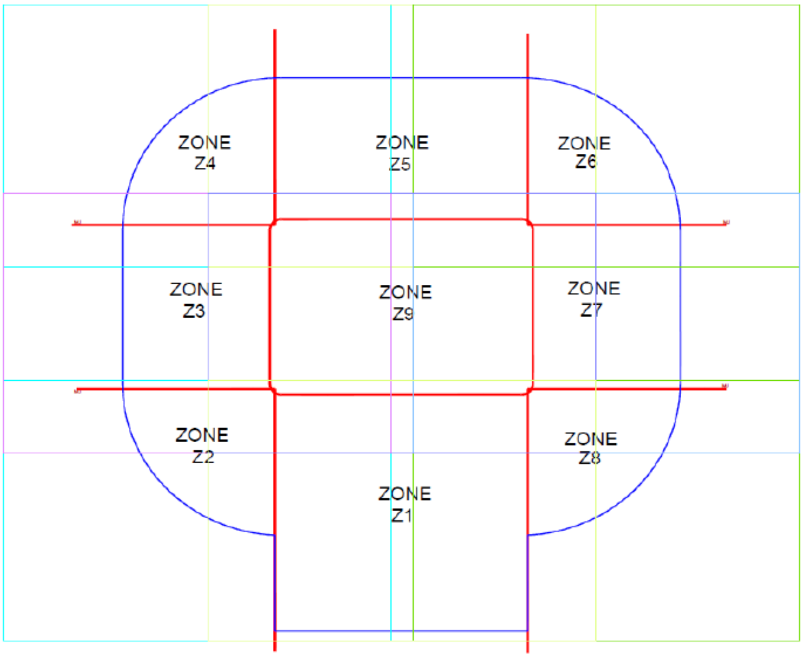


Figure 7 The stadium zoning plan

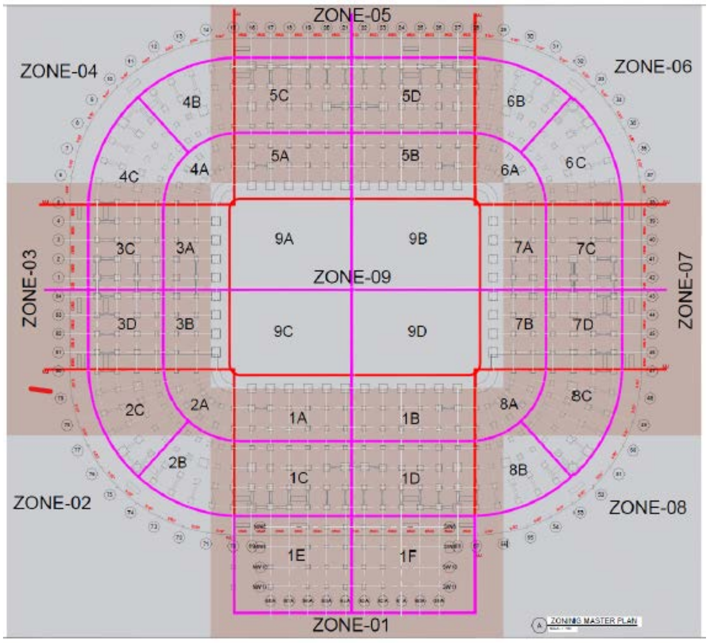


Figure 8 The stadium part zoning plan

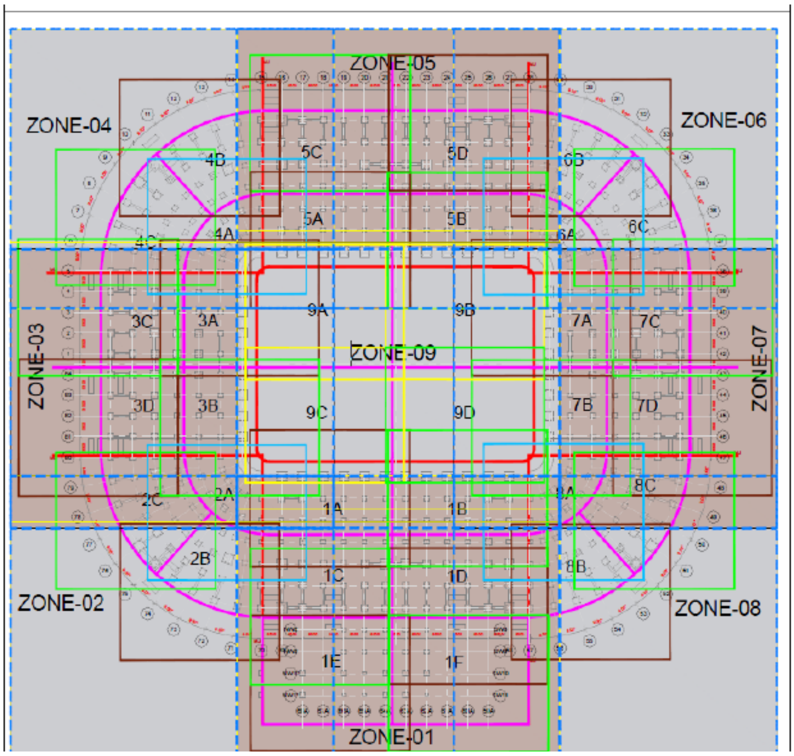


Figure 9 The stadium zoning layout and part zoning layout

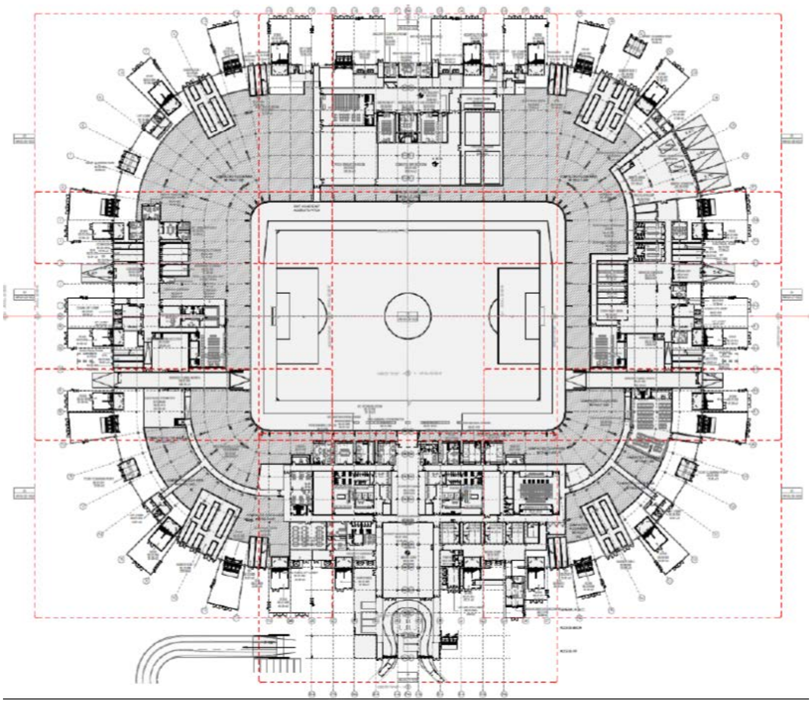


Figure 10 The stadium floor plan with zoning implemented

j. Moving forward it is highly recommending and almost mandatory that the project BIM management team mentioned the volume segregation strategy. This should be separately developed in the BIM manual and will be referred to in the BIM management plan \ BIM execution plan. The team needs to mention an overview of the project volume strategy in this subsection, where they may be producing a table similar to table 13.

Table 13 Project Volume Segregation overview

Discipline \ trade	Number of models
Architecture	05
Structure	01
Mechanical	08
Electrical	10
Interior Design	07
Façade	04
Wayfinding and signage	03
Streel structure	01
Containers	106
ICT	05

k. Then it is essential to explain the collaboration needs and methods, which platform will be used for design and BIM collaboration, and how the information exchange within the delivery team and within the common data environment will happen. screen shots from the collaboration exchange platform and common data environment are highly recommended to be added in this section (Fig. 11 shows a sample of the collaboration platform "AUTODESK A360" of the stadium), with a description of each folder among the environments.

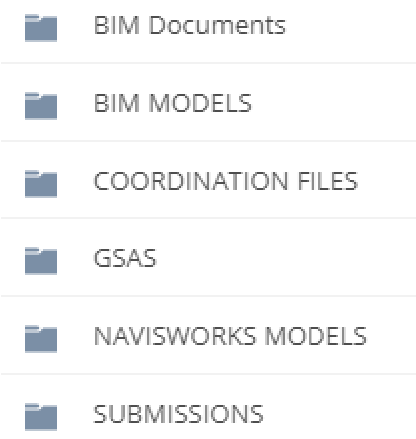


Figure 11 Collaboration platform main folder structure

Following is a sample description of the folders:

1. The **BIM Models folder** shall be updated weekly and contain the latest version of the project in Revit.
2. The **BIM Documents folder** contains the latest version of the BIM management documents.

   Other coordination folders are created for the following purposes:
3. To facilitate coordination issues. Coordination models extracted from main Revit models shall be saved in the **Coordination Files folder**.

4. The **Navisworks folder** shall store the coordination models in the NWD format.
5. Official Submissions to be saved in the **Submissions folder.**

The above structured common data collaboration environment will help control the flow of the significant amount of information during the project life cycle and will help track the progress, collaboration, and coordination activities, as well as helps to structure the methodology of recording information, submissions, and project documents.

ii. In the following few sections when it comes to coordination and information exchange, the BIM management team may be dividing data exchange into internal and external levels. The information exchanged internally might be the work in progress information (WIP), the developing information, and files to help each department, team, and organization on the project to work with the others effectively. The information exchanged externally will be the approved, authorized, and shared documents and files that can be used either for coordination or construction.

iii. Later in the next subsection workflow for sharing work in progress with the client should be discussed and presented with clarifying illustrations, Fig. 12 shows a sample of illustrations might be guiding teams in creating their project illustrations for this purpose.

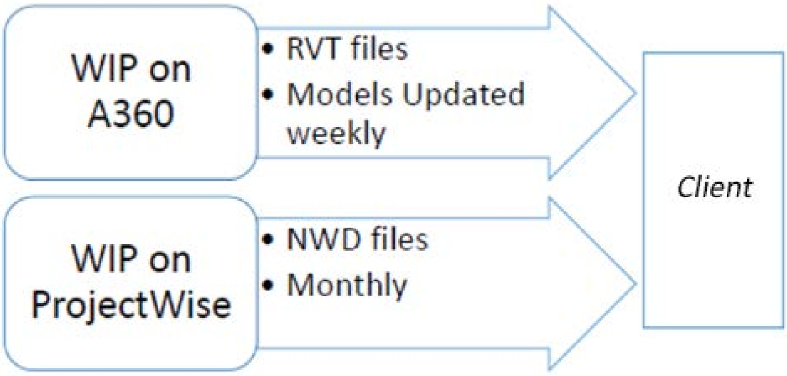


Figure 12 Guide illustration for sharing work in progress files

iv. Deliverables of each milestone should be clearly defined by mentioning:

1. Milestone definition
2. BIM model deliverables
3. Drawing's deliverables
4. Schedules
5. Documents
6. Any other deliverables needed or required by the client or the project specifications.

v. BIM meetings should be discussed, agreed, and confirmed. The frequency of meetings, locations and time should be mentioned. table 14 can be used as a guidance in creating BIM meeting Schedules in the BIM management plans \ BIM execution plans.

Table 14 BIM meeting schedule

Meeting title	Agenda	Attendees	frequency	Additional details
BIM meeting	Revise BIM Documents	BIM Authors BIM Coordinators BIM Managers	Weekly – once – Sunday – 9:00 AM	Discuss BIM PMP, MED Matrix, Volume partition and

Table 14 BIM meeting schedule

				other relevant BIM Issues
Coordination information exchange	Update models across all disciplines for coordination purposes	BIM Coordinators BIM Managers	Biweekly – once – Thursday – 9:00 AM	Every Friday models shall be uploaded to the A360 by all disciplines DCs involved in the project. Models can be uploaded more frequently under request for coordination purposes.
To be discussed	----	----	----	----
To be discussed	----	----	----	----

Note: A separate BIM meeting manual should be developed in complex projects, which require more than one type of BIM meetings. The frequency needs to be specified, recorded and distributed among the teams to guarantee attendance of all the required participants.

vi. In large scale projects with a high level of coordination, complexity, and a need for a fast track; look ahead BIM plans should be provided, with a template to be used by the team to author and produce a fresh plan every month.

Fig.13 represents a sample of a look ahead plan which might be used as a guidance for the BIM teams to create and develop their own project look ahead plans:

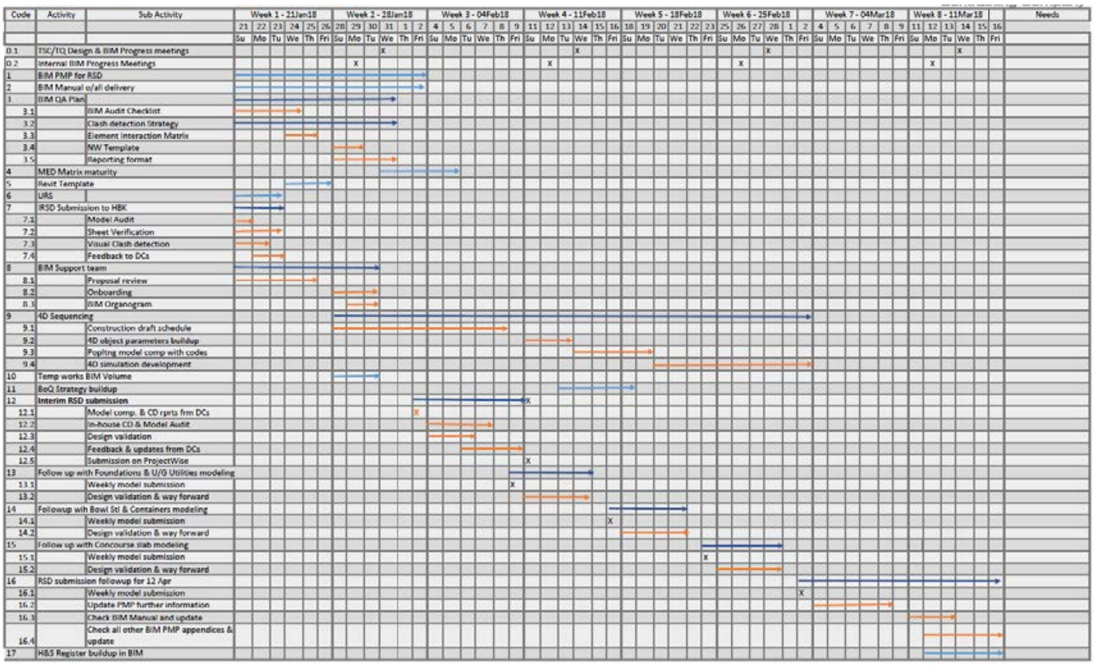


Figure 13 BIM look ahead plan sample

In addition to the look ahead plans, a weekly and monthly progress reports should be also provided to make sure that the project is moving as planned and to spot any obstacles or mistakes in the progress early.

4- The next section of the BIM management plan \ BIM execution plan is specifically discussing the project BIM outcomes delivery plan. This section begins with a table showing the targeted outcomes for each stage \ BIM use. In the stadium case study, the targeted outcomes are:

   a. Developing and Communicating Coordinated and Compliant Design.
   b. Tournament Planning.
   c. Legacy Planning.
   d. Construction Planning.
   e. Field BIM.
   f. Asset Information Model (AIM).
   g. COBie.

Where each of the mentioned main titles covers multi-points outcomes, and the table provides the needed information, which assigns each targeted outcome to a specific responsible party in each project life cycle phase using the following column headers:

i. Revised design stage requirements
ii. IFC stage
iii. Shop drawings stage
iv. Construction stage
v. As built stage
vi. Handover stage

h. This section should also cover many other areas in the project BIM management, like but not limited, developing, and communicating coordinated compliant design through the communication of drawing outputs, design reviews and client engagement, schedules, specifications, cost planning, spectator sight lines analysis for stadium seating, accessibility studies (maintenance and vehicular), structural analysis, lighting analysis, energy analysis.

i. Clash detection requirements, matrix, and procedures should also be covered. In addition to the software used, and many other topics might be covered in this section depending on the project stage, complexity, and scale; to mention some main areas:

1- construction planning
2- constructability studies
3- logistics planning
4- visual method statements

5- construction sequencing

6- progress monitoring

7- modular construction

8- material passports

9- ability to dismantling

10- recyclability

11- reusability

12- Design for manufacture and assembly

13- People and human resources planning

a. In-house BIM team

b. BIM candidate category

c. BIM training

d. Supply chain capability assessment

14- IT environment

a. Hardware

b. Software

c. IT plan

d. Information security

5- The last section of the BIM management plan \ BIM execution plan is discussing the project references and other documents. Which the BIM team can refer to, to better manage the BIM scope; like but not limited to:

a. Project BIM contacts of key personnel of the Client firm, consultants, contractor, subcontractors, and others.

b. Project BIM Quality Assurance Plan

c. Project BIM Manual

d. Project BIM Documents Register

e. Model Element Definition (MED) Matrix

f. BIM Meetings Schedule

g. AIM Development & Validation Procedure

h. Circular economy requirements

i. Design for disassembly manuals

j. Material passports requirement management plan

4.1.2. BIM Manual

In this sub-section of the thesis proposal, the author chose to analyze the stadium BIM manual. BIM manual is created and authored by the Main contractor BIM management team and was given a document reference name and number complying to the project naming convention. The revision studied was revision 01. The document owner is the BIM manager of the contractor organization and his signature on the document is required to be eligible to be officially submitted. The document was prepared by the contractor BIM manager, and checked by the QAQC manager, Design manager, and was approved by the project director of the main contractor, prior to the official submission. This document is to be authored by the main contractor in the construction projects (construction phase of the design-build projects) or by the design consultant in the design phase of the project and by the contractor in the construction phase of the project in the design-bid-build projects.

The BIM manual should be approved with no objection by the following parties where applicable, depending on the validity of these roles based on the organizational project chart:

1- The client

2- The project management consultant

3- The construction management consultant

4- Construction supervision consultant

5- The client representative

In the BIM project manual, the BIM management team starts with the acronyms and abbreviations; to ensure full understanding of the document intentions and content. Followed by the terms and definitions in a similar way to the method used in the BIM project management plan (BIM PMP), and the BIM execution plan (BEP), and other BIM management documents.

The BIM manual should address and cover the main sections of BIM management areas namely; scope, project setup standards, project software standards (in the stadium the software addressed is AUTODESK Revit), discipline specific software standards, non-authoring tools and workflows (like AUTODESK Navisworks, CDE, 4D parameters, 5D and cost planning and other tools and workflows), information exchange, in addition to the needed appendices, like the room data sheet format and other appendices based on the project specific needs and requirements, based on the (EIR) or the project specifications and industry standards specified in the BIM PMP and the BEP.

In the scope section the BIM management team should identify the project BIM manual scope. This should serve as a key document and guideline for reviewing project BIM deliverables and workflows, in addition to BIM purposes which will be mentioned in the BIM project management plan \ BIM execution plan.

In each project submission BIM milestone, an updated version of the BIM manual should be submitted in an up-to-date status, to convey the most up to date structure of the project BIM workflows and uses. This document is the responsibility of the main contractor who should manage the BIM delivery.

a. The project setup and standards

This section of the BIM manual should cover the areas of the naming convention of the model files, drawing sheets, model components and families, drawing title block, health and safety information and the north arrow symbol and hazard symbols.

1- The project origin and coordinates are an essential part of the BIM manual which should be specified accurately. Using the exact easting and northing coordinates in addition to the project elevation point which represents the height of the datum coordinates point as per the project survey points, the BIM team specifies to location setup in the authoring software. In AUTODESK Revit the BIM author should use the option of the project base point and survey point to specify the exact coordinates of the project. Fig. 14 below shows a sample of the specified project coordinates in the stadium.

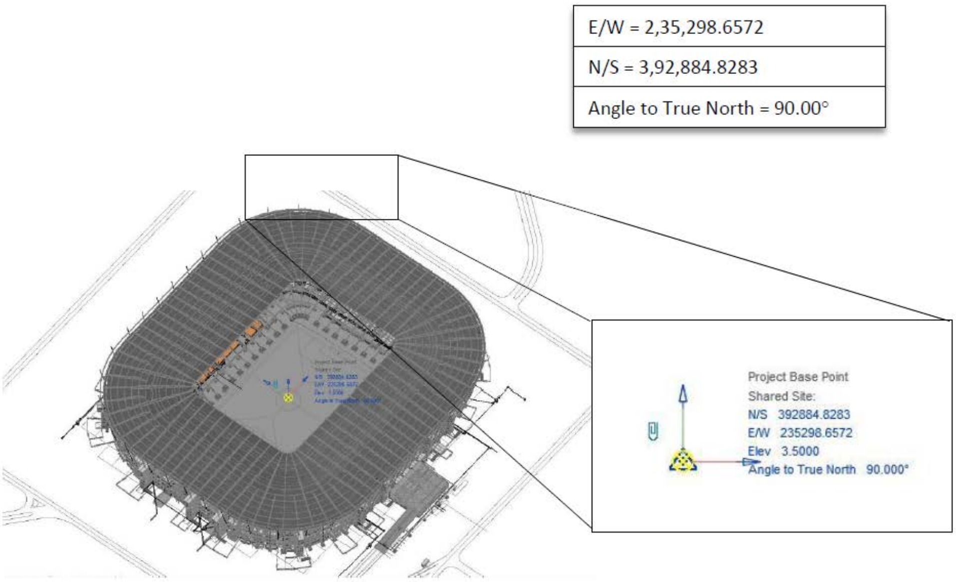


Figure 14 Project setup and coordinates system in AUTODESK Revit

2- Later in the next section, the BIM team should identify the volume strategy, and clarify the logic behind the model's segregation criteria. Volume strategy should allow different teams to work in different files and maximize the efficiency and pace of work, in addition to maintaining the project file sizes within the agreed manageable model file sizes. The team should identify the model structure, from different point of views namely:

- Federated model
- Individual model breakdown
- Documentation and drawing models

This model segregation strategy should cover the project trades, architecture, structure, mechanical, electrical, plumbing, landscape, and master plan federated models, with the clear definition of the sub-trade models. These models will be stand-alone models and will be linked to the federated models to shape the full project model representation. Fig.15 shows a sample model volume segregation strategy which can be used as a guide for the project teams in their task. Fig.16 shows the revised schematic design volumes breakdown from the stadium BIM team. While Fig.17 shows the volume strategy applied in the stadium in the IFC stage. The following two important notes were an essential part of these figures.

Notes:

- From IFC stage, New Family for each type of container should be created, and all shipping containers modules will be binding inside each architecture file and any modification in one container occurs it will have to be done in each instance.
- Splitting models should follow the above volume strategy, in case models reach a big file size “more than 200MB”.

While Fig. 18-35 shows graphical representations of the stadium 3Ds volumes and BIM models workflow.

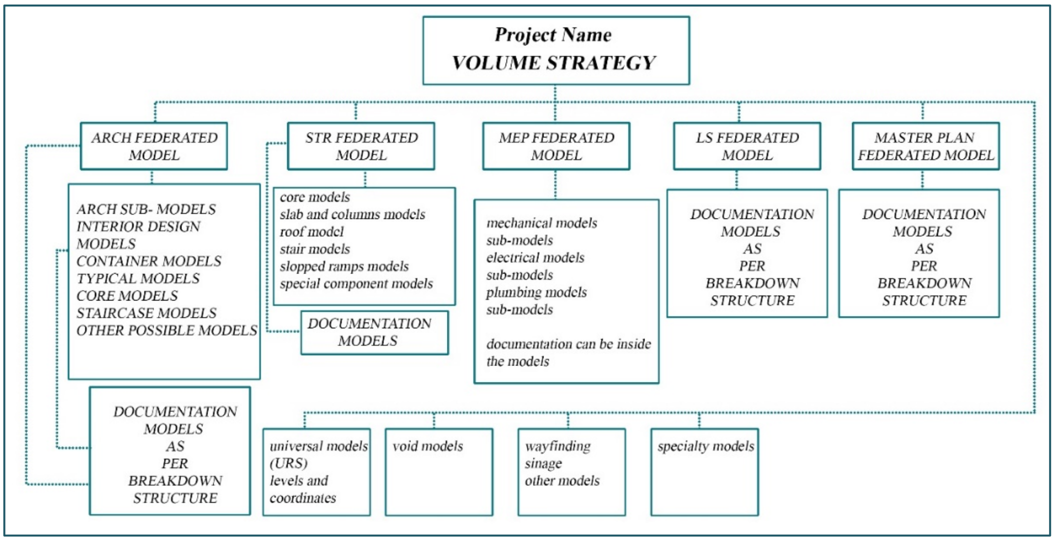


Figure 15 BIM volume segregation strategy sample

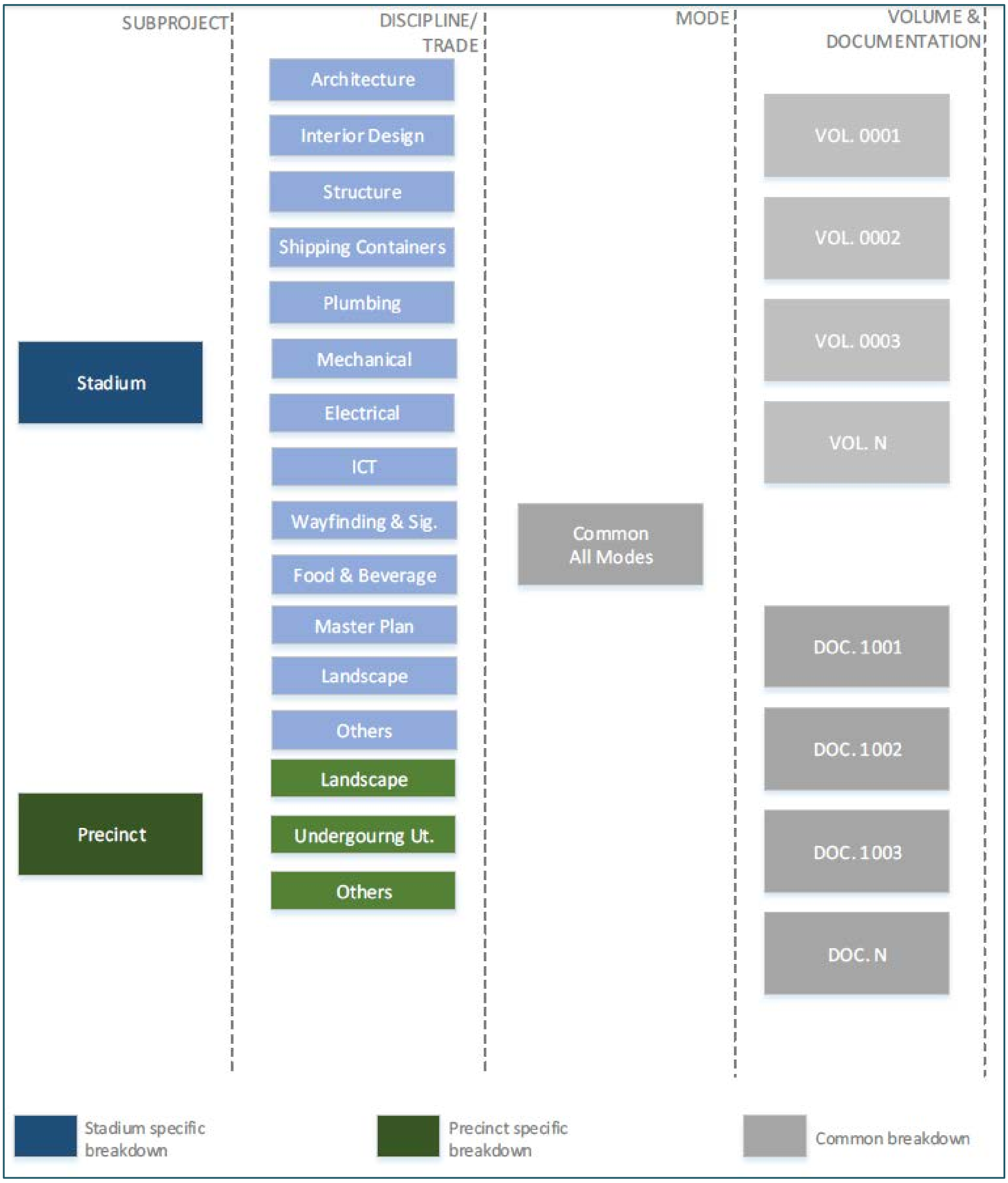


Figure 16 Revised schematic design volumes breakdown for the stadium

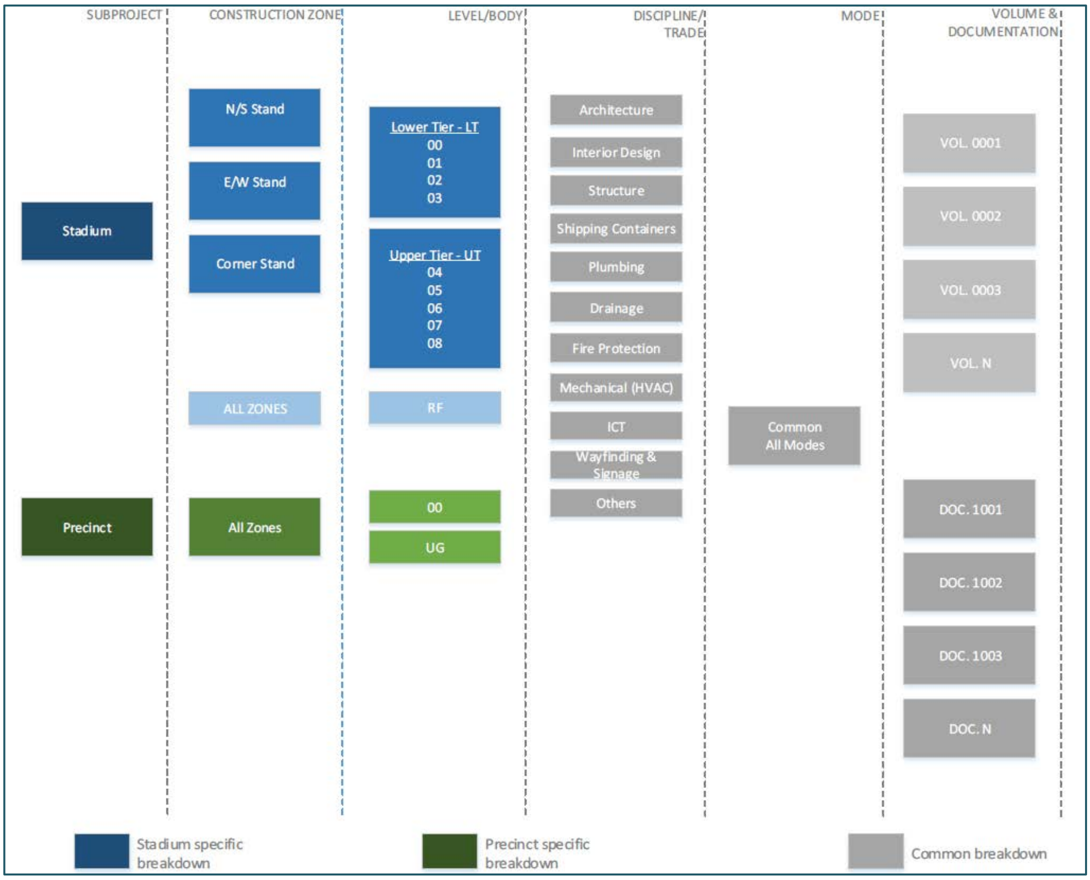


Figure 17 The stadium volume strategy applied in the stadium in the IFC stage

Figure 18 Federated Architecture BIM model

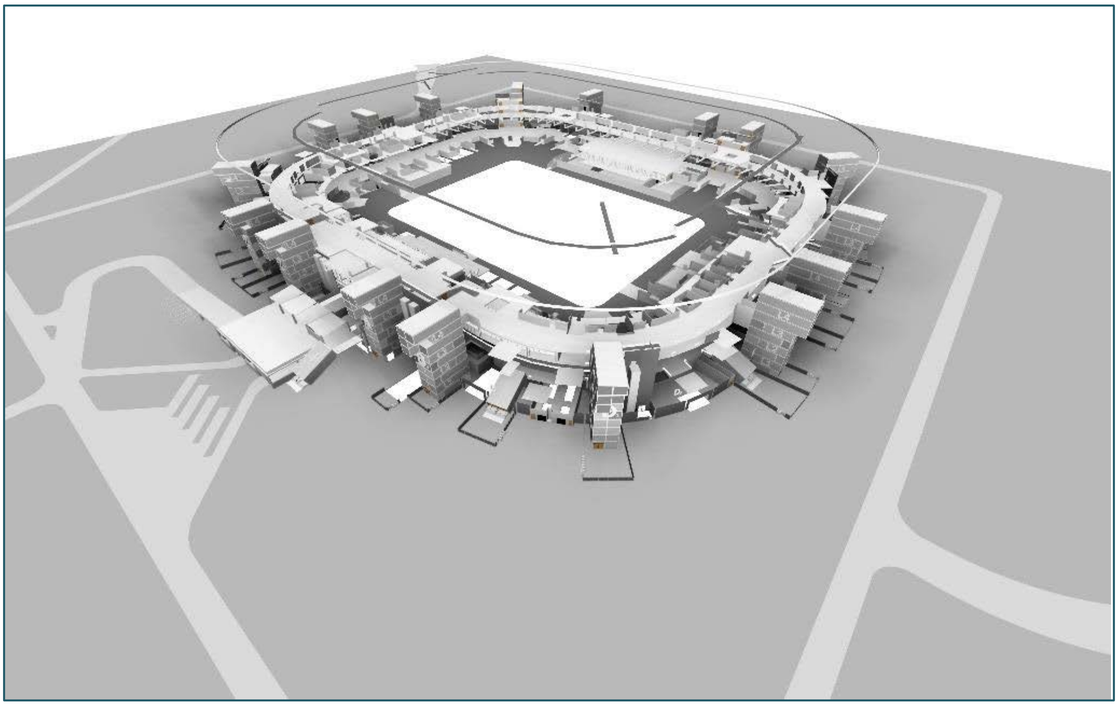


Figure 19 Main Architecture BIM model

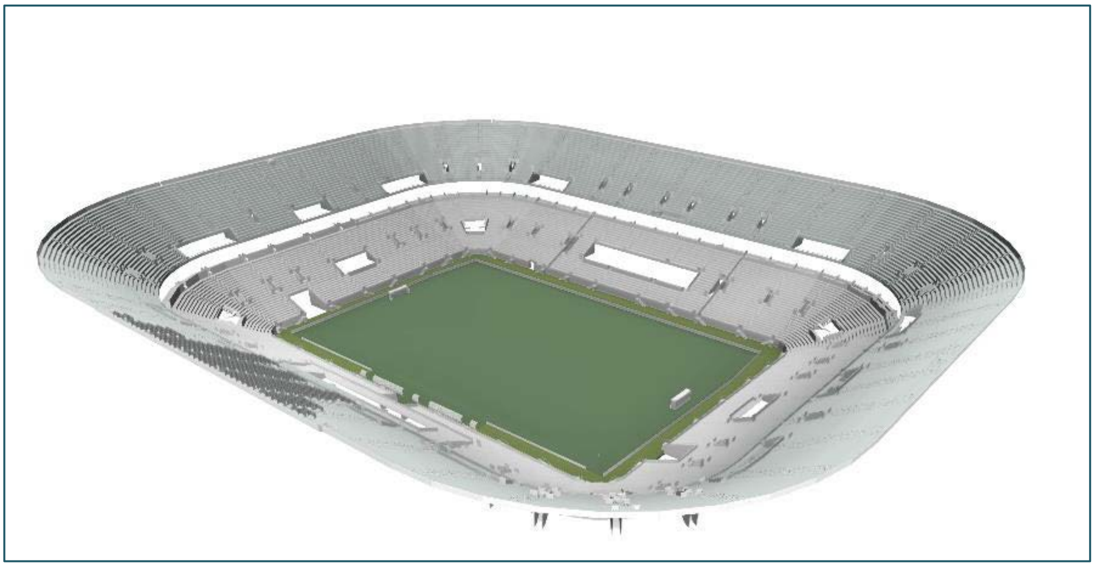


Figure 20 Bowl BIM model

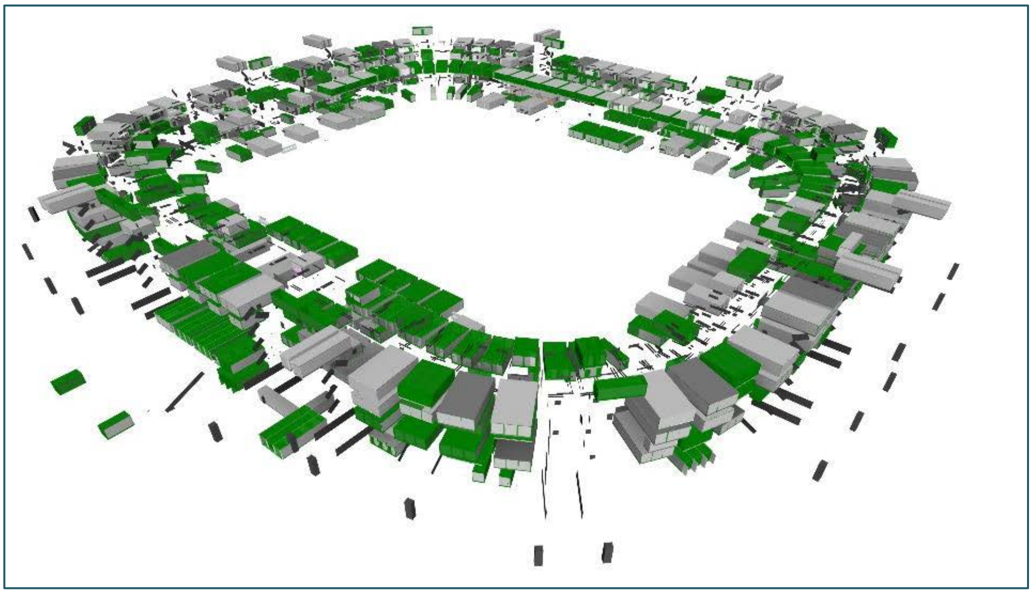


Figure 21 Container Federated BIM model

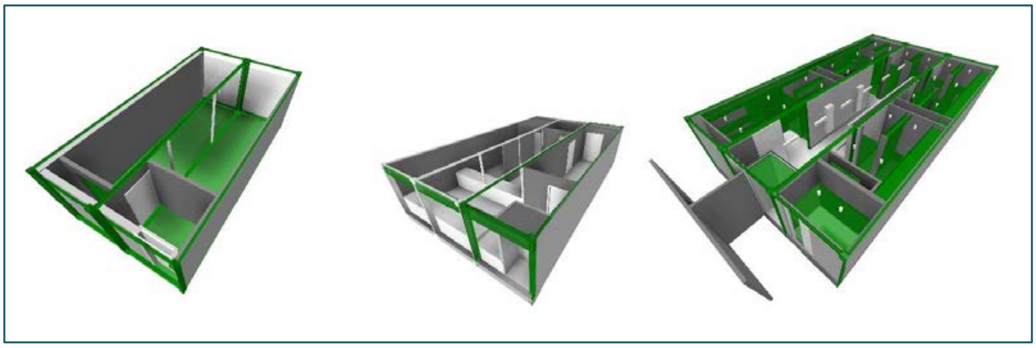


Figure 22 Container Module BIM model

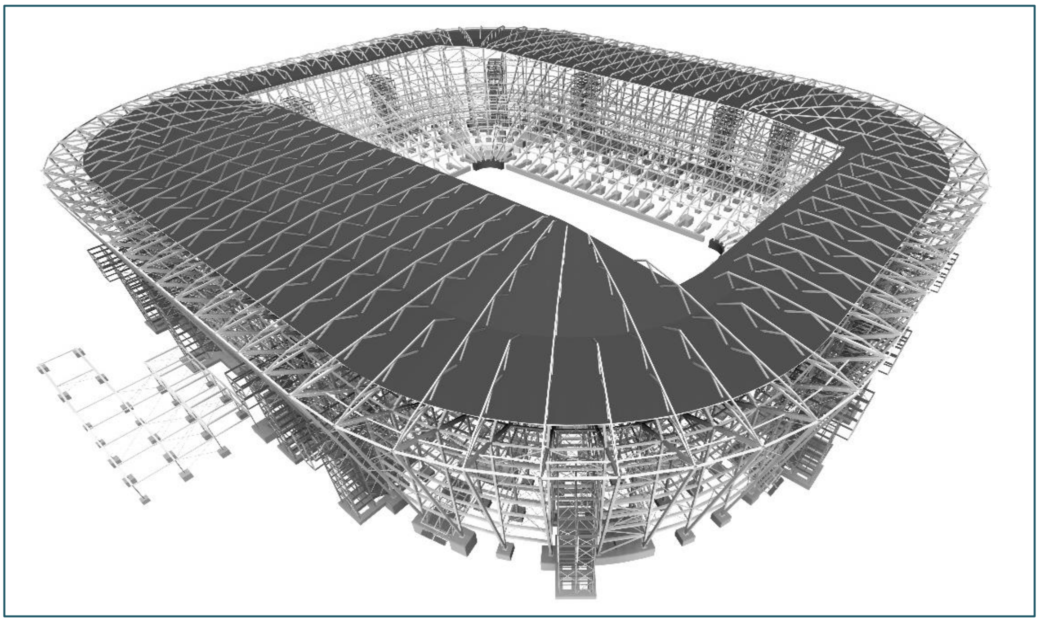


Figure 23 Structure Federated BIM model

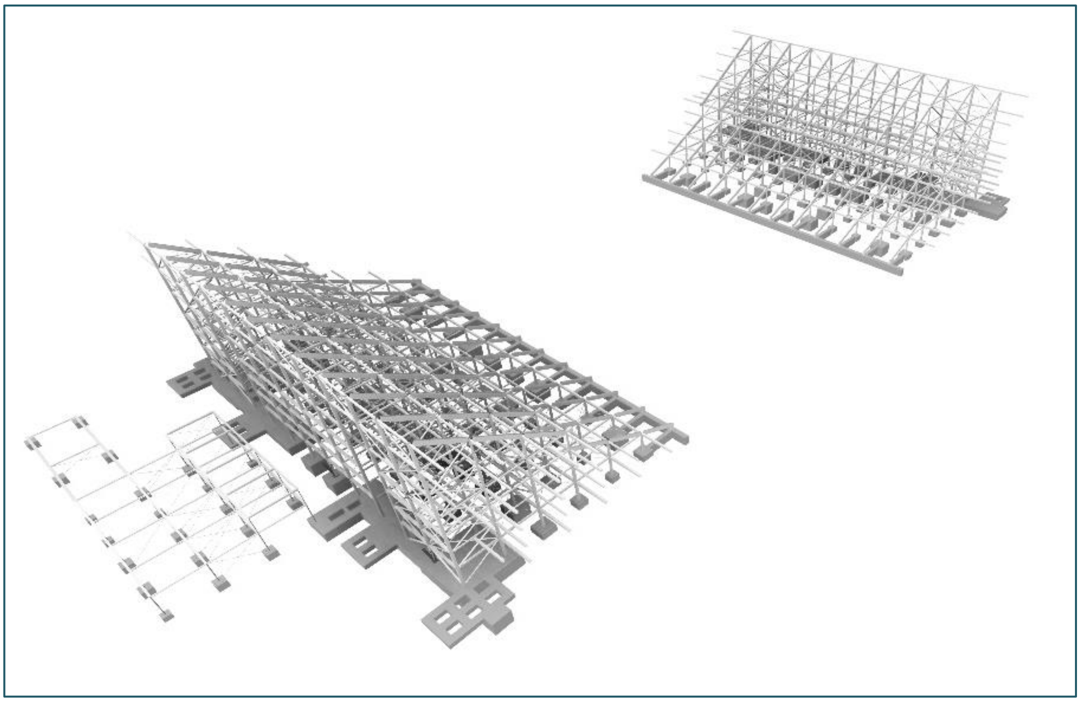


Figure 24 East and West Stands Structure BIM model

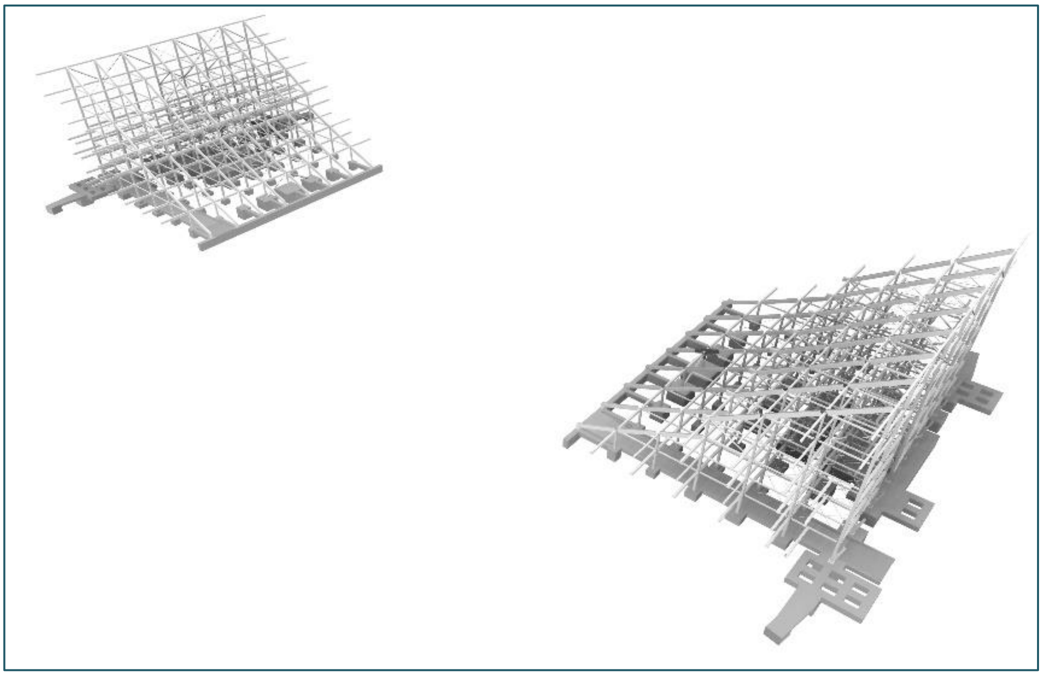


Figure 25 East and West Stands Structure BIM model

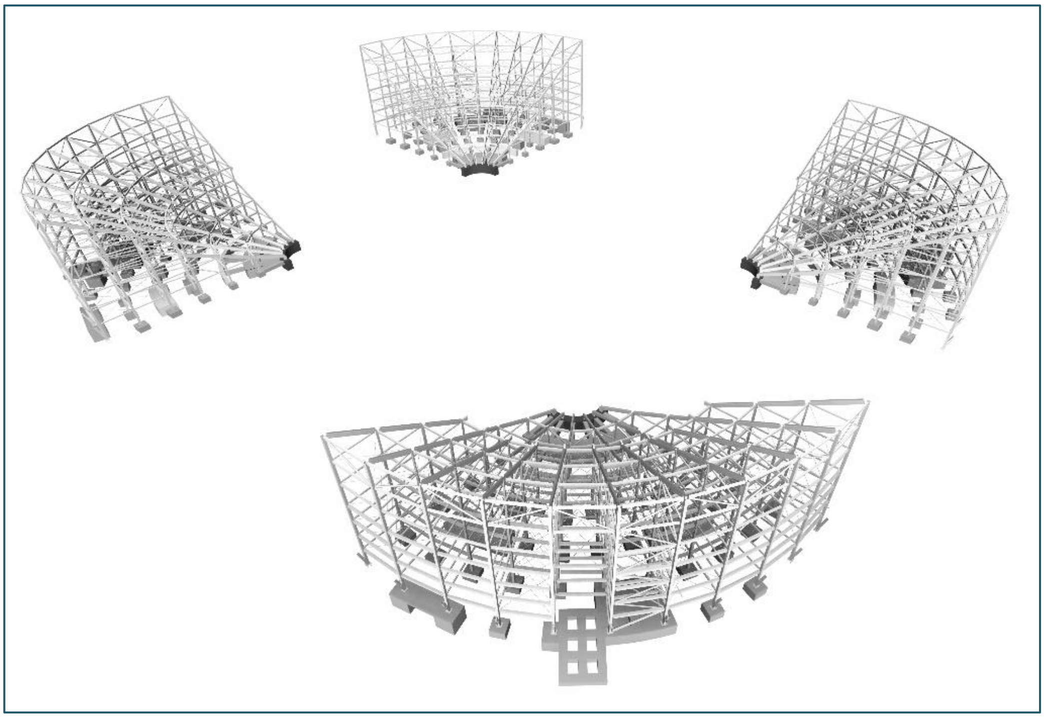


Figure 26 Corners Structure BIM model

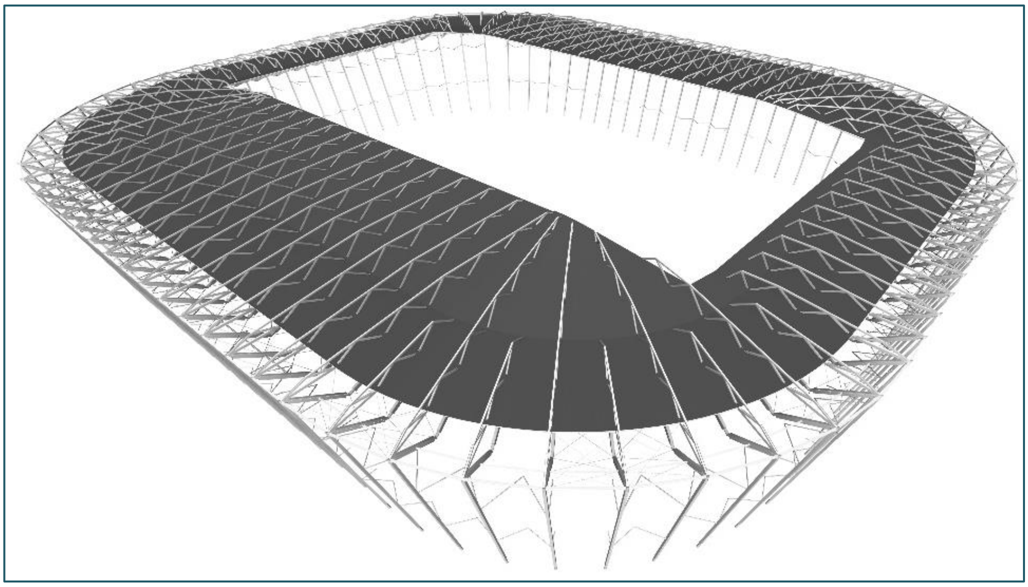


Figure 27 Roof Structure BIM model

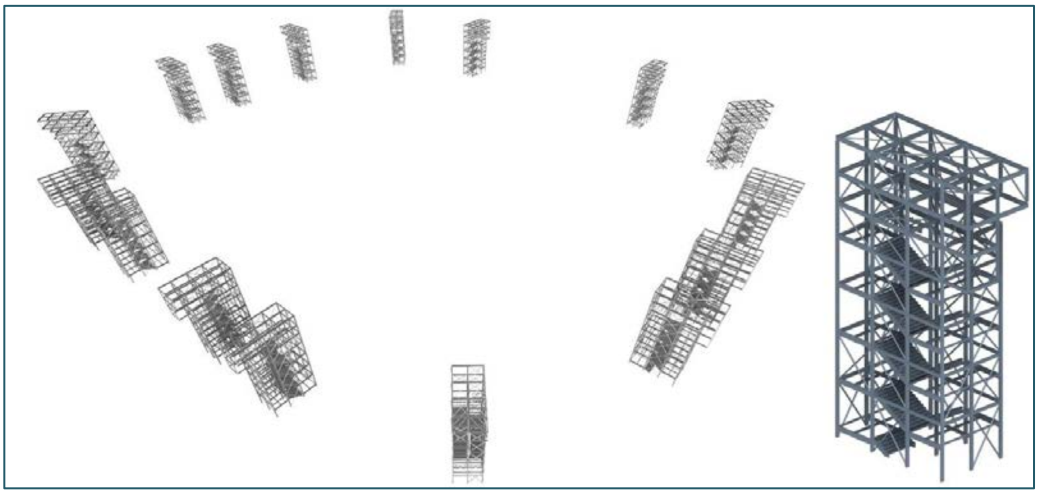


Figure 28 Stair Tower Structure BIM model

Figure 29 Sloped Stair Tower Structure BIM model

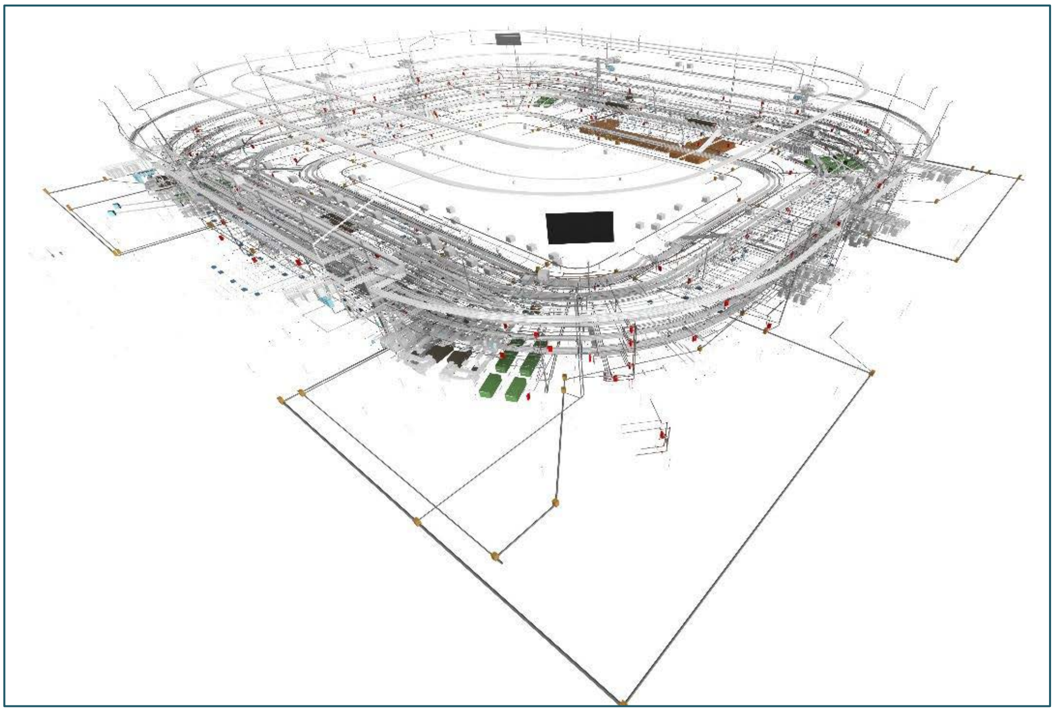


Figure 30 MEP Federated BIM model

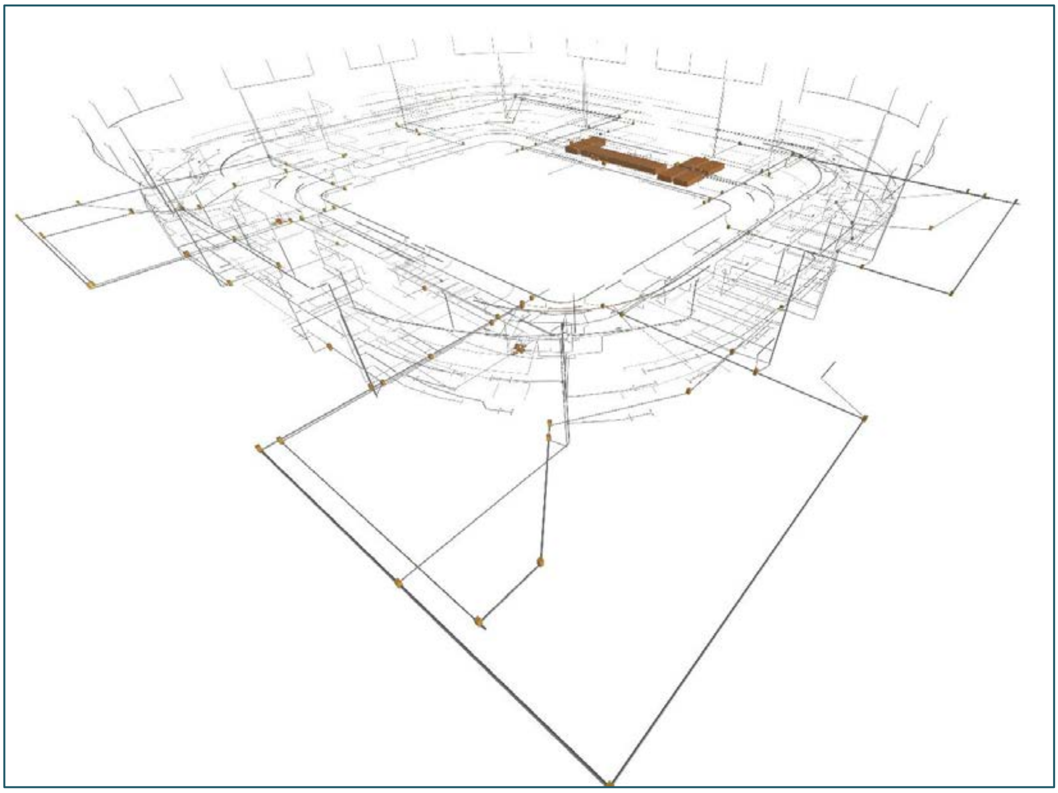


Figure 31 Drainage BIM model

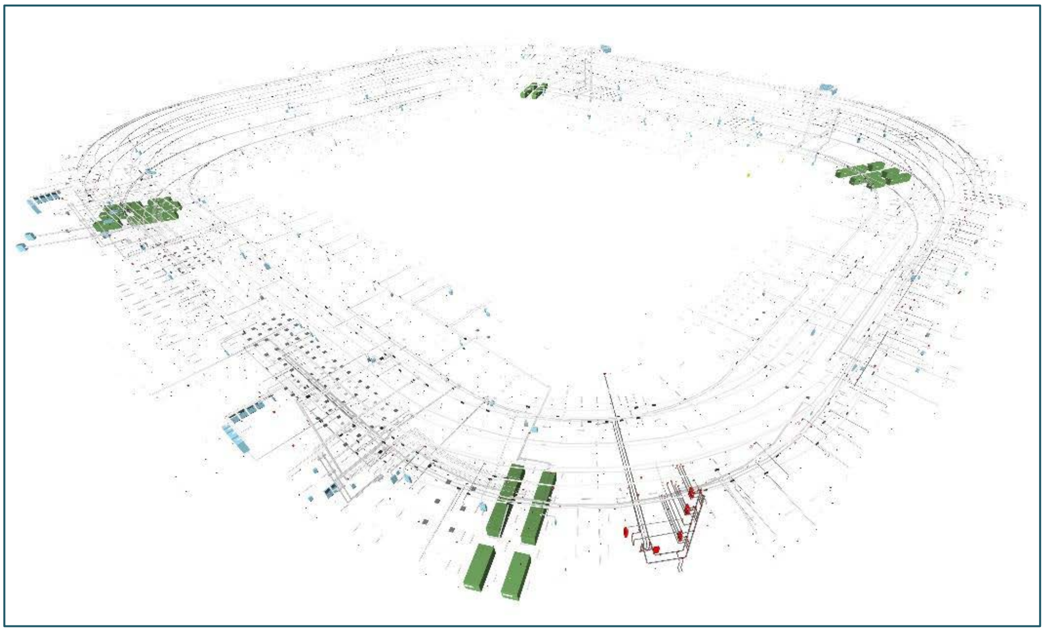


Figure 32 Electrical Containment BIM model

Figure 33 Small Power BIM model

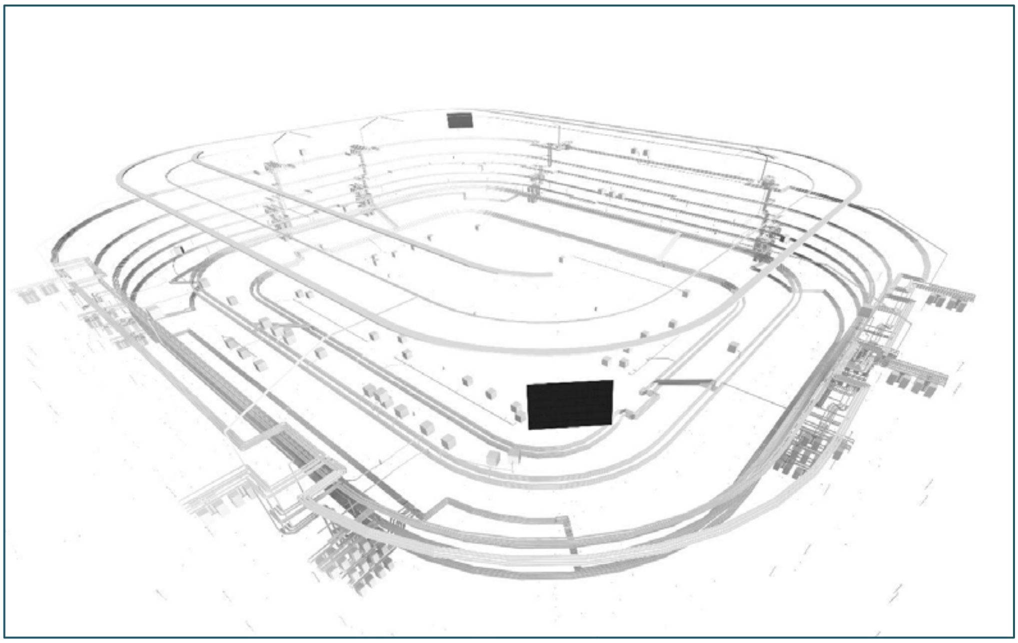


Figure 34 ICT BIM model

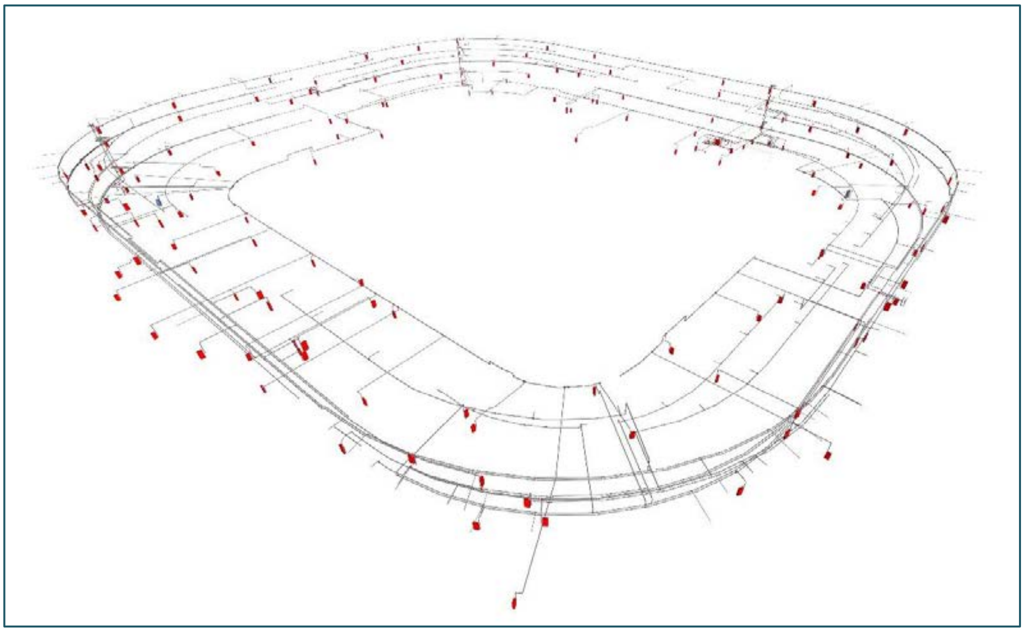


Figure 35 Fire Protection BIM model

After having the volume strategy specified and clearly defined in the BIM manual, the BIM team should be identifying all the BIM model files names, types, subproject related, volume numbering, discipline, and model title. The volume strategy should be followed by some notes describing the naming and numbering methodology used. Then the team should mention the project phasing to be created in the AUTODESK Revit models to fit the project modeling workflow. The teams may be referring to table 15 for reference and guidance to prepare such information.

Table 15 BIM models information

Doc Type	Sub-project	Volume No.	Discipline	Title
RVT	Stadium	X00-CON-M-STA-T-AR-AL-AZ-0001	ARCH	Architecture document model
RVT	Stadium	X00-CON-M-STA-T-AR-AL-AZ-0101	ARCH	Container document model
XXX	XXXX	XXXX	XXX	XXXX

- The table should be expanded\shrunk to fit the project needs and mention all the models used on the project.

3- The BIM manual is to be clearly explaining the drawing naming criteria which in most of the projects refers to one of the following (or a combination of both):

- Client organization standards for naming convention
- BS EN ISO Standards and PAS standards.

Following any of the above will result in using a formula closed to the mentioned below:

- Project identification code which should not change along the duration of the project and all project stages. (3 digits abbreviation – one letter and two numbers)
- Originator organization abbreviation (three letters abbreviation)

- Document type (one letter for example D for drawings other than shop drawings, S for shop drawings and M for model)
- Sub-project of 3 letters abbreviation; for example, STA for stadium, CAI for external works, TWS for temporary works)
- Mode or phase, in the stadium for example the team used T to refer to tournament phase.
- Discipline code, (two letters abbreviation); for example, AR for architecture, ST for Structure and so on; which should be mentioned in a separate table for all disciplines and referred to in this section.
- Level (two digits number for the abbreviation), for example, 00 for ground floor, 01 for first floor and so on.
- Zone, two letters abbreviation
- Sheet type (a separate table to be attached to explain the sheet type numbering reference system), it should be 4 digits number.

For further information the BIM team can refer to a separate document for the naming convention explanation, namely, BIM document register.

Below is a sample for a document naming using the above formula:

C03-7DC-S-STA-T-AR-00-AZ-0001

4- The following section from the BIM manual is showing the room naming and numbering standards. Naming and room numbers should follow the client room numbering format accurately. For the stadium, the team used two digits abbreviation; one to name the level, followed by a hyphen for the zone code. Followed by a three digits number with an optional letter at the end describes the specific room number. Figure 36 shows an illustration of the room naming and numbering system to guide the BIM team creating their own room naming standards.

Part 1			Part 2			Part 3			
Level Code 2 Characters			Zone Code 2 Characters			Room Number 3-4 Characters			
L	L	-	Z	Z	-	N	N	N	A

Figure 36 Fire Protection BIM model

Following is an example of using the above methodology:

<u>03-Z9-725</u>

Meaning this room is located at level 9, zone 6 and its number is 725.

5- Besides mentioning what exactly is to be modeled inside the BIM models, the BIM manual should mention the exclusions and variances. This shows which elements will not be modeled or included in the BIM models, based on the understanding that the standards of a certain level of development do not include those elements. It also covers the modeled elements that will not be efficient to be included in the 3Ds model, and they might be added manually in 2Ds drawings after the export of the drawings from the 3Ds models. Like but not limited to the elements described in table 16.

Table 16 BIM model element exclusions

Discipline	**Comment**
MEP	Until LOD 300 (design models) Pipes less than 25mm of diameter will not be modelled.
ARCH/ID	FF&E interior design furniture to be developed in 3D using Revit at LOD300.
STR/ARC	Only structural relevant members will be considered. Non-load carrying elements will not be considered in the structural model nor on drawings.
All	Interfaces and detailing will be considered at the adequate LOD as per the specifications of the BIM Catalogue.

- Table includes a simple sample for guidance and does not cover all the exclusions for any project.

b. The project software (REVIT) standards

In this section the BIM team should provide guidance on the project file units and other sittings. They need to mention dimension units, round off sittings, angular measurements, decimal degrees agreed, length, area, and volume units. The team should also mention the project information landing sheet structure and content. Fig. 37 shows a sample that can be used as a guidance. After that the BIM team should explain the workflow of the universal reference source (URS) which should mention what the REVIT URS file contains, namely, grids, coordinates, and levels. All other files should link the URS one to acquire coordinates and copy and monitor the rest of things. The purpose of this method is to make sure no deviations will happen among the files and spot any changes or errors in the levels and grids as they are the most important model elements. The BIM manual will also mention the file project base point and survey point and provide snaps from inside the Revit models like the ones showing in Fig.37 and Fig.38. It is worthy to mention that the project base point shall not be change throughout the project execution, but the survey point may be subject to change under the client recommendation and can be updated in the Revit files.

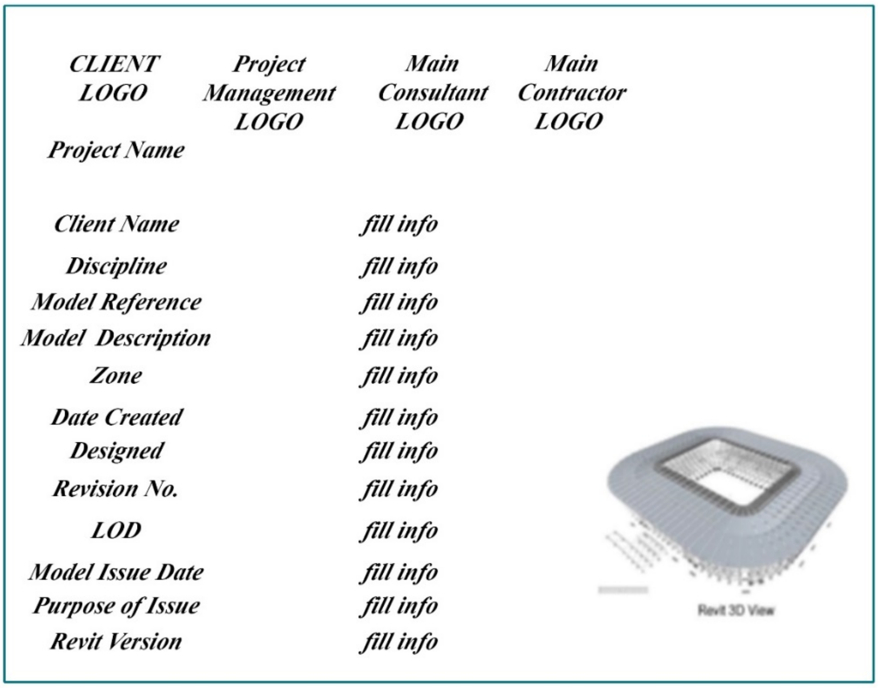
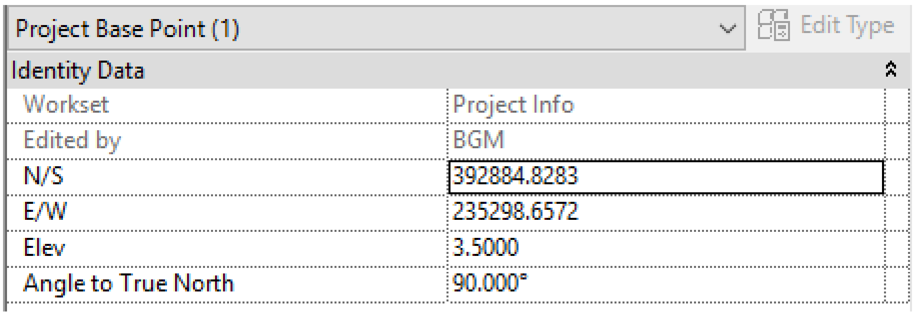


Figure 37 Project information and landing sheet



Project Base Point (1) — Edit Type

Identity Data	
Workset	Project Info
Edited by	BGM
N/S	392884.8283
E/W	235298.6572
Elev	3.5000
Angle to True North	90.000°

Figure 38 Revit model project base point information and parameters

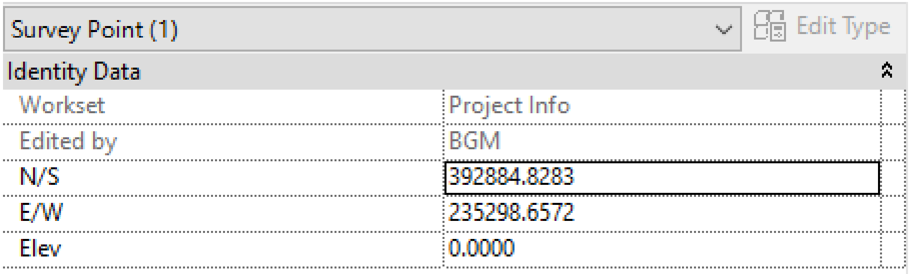


Figure 39 Revit model project survey point information and parameters

After that, the project BIM team should be providing information that covers the topics of copy and monitor, scope boxes setup, Grids, master grids (radial and multi segmented grids), and grid check. Where other subjects should be also covered within this section, like but not limited to:

1- shared coordinates.

2- Model content matrix.

3- Drawing title block information.

   a. (Revision history, client name and logo, management company name and logo, main contractor logo, design consultants names and logos, project title and other relevant information),

4- Working on model files methodologies.

5- Best practices recommended for the project.

6- Model linking rules

The BIM manager and BIM team should be providing screen shots from inside the Revit models. like the ones shown in Fig. 40 shows an illustration of some samples for the Revit model linking settings. While Fig. 41 describes a sample illustration of the Schedules creation settings. This section should clarify all the information needed for the work sets creation and setup.

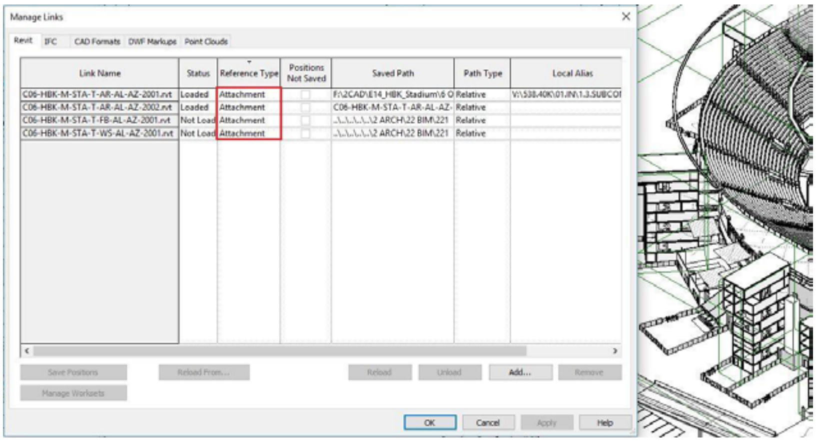


Figure 40 Revit model linking sittings

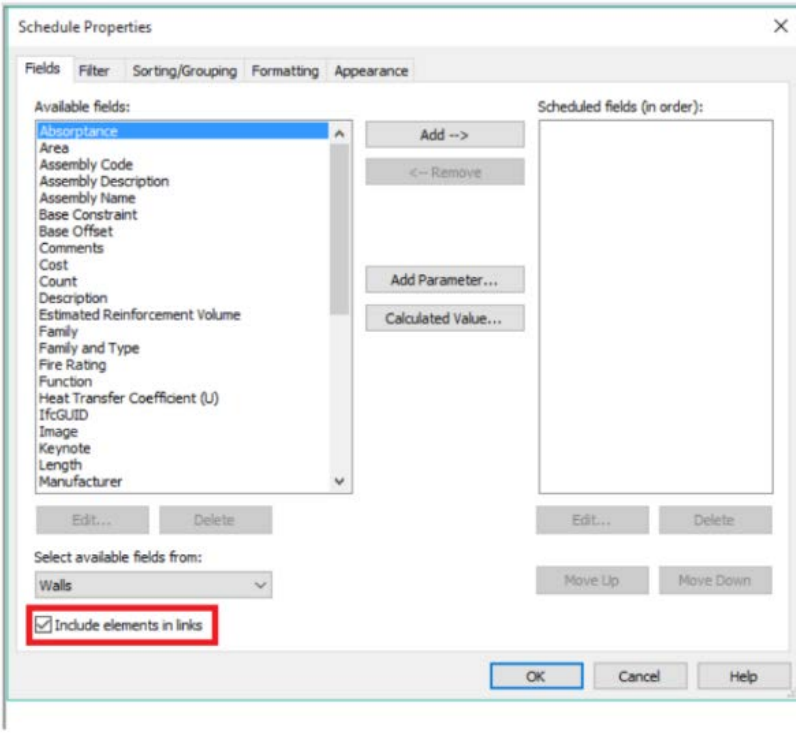


Figure 41 Revit schedules creation – elements from links treatment.

c. Non-authoring tools and workflows

The BIM team should clearly state the views and filters selection, naming, and color system that will be used for each trade or sub-discipline. These settings will be assigned to each corresponding view, providing screen shot to easily understand the content of this section. Fig.42 shows a sample of filters for 4D parameters as an example.

The BIM manual should also address the clash detection software, workflow, and procedures to be followed to specify and identify clashes within the models. It also shows how to identify the history of clashes in the clash detection report. In addition to the priority specifications of the clashes, as well as the type of clashes (hard Vs. soft), it must mention the exports-imports methods from Revit to Navisworks as mentioned. A guidance from Fig. 43 can be taken to help the team to do it properly. Additionally, any migration methodology needed between the used software packages, versions and formats should be mentioned and explained.

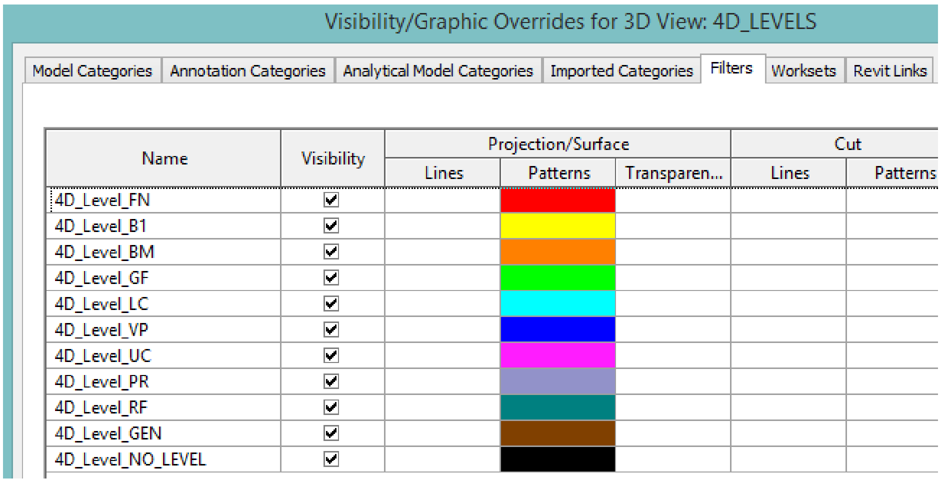


Figure 42 Sample of filters for 4D parameters

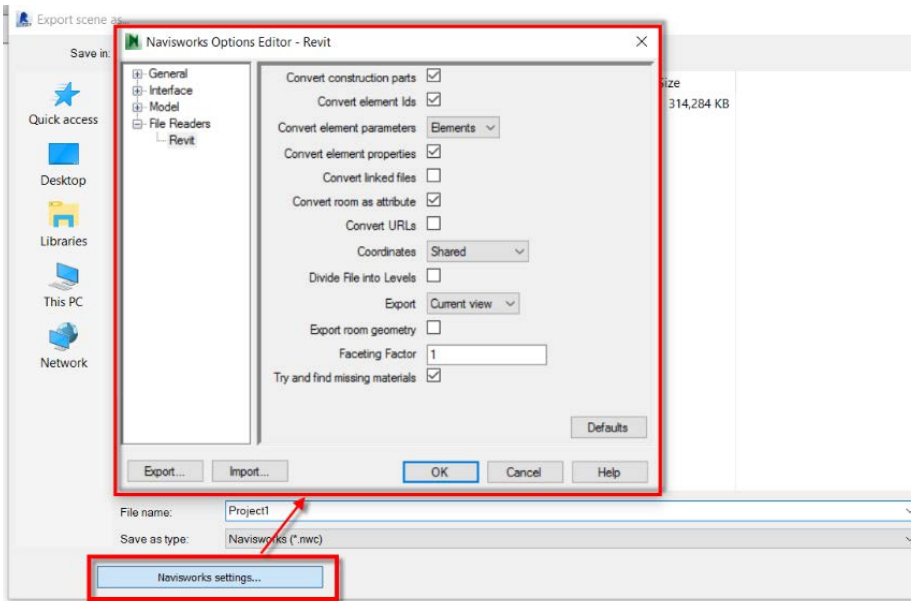


Figure 43 Revit export to Navisworks sittings

It is important to note that the BIM manual is an essential part of the BIM management documents. This document should be issued at the beginning of the project at the kick of stage; to make sure that all the participating teams are following the same procedures and methodologies. The benefit is to limit the errors and boost the productivity and teams' efficiency.

4.2.Thesis Built Model Practice, Analysis, and Results

In the BIM model building section of this thesis the author is planning to build a management model and document system based on the findings of the analysis of the case study done in the previous section. The purpose of this section is to find the best practice workflow that will support the objectives of the proposal in:

1- Managing BIM,
2- Building BIM models, and
3- Recording, measuring, and quantifying the circularity of the designed and built asset.

To achieve the above purpose, the author has followed the following step by step road map:

1- Analyzing the EIR document of another real project in Qatar.
2- Using the design model of the building which the EIR in step one of this section was designed for; and shared in the tender phase.
3- Develop the construction phase model to the LOD 400 level, which is used for the construction phase and shop drawings
4- Check if the circular economy components and concepts of design for disassembly, material passports and circularity measures parameters were added.
5- If the parameters were not added, the author will use the same model to develop the needed parameters, create the needed schedules, and explain the workflow used to implement the methodology
6- analyze the results of the BIM model and identify the circularity rate and ranks of some of the building components.
7- Recommend enhancements needed for the BIM models and the design criteria to enhance the circularity rank of the built asset.

The building chosen for the purpose of this section is located in Doha near to Doha corniche area shown in Fig. 44 below. The project phase achieved to date of this proposal information and models collected is the design phase models LOD 300, which were developed to construction phase models LOD 400.

Figure 44 Thesis proposal developed model.

The BIM management documents created to support the management of this project are complying to the EIR requirements were:

1- BIM execution plan,

2- BIM manual,

3- BIM QAQC management plan,

4- BIM compliance reports and BIM QAQC checklists.

While analyzing the EIR requirements for this project, it was found that the focus is on the construction phase of the project. That was due to delivering the project through a Design-Bid-Build delivery system. The project phase was the construction to handover phase; so the design was already done before the tendering. The project focuses on the purpose of supporting BIM workflow and procedures, sustainability, and engineering analysis, without having any requirements for the circular economy, so it is expected to get a low circularity rank of the built asset.

The building scope summary of the project is as shown in Table 17 but for the sake of this proposal. Due to the time constraint, the author chose to focus on the multifunctional building from package 01 of this project. And the area statement of package 01 is shown in table 18.

Table 17 Scope summary

No.	Building
01	Multi-functional Building
02	Existing restaurant
03	Existing prayer room
04	Existing gifts shop
05	Existing cafe

Table 18 Package 01 - Multi-functional building area statement

No.	Description	External area (m2)	Geo tank volume (m3)	Built up area (m2)	Type of structure
01	Multi-functional building (G+1st+roof+upper roof) MFB			5753.00	Concrete
02	Electrical substation SS01			200.34	Concrete
03	Water tanks and pump station 1 PS01			384.80	Concrete
04	Water tanks and pump station 1 PS01			285.65	Concrete
05	Landscaping including the MSE wall and green building wings covering	16000.00			
06	Storm water tanks		628.50		
07	MEP network				

After analyzing the LOD 300 design models of the multifunctional building has uncovered the fact that the models need to be developed. The development will be achieved by adding the needed construction phase models, solving the clashes between the trade elements, adding the COBie parameters, and adding the circular economy measurement parameters of the recyclability of elements, reusability of building components and the ability to remanufacturing element components.

Developing the construction model components has consumed 4 months in row of a team of engineers and BIM specialists from all trades. The team roles needed to develop the models were:

1- BIM manager to develop the BIM methodology, workflow and management documents.
2- BIM architecture engineers,
3- BIM architecture modelers,
4- BIM structure Engineers and modelers,
5- BIM electromechanical engineers and modelers,
6- BIM landscape engineers and modelers,
7- BIM coordinators
8- Information manager.

Fig.45 - 46 shows the resulting BIM model of the construction phase LOD 400. It was found the main building structure was designed using concrete and reinforcement, with a glazed façade on the exterior envelop and an MSE and botanical walls covering the building on the exterior shell. The green cover of the building has enhanced the sustainability rating of the building. It was required by the client to achieve a minimum of 3 stars on the GSAS rating system. The project comes with an outdoor landscape area to enhance the user experience and to provide outdoor park to support the project purpose.

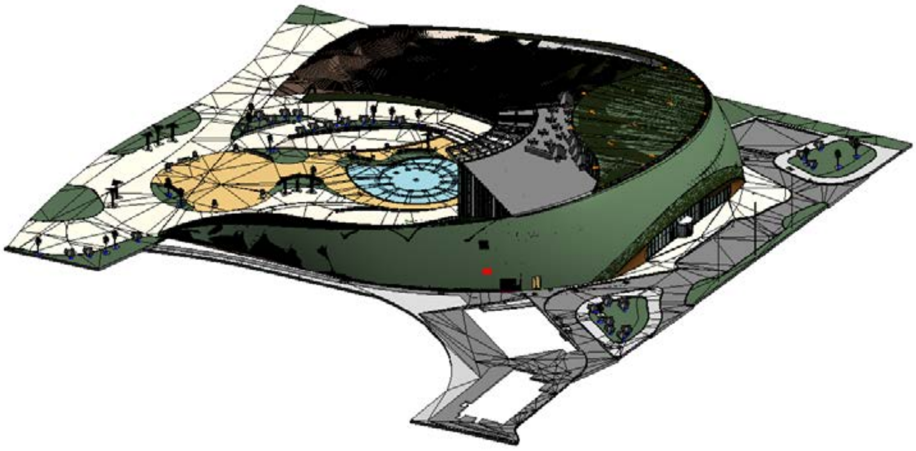


Figure 45 Thesis Developed BIM LOD 400 Revit Model – View 01

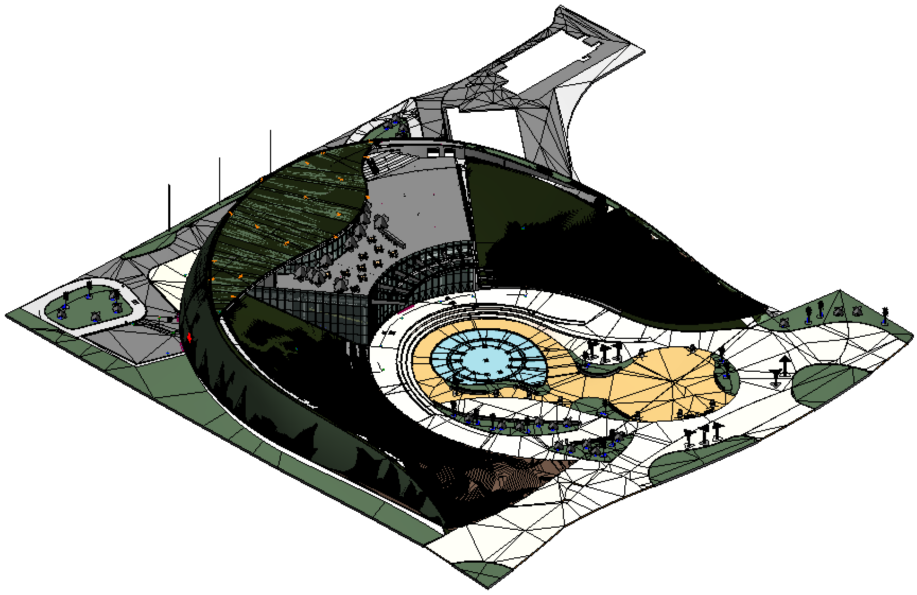


Figure 46 Thesis Developed BIM LOD 400 Revit Model – View 01

To be able to measure the circularity of the building components and the built asset; the author has created many shared parameters added to the LOD 400 model. These shared parameters were added to be able to create the schedules that may be able to measure and record the circularity. To achieve the same purpose; the manufacturer and contractor’s inputs were imported within the parameters. In addition to the specialist inputs gathered throughout the project, execution duration was also loaded to the model components. The method used to create the parameters is shown in Fig.47-54. The steps followed to make sure the maximum efficiency and practicality within AUTODESK Revit 2019 software after specifying what parameters needed are as follow:

1- Open Revit model project environment.
2- Go to manage tap and select shared parameters option.
3- Edit shared parameters popup window shows, select create option.
4- Create shared parameters dialogue box shows, first specify the shared parameter file name and location, specify shared parameter file type, click on save.
5- After saving the shared parameter file to the desired location, another dialogue box appears to edit the shared parameters, first the user needs to decide the grouping criteria for the shared parameters where he\she decides which group of parameters includes which specific parameters, the author decided to create four groups, namely, location, designed for disassembly, circularity, and other information parameter groups to include all the parameters needed. Shown in Fig. 48. The creation method is through clicking on new option button under Group option from the dialogue box.
6- After selecting which group the parameter refers to, click on new option button under the parameters option of the same dialogue box to initiate the parameter creation process.
7- A new pop-up window shows, the user needs to fill the needed parameter information by adding a name, selecting a discipline from the drop-down menu, and a type of parameter.
8- The user needs to follow the same method and repeat the same steps until he\she is done with creating all the needed parameters.

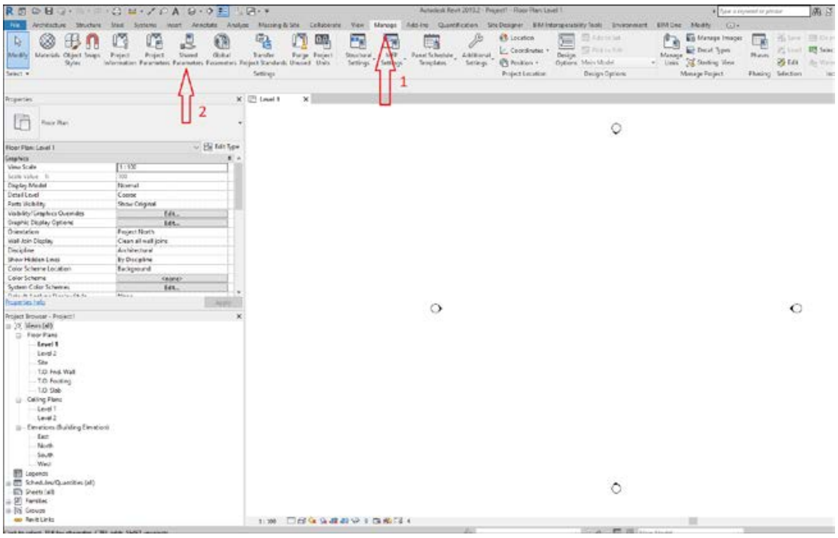


Figure 47 Creating shared parameters file option – Revit 2019

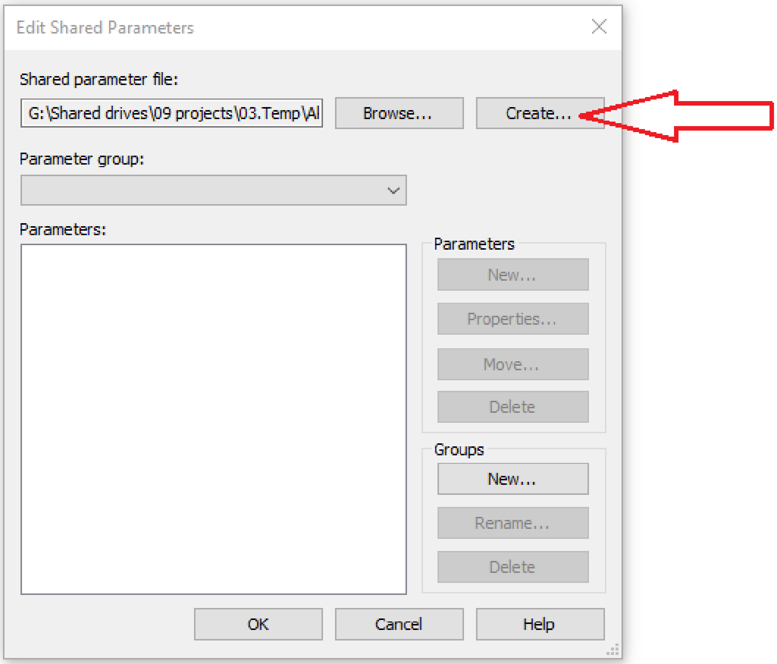


Figure 48 Edit shared parameters dialogue box – Revit 2019

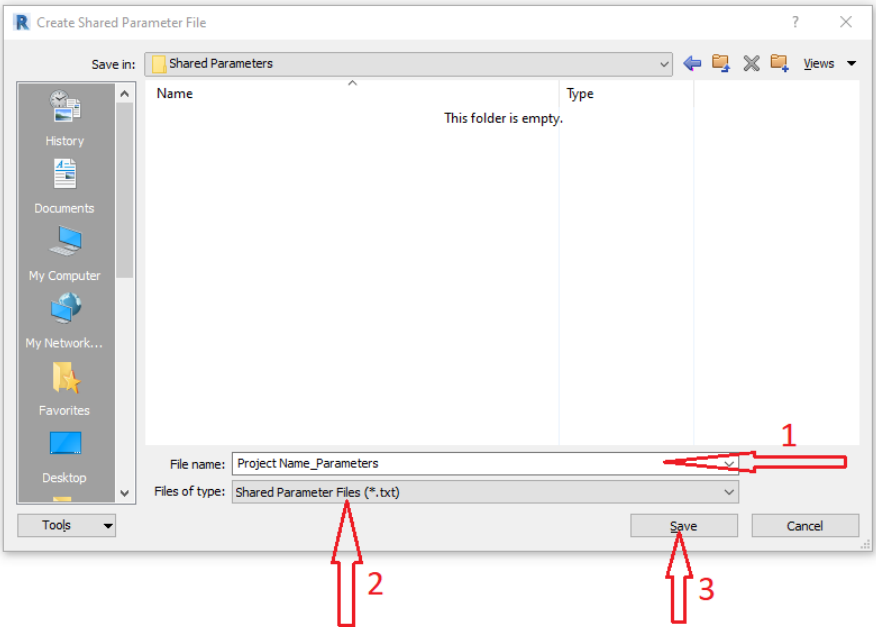


Figure 49 Create shared parameters file dialogue box – Revit 2019

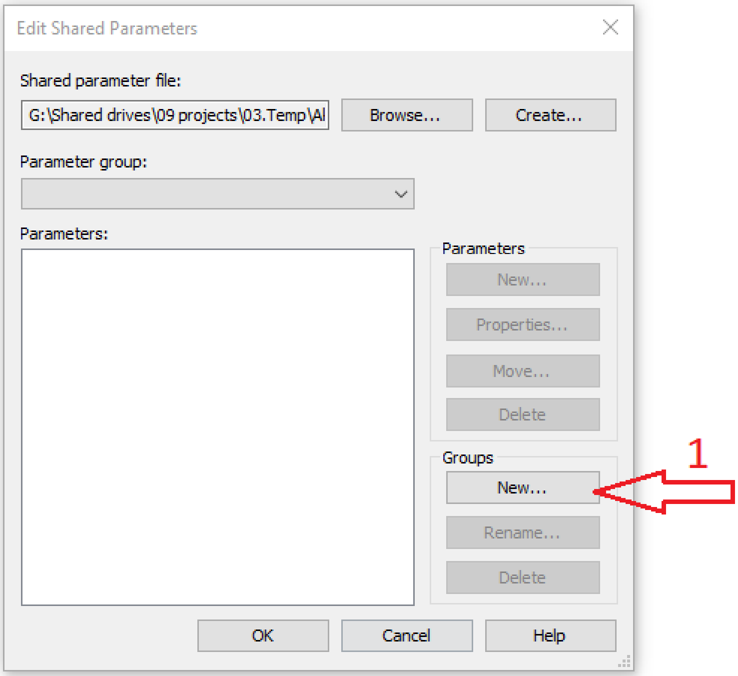


Figure 50 Edit shared parameters dialogue box – Revit 2019

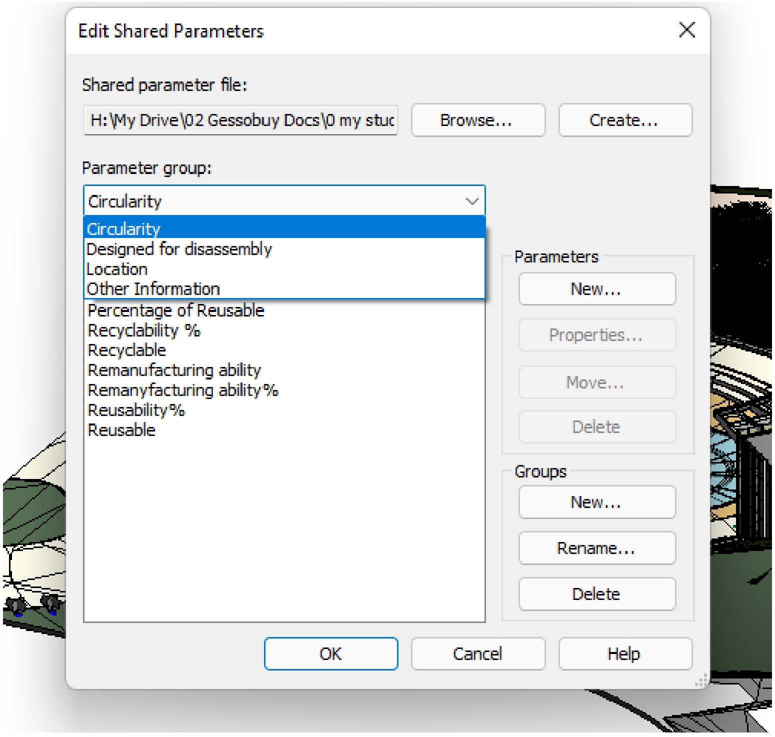


Figure 51 Creating shared parameters group dialogue box – Revit 2019

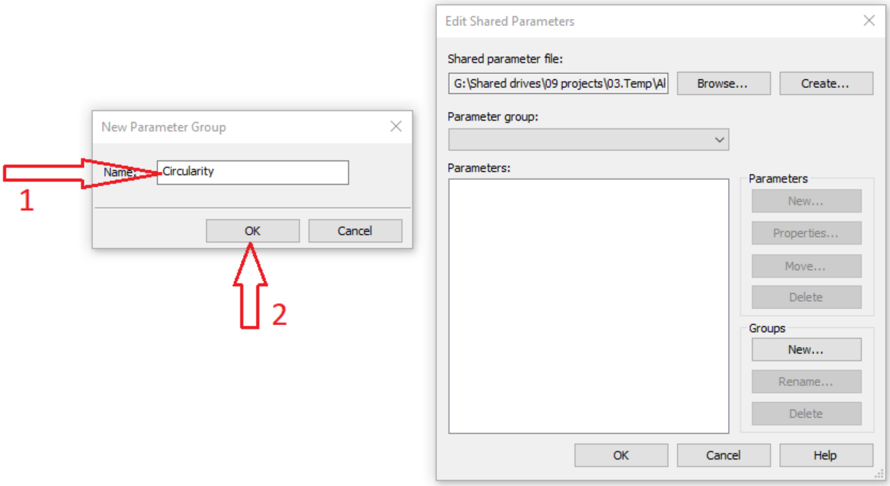


Figure 52 Specifying shared parameters group name dialogue box – Revit 2019

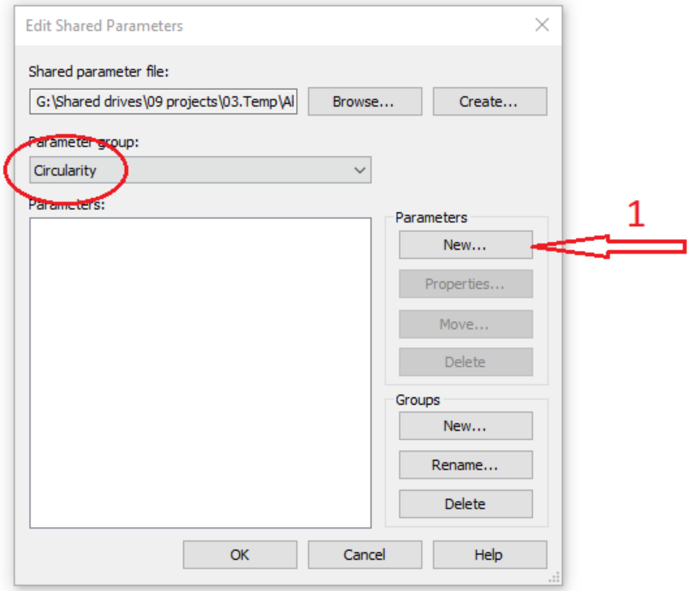


Figure 53 Creating new specific shared parameters group – Revit 2019

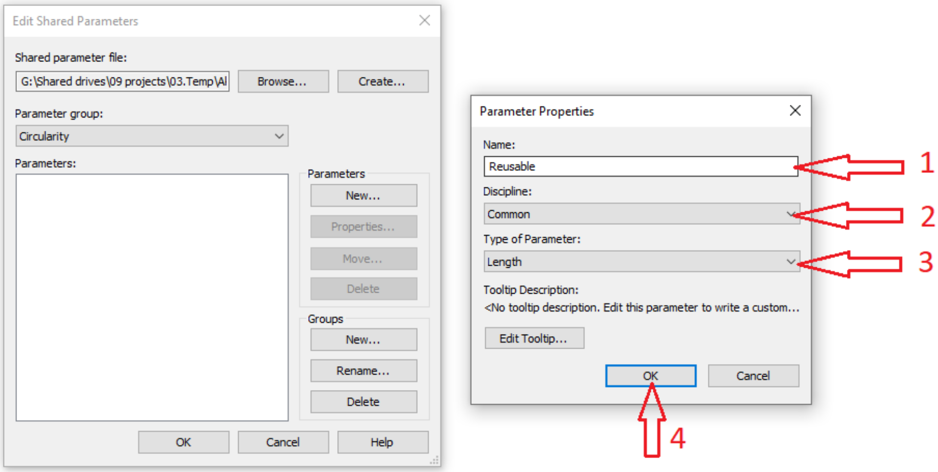


Figure 54 Creating new shared parameter information– Revit 2019

Now all the model components are modeled and loaded with all the information needed as per the agreed model element definition matrix, BIM execution plan, and the EIR requirements in addition to the LOD confirmed for the project stage, the user needs to move forward and start creating the circularity specific schedules to be able to start measuring the building circularity rate by selecting view option from the tools panel in AUTODESK Revit 2019, selecting schedule option and then clicking on schedule\quantity schedule type shown in Fig.55. The BIM author may use the following step by step methodology to create schedules:

1- Schedule properties window shows, the user begins to create new parameters, by clicking on new parameter option from the opened window (Fig.56).
2- Parameter's properties window shows (Fig.57). Select shared parameter type, click on select (Fig.58). SHARED PARAMETERS creation and selection dialogue box appears (Fig.59) to give the ability to select which shared parameters needs to be added to the schedule, the user selects the needed one. It is worthy to mention that the selection in this step will be among the created shared parameters in the shared parameter text file the user has already created in the previous steps.

3- After adding the new parameter, the user should specify that the parameter will be a type of parameter or an instance parameter (Fig.59). In addition, the author should specify which categories of the building components will have this added parameter in the schedule, for example, doors, windows, furniture, column, HVAC ducts and so on (Fig.59).

4- Then the user can start creating all the needed schedules by component separately (doors, windows, walls, column, furniture, etc.) (Fig.60). Or to create a multi category schedule that contains different categories, and selecting which fields are needed to be shown on the schedules created.

5- For the study of this proposal, the author created specific component schedules in addition to experiencing multi category schedules.

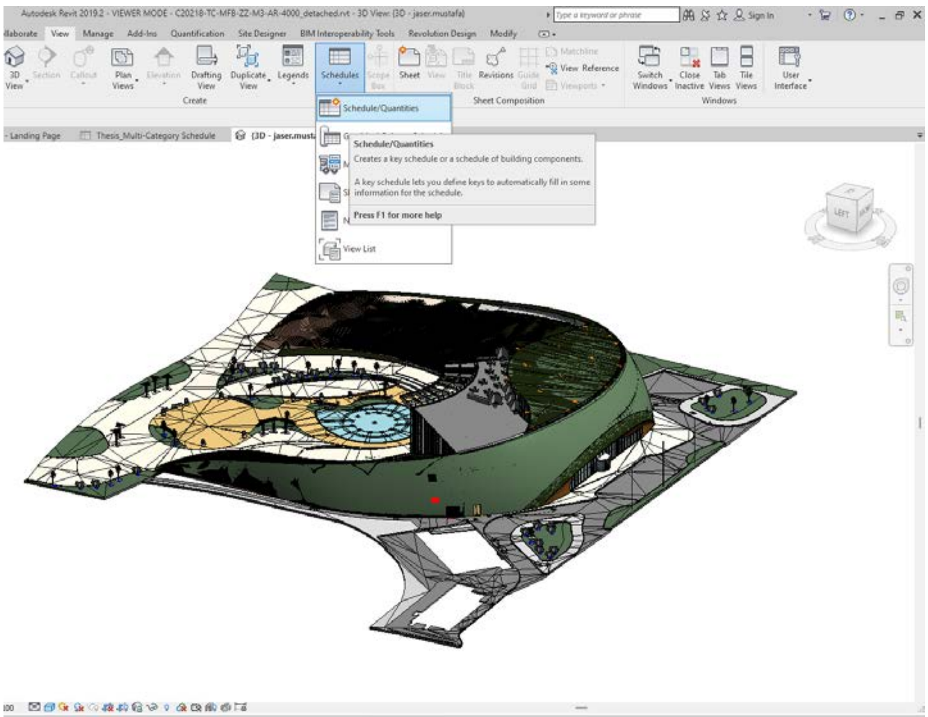


Figure 55 Creating circularity ranking schedules – Revit 2019

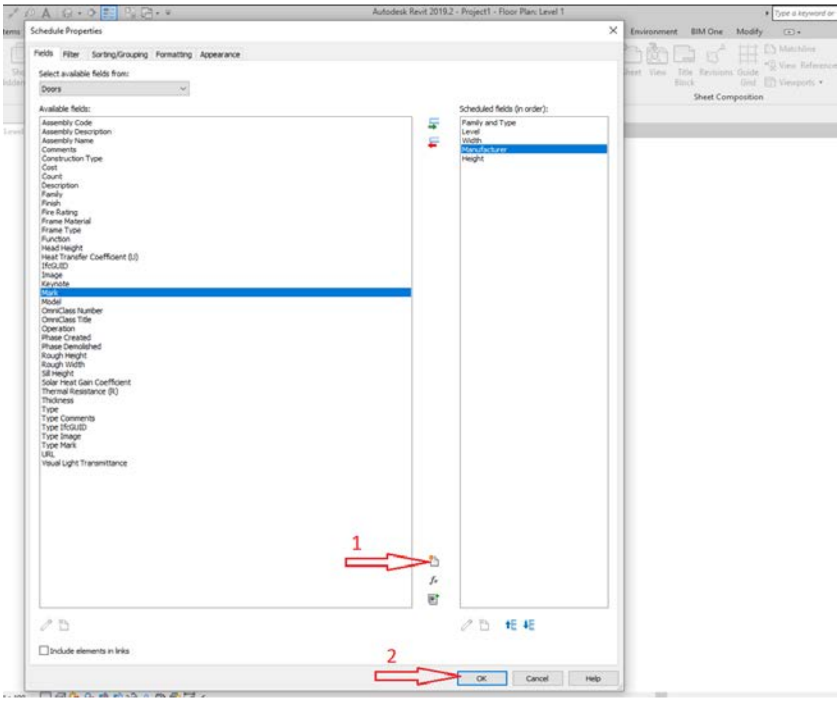


Figure 56 Creating shared parameters and adding them to circularity ranking schedules – Revit 2019

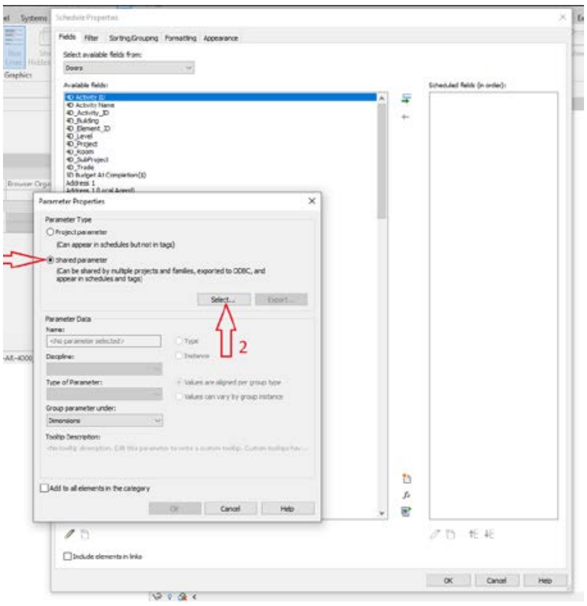


Figure 57 Specifying shared parameters properties and adding them to circularity ranking schedules – Revit 2019

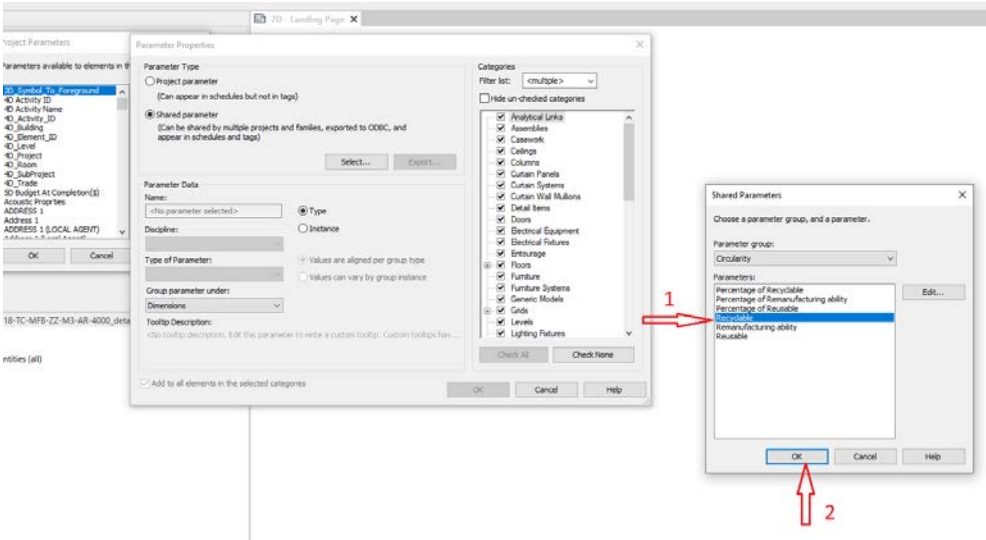


Figure 58 Adding shared parameters to circularity ranking schedules – Revit 2019

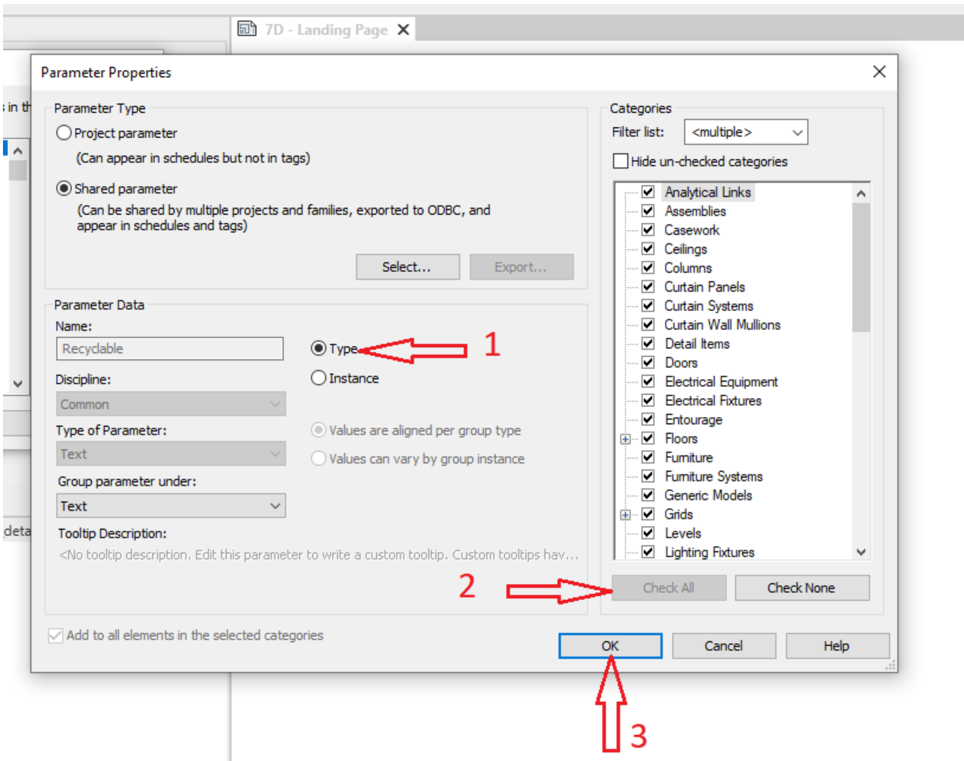


Figure 59 Adding shared parameters properties and adding them to circularity ranking schedules – Revit 2019

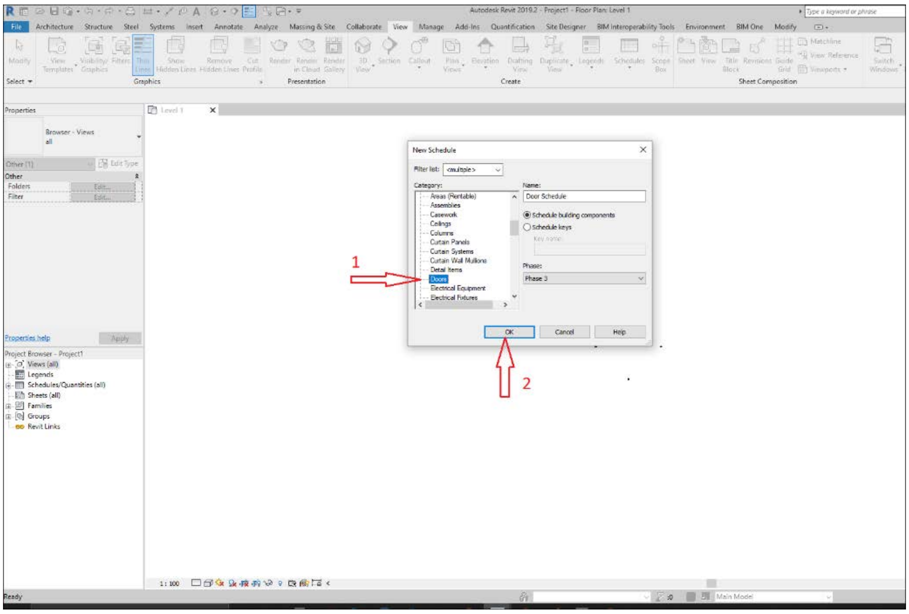


Figure 60 Creating specific component circularity ranking schedules – Revit 2019

After adding and creating all the schedules needed for the circularity ranking inside the upgraded LOD 400 models, the BIM specialists and engineers should gather all the information from the suppliers and specialists of the approved materials and furniture for the building in the construction phase. Then the BIM authors use the collected information and fill them accurately in the BIM circularity ranking schedule. This can be achieved by adding the recyclability, reusability, remanufacture, and design for disassembly percentages information. This will make it easier for the engineers and stakeholders to figure out each building component's circulatory parameter rank. This will also develop a comprehensive parameter rank. The author of this proposal suggested creating a circularity calculation parameter by adding a CALCULATED PARAMETER to the schedule. This added parameter will automatically calculate the total circularity of the components by using the simple average formula below:

Circularity percentage = (reusability% + recyclability% + ability to remanufacture%)/3

For example, a door family can have the parameters of reusability, recyclability, and ability to remanufacturing options as shown in Fig.61. The same method applies to every single component in the model. Many other parameters are added to measure and record all the component information, manufacturing information, assembly and disassembly parameters, and all other information. Fig. 62-65 show the parameters added.

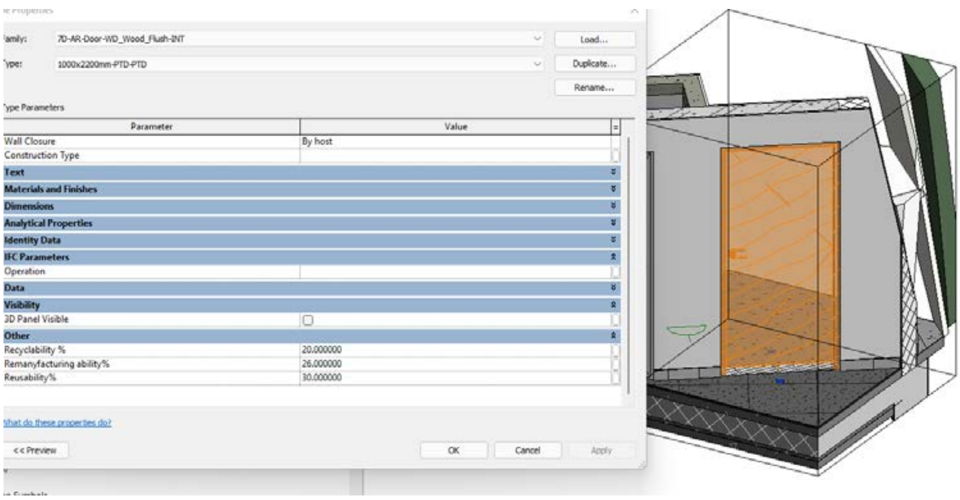


Figure 61 Door family circularity type parameters – Revit 2019

The schedules created for the purpose of satisfying this thesis proposal included the following parameters:

1- Family and Type, which shows the information of the model component.

2- Building which shows the building that the component is a part of

3- Zone, level, and space\room of the component.

4- Circularity measuring parameters

   a. Reusable (if the component is reusable after at the end-of-life stage which is a yes or no parameter)

   b. Percentage of reusability (percentage parameter)

c. Recyclable (if the component is recyclable after at the end-of-life stage which is a yes or no parameter)
d. Percentage of recyclability (percentage parameter)
e. Remanufacturing ability (if the component can be remanufactured after at the end-of-life stage which is a yes or no parameter)
f. Percentage of Remanufacturing ability (percentage parameter)
g. Dissamble parameter, tell if the component can be disassembled at the end-of-life stage)

5- In addition to other industry standards parameters:

a. Master Class Format
b. Classification Master Format Description
c. Classification Master Format Number
d. COBie Reference
e. COBie Component Description
f. COBie Created By (name)
g. COBie Created On (date)
h. COBie Finish
i. COBie Grade
j. COBie Height
k. COBie Length
l. COBie Manufacturer
m. COBie Master Format
n. COBie Material
o. COBie Model Number
p. Supplier

q. Warranty

r. Warranty Duration

s. Warranty Description

t. COBie Component Warranty Start Date

u. COBie Component Serial Number

v. COBie Component Name

It is worthy to mention that the above parameters specifically COBie and master format parameters are mandatory. They are used in the facility management and asset management model delivery. This model is going to be used in the operation and in use phase of the project life cycle. And the purpose of this model is to help facility management team and maintenance and operation teams to operate and maintain the asset.

After the creation of all the parameters needed and specified by the engineering teams working on the project should be creating the needed circularity schedules. This should be achieved with the confirmation of the client engineering teams and the supervision consultant. The goal of this process id to be able to measure the circularity of an asset. The resulting schedules should be similar to the ones shown in Fig. 62-65.

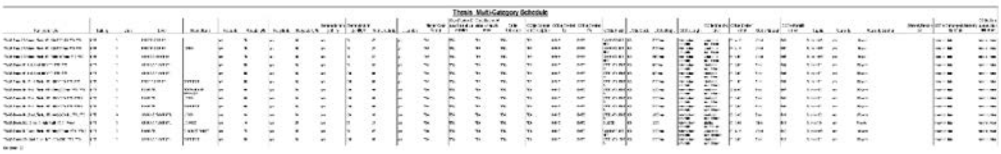


Figure 62 Door circularity schedule sample – Revit 2019

Family and Type	Building	Zone	Level	Room: Name	Reusable	Reusability%	Recyclable	Recyclability %	Remanufacturing ability	Remanufacturing ability%	% of Circularity	Dissamble	Master Class Format	Classification.MasterFormat.Description	Classificati
TD-AR-Door-WD_Wood_Flush-INT 900x2200MM-PTD-PTD	MFB	01	FIRST FLOOR-FFL		yes	75	yes	95	yes	90	87	yes	TBA	TBA	TBA
TD-AR-Door-WD_Wood_Flush-INT 920x2200mm-PTD-PTD	MFB	01	FIRST FLOOR-FFL	LOBBY	yes	75	yes	95	yes	90	87	yes	TBA	TBA	TBA
TD-AR-Door-WD_Wood_Flush-INT 1000x2400mm-PTD-PTD	MFB	01	GROUNDFLOOR-FFL		yes	75	yes	95	yes	90	87	yes	TBA	TBA	TBA
TD-AR-Doors-AP_HM_Steel 500x800_PTD_PTD	MFB	01	GROUNDFLOOR-FFL		yes	90	yes	98	yes	90	93	yes	TBA	TBA	TBA
TD-AR-Doors-AP_HM_Steel 500x800_PTD_PTD	MFB	01	GROUNDFLOOR-FFL		yes	90	yes	98	yes	100	96	yes	TBA	TBA	TBA
TD-AR-Doors-HM_Steel_Flush_INT 1500x2200_PTD_PTD	MFB	01	FIRST FLOOR-FFL	CORRIDOR	yes	90	yes	98	yes	100	96	yes	TBA	TBA	TBA
TD-AR-Doors-HM_Steel_Flush_INT 1500x2200mm_PTD_PTD	MFB	01	ROOF-FFL	RESTAURANT TERRACE	yes	90	yes	98	yes	100	96	yes	TBA	TBA	TBA
TD-AR-Doors-HM_Steel_Flush_INT 1550x2200_PTD_PTD 2	MFB	01	ROOF-FFL	LOBBY	yes	90	yes	98	yes	100	96	yes	TBA	TBA	TBA
TD-AR-Doors-HM_Steel_Flush_INT 1550x2200_PTD_PTD 2	MFB	01	ROOF-FFL	CORRIDOR	yes	90	yes	98	yes	100	96	yes	TBA	TBA	TBA
TD-AR-Doors-HM_Steel_Flush_INT 1800x2400MM_PTD_PTD	MFB	01	GROUNDFLOOR-FFL	LOBBY	yes	90	yes	98	yes	100	96	yes	TBA	TBA	TBA
TD-AR-Doors-SGL_Glass_Curtain Wall HD_01_Wood	MFB	01	GROUNDFLOOR-FFL	LOUNGE	yes	10	yes	25	yes	35	23	yes	TBA	TBA	TBA
TD-AR-Doors-SL_Wood_Flush_INT 900x2200mm_PTD_PTD 2	MFB	01	ROOF-FFL	DISABLED TOILET	yes	75	yes	95	yes	90	87	yes	TBA	TBA	TBA
TD-AR-Doors-WD_Steel_Flush_INT 1800x2200_PTD_PTD	MFB	01	GROUNDFLOOR-FFL	CORRIDOR	yes	90	yes	98	yes	100	96	yes	TBA	TBA	TBA

Grand total: 20

Thesis_Multi-

Figure 63 Door circularity schedule sample part 01

Thesis_Multi-Category Schedule

Classification.MasterFormat.Description	Classification.MasterFormat.Number	CoBie.Reference	COBie.ComponentDescription	COBie.Created By	COBie.Created On	COBie.Finish	COBie.Grade	COBie.Height	COBie.Length	COBie.Manufacturer	COBie.MasterFormat	COBie.Material	COBie.ModelNumber	Supplier	Warranty	Warranty Duration	WarrantyDescription
TBA	TBA	TBA	TBA	NAME	DATE	WOOD-POLISHED	N/A	2200mm	refer to door schedule	wood door manufacturer	081416	Wood	D01	Supplier W01	yes	10 years	
TBA	TBA	TBA	TBA	NAME	DATE	WOOD-POLISHED	N/A	2200mm	refer to door schedule	wood door manufacturer	081416	Wood	D02	Supplier W01	yes	10 years	
TBA	TBA	TBA	TBA	NAME	DATE	WOOD-POLISHED	N/A	2400mm	refer to door schedule	wood door manufacturer	081400	Wood	D03	Supplier W01	yes	10 years	
TBA	TBA	TBA	TBA	NAME	DATE	STEEL-POLISHED	N/A	800mm	refer to door schedule	steel door manufaturer	081300	Steel	D04	Supplier S01	yes	25 years	
TBA	TBA	TBA	TBA	NAME	DATE	STEEL-POLISHED	N/A	800mm	refer to door schedule	steel door manufaturer	081300	Steel	D05	Supplier S01	yes	25 years	
TBA	TBA	TBA	TBA	NAME	DATE	STEEL-POLISHED	N/A	2200mm	refer to door schedule	steel door manufaturer	081100	Steel	D06	Supplier S01	yes	25 years	
TBA	TBA	TBA	TBA	NAME	DATE	STEEL-POLISHED	N/A	2200mm	refer to door schedule	steel door manufaturer	224400	Steel	D07	Supplier S01	yes	25 years	
TBA	TBA	TBA	TBA	NAME	DATE	STEEL-POLISHED	N/A	2200mm	refer to door schedule	steel door manufaturer	081300	Steel	D08	Supplier S01	yes	25 years	
TBA	TBA	TBA	TBA	NAME	DATE	STEEL-POLISHED	N/A	2200mm	refer to door schedule	steel door manufaturer	081300	Steel	D09	Supplier S01	yes	25 years	
TBA	TBA	TBA	TBA	NAME	DATE	STEEL-POLISHED	N/A	2600mm	refer to door schedule	steel door manufaturer	081300	Steel	D10	Supplier S01	yes	25 years	
TBA	TBA	TBA	TBA	NAME	DATE	GLAZED	N/A	2200	refer to door schedule	glazing maufacturer	081301	Glass	D11	Supplie G01	yes	5 years	
TBA	TBA	TBA	TBA	NAME	DATE	WOOD-POLISHED	N/A	2200mm	refer to door schedule	wood door manufacturer	081416	Wood	D12	Supplier W01	yes	10 years	
TBA	TBA	TBA	TBA	NAME	DATE	STEEL-POLISHED	N/A	2200mm	refer to door schedule	steel door manufaturer	081300	Steel	D13	Supplier S01	yes	25 years	

Figure 64 Door circularity schedule sample part 02

COBie.Created On	COBie.Finish	COBie.Grade	COBie.Height	COBie.Length	COBie.Manufacturer	COBie.MasterFormat	COBie.Material	COBie.ModelNumber	Supplier	Warranty	Warranty Duration	WarrantyDescription	COBie.Component.WarrantyStartDate	COBie.Component.SerialNumber
DATE	WOOD-POLISHED	N/A	2200mm	refer to door schedule	wood door manufacturer	081416	Wood	D01	Supplier W01	yes	10 years		operation date	serial number
DATE	WOOD-POLISHED	N/A	2200mm	refer to door schedule	wood door manufacturer	081416	Wood	D02	Supplier W01	yes	10 years		operation date	serial number
DATE	WOOD-POLISHED	N/A	2400mm	refer to door schedule	wood door manufacturer	081400	Wood	D03	Supplier W01	yes	10 years		operation date	serial number
DATE	STEEL-POLISHED	N/A	800mm	refer to door schedule	steel door manufaturer	081300	Steel	D04	Supplier S01	yes	25 years		operation date	serial number
DATE	STEEL-POLISHED	N/A	800mm	refer to door schedule	steel door manufaturer	081300	Steel	D05	Supplier S01	yes	25 years		operation date	serial number
DATE	STEEL-POLISHED	N/A	2200mm	refer to door schedule	steel door manufaturer	081100	Steel	D06	Supplier S01	yes	25 years		operation date	serial number
DATE	STEEL-POLISHED	N/A	2200mm	refer to door schedule	steel door manufaturer	224400	Steel	D07	Supplier S01	yes	25 years		operation date	serial number
DATE	STEEL-POLISHED	N/A	2200mm	refer to door schedule	steel door manufaturer	081300	Steel	D08	Supplier S01	yes	25 years		operation date	serial number
DATE	STEEL-POLISHED	N/A	2200mm	refer to door schedule	steel door manufaturer	081300	Steel	D09	Supplier S01	yes	25 years		operation date	serial number
DATE	STEEL-POLISHED	N/A	2600mm	refer to door schedule	steel door manufaturer	081300	Steel	D10	Supplier S01	yes	25 years		operation date	serial number
DATE	GLAZED	N/A	2200	refer to door schedule	glazing maufacturer	081301	Glass	D11	Supplie G01	yes	5years		operation date	serial number
DATE	WOOD-POLISHED	N/A	2200mm	refer to door schedule	wood door manufacturer	081416	Wood	D12	Supplier W01	yes	10 years		operation date	serial number
DATE	STEEL-POLISHED	N/A	2200mm	refer to door schedule	steel door manufaturer	081300	Steel	D13	Supplier S01	yes	25 years		operation date	serial number

Figure 65 Door circularity schedule sample part 03

The circularity parameters are to be filled using the manufacturer and specialists' input. The parameters should tell the percentage value for the reusability, recyclability, and ability to remanufacture. Finally, a calculated parameter of the circularity percentage will calculate the total circularity factor. This will be achieved using the average formula shown in the previous sections. A sample of the circularity measurement is shown in Fig. 66.

Reusable	Reusability%	Recyclable	Recyclability %	Remanufacturing ability	Remanyfacturing ability%	% of Circularity	Dissamble
yes	75	yes	95	yes	90	87	ye
yes	75	yes	95	yes	90	87	ye
yes	75	yes	95	yes	90	87	ye
yes	90	yes	98	yes	90	93	ye
yes	90	yes	98	yes	100	96	ye
yes	90	yes	98	yes	100	96	ye
yes	90	yes	98	yes	100	96	ye
yes	90	yes	98	yes	100	96	ye
yes	90	yes	98	yes	100	96	ye
yes	90	yes	98	yes	100	96	ye
yes	10	yes	25	yes	35	23	ye
yes	75	yes	95	yes	90	87	ye
yes	90	yes	98	yes	100	96	ye

Figure 66 Circularity parameters and circularity calculated parameter

Following the above-mentioned methodology and workflow will enable practitioners and industry professionals to use the BIM models in an efficient way to figure our building components circularity factors and percentages. This will inform stakeholders and project users, and teams on the circularity potential. Having this piece of information will provide a solid and reliable database that can support the decision-makers and building designers and engineers to make the best decisions on the enhancements and development criteria of the design of the built asset to achieve better circularity and sustainability raking.

Due to the time constraint on this proposal, the study was limited on building the model, updating the model component to LOD 400, adding the circular economy parameters, measure the circularity of one of the building components as a case study and validation test of the built model. This process should be repeated to all project components in the Revit models and among all the project trades and disciplines. Achieving the mentioned will provide a great potential for future expansion of this study area. The purpose of the future expansion is to enhance the built model and methodology to serve wider range of industry areas, provide more enhanced and sophisticating methodology, and connect it to a cloud base model. This will also involve big and open BIM in the process.

4.3.Survey Analysis

As discussed in previous chapters of this thesis and as explained in the thesis structure section previously, the survey has covered the areas of practice and workflow. Those areas that needed to be clarified and required an input from the field professionals; to support the purpose and objective of this proposal. The survey areas are as follows:

1- BIM practice in the construction industry,

2- BIM workflow challenges,

3- BIM workflow benefits for minimizing construction errors,

4- BIM benefits to implement circular economy concepts,

5- BIM practice gaps, Recommendations for better BIM circularity.

The Circular Economy, building information modeling, and sustainability in the construction survey was distributed among 40 specific professionals from the industry. Those professionals are believed to have the needed competency and capability with the required skills and accumulative experience. The scope of the professionals is to answer the survey properly and give reliable answers and recommendation, which the author can rely on when building the thesis recommendations and future practice. The purpose is to serve both the research and academia, and professional practice sector. Among the 40 responding professionals, for the past five years, there were 17 practitioners located in Jordan, (4 of them stated are working also in other locations), 15 professionals working in Qatar, (1 of them has stated that he\she is working in Saudi Arabia as well), 1 professional from the UAE, another professional from USA, in addition to 1 more practitioner from UK, 1 Engineer from Canada, 1 professional practitioner from Egypt, one practitioner has missed the answer and mentioned his company name which the author considered in Qatar, and 1 professional from Mauritius, with the last professional respond which did not show the location properly. The chart in Fig. 67 shows the analysis of the professionals' work location in the past five years.

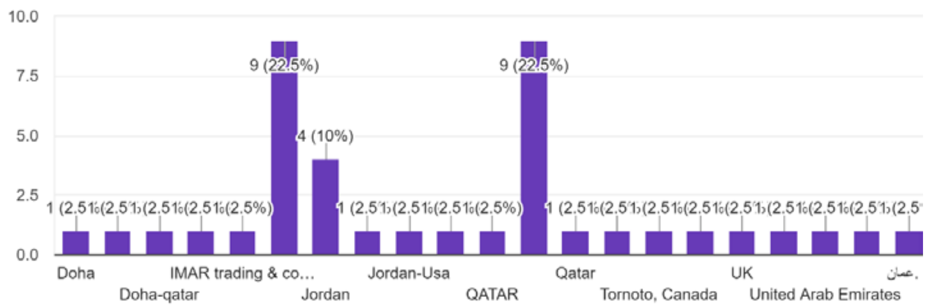


Figure 67 Work location during the last 5 years of the survey participants

When it comes to the years of experience, the survey has provided three main categories to divide the participants based on their relevant years of experience, namely, less than 5 years of experience, 5-10 years of experience, and more than 10 years of experience, with corresponding answers percentages on the survey form of 12.50%, 40%, and 47.5% respectively. This makes our results more reliable and trustworthy. That is because the majority of the participants are with more than 10 years of experience. The second category with a higher percentage of participants in the 05-10 years of experience.

On the other hand, the survey has also investigated the positions and roles of the participating engineers. It was found that 10 of the professionals are in BIM coordinator positions, with the highest percentage among the participants. The percentage of the coordinator position has reached the edge of 25%. 17.5% BIM managers among the total of the engineers who have answered the survey, representing 7 Engineers. While team leaders have participated and shared their inputs for the use of this thesis, which represents a percentage of 12.5%. 10% (4) design managers had added their input as well. The remaining percentage was distributed among the other positions of BIM modeler, project manager, department head, BIM lead, senior design manager, construction manager, and faculty member. Fig. 68 shows a representation of the professional information gathered from the participants in the first section of the thesis survey.

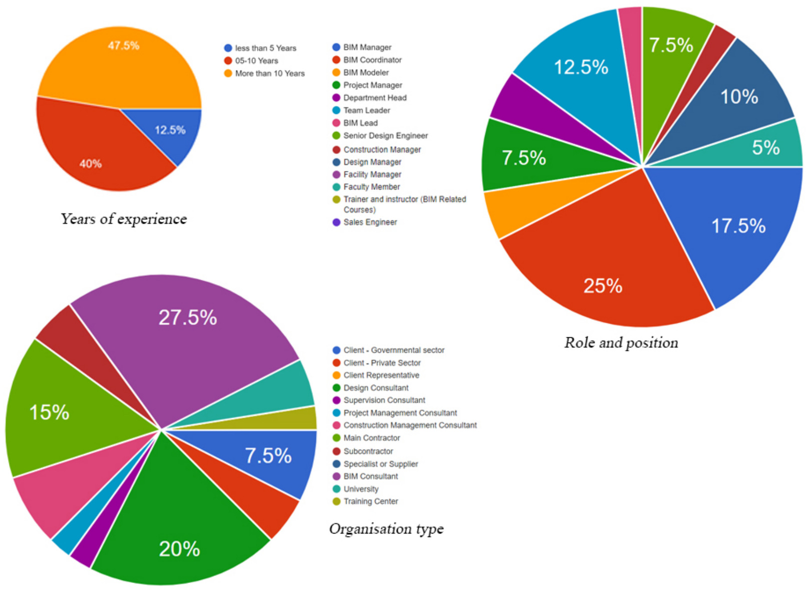


Figure 68 Participants professional information

In the second part of the survey the author has investigated on the BIM practice in the construction industry. This section is asking BIM, type of scope, level of development, sustainability, circular economy, material passports, and software-based questions; to make sure that the targeted participants are from the field. This can serve the thesis objective, where the results were as follows:

1- 75% of the participants had BIM requirements in their latest five projects while 25% had not.

2- 60% of the participants are from a construction phase background as there latest 2 projects they have worked on were in the construction stage, while the remaining 40% were from a design stage environment.

3- When it came to the Level of development (LOD) required in their latest projects, it was found that 10% of the responds had an LOD 200 requirements in their projects, 22.5% had LOD 300, 25% had LOD 400 and the remaining 42.5% had LOD 500 among their BIM requirements.

4- Regarding the sustainability and green design requirements, the survey showed that 40% did not have requirements among their latest projects. While the remaining 60% is divided equally between having sustainability requirements among all their projects and having the requirements among some of them.

5- When asked about circular economy requirements, 25% of the participants had Circular economy requirements in their latest projects. The remaining 75% did not have any requirements. This shows the gap in the practice where the majority of the practitioners did not have any circular economy requirements among their latest projects.

6- The survey had shown that 75% of the participants had the requirements of setting up and use of well-structured Common Data Environments for the project information exchange, design collaboration, coordination, development, and other information management requirements.

7- Among the organizations the participants represent, 67.5% had satisfied the BIM requirements of their projects. 22.5% had no BIM requirements, and 10% could not satisfy the requirements.

8- 22.5% of the participants' organizations had not comply to the circular economy requirements, while 52.5% did not have any requirements. But 25% of the participants had stated that their organizations could satisfy the circular economy requirements on their latest projects.

9- Only 50% of the projects' clients had issued BIM exchange information requirements (EIR) before the kickoff of the project.

10- 67.5% of the companies had issued a corresponding BIM execution plan (BEP), 17.5% had not produce the required BEP while 15% of the companies did not have BEP requirements in their latest projects.

11- 20 professionals have stated that they have issued a BIM manual to support the project team achieving the BIM requirements on the project. 8 of the engineers had not issue the BIM manual, and the remaining 12 engineers had stated that it was not required in their projects.

12- When asked about the BIM quality assurance and quality control plan and check lists, only 24 professionals among the 40 participants had created the BIM QAQC plans and checklists.

Points 1 through 4 make this survey results super fit to this thesis proposal main objective of building a reliable framework for the industry practitioners; to connect the three pillars of BIM, Circular Economy, and sustainability in the construction industry. It also makes the results very trustworthy and reliable. Having a deep look on Point 5 shows that there is a gap in the practice, when it comes to requiring Circular economy on the projects. This in a way or another will help promoting and support the implementation of circular economy in the construction industry. Points 6 into 12 show some failure rates among the participants' organizations in satisfying the project requirements of BIM, Circular economy, and sustainability. This also represents the failure in issuing, authoring, and producing the BIM management documents, which should help the teams to achieve a better rate of success at the project completion stage. Fig.69 shows a graphical representation on the survey results analysis to a better understanding of the mentioned points.

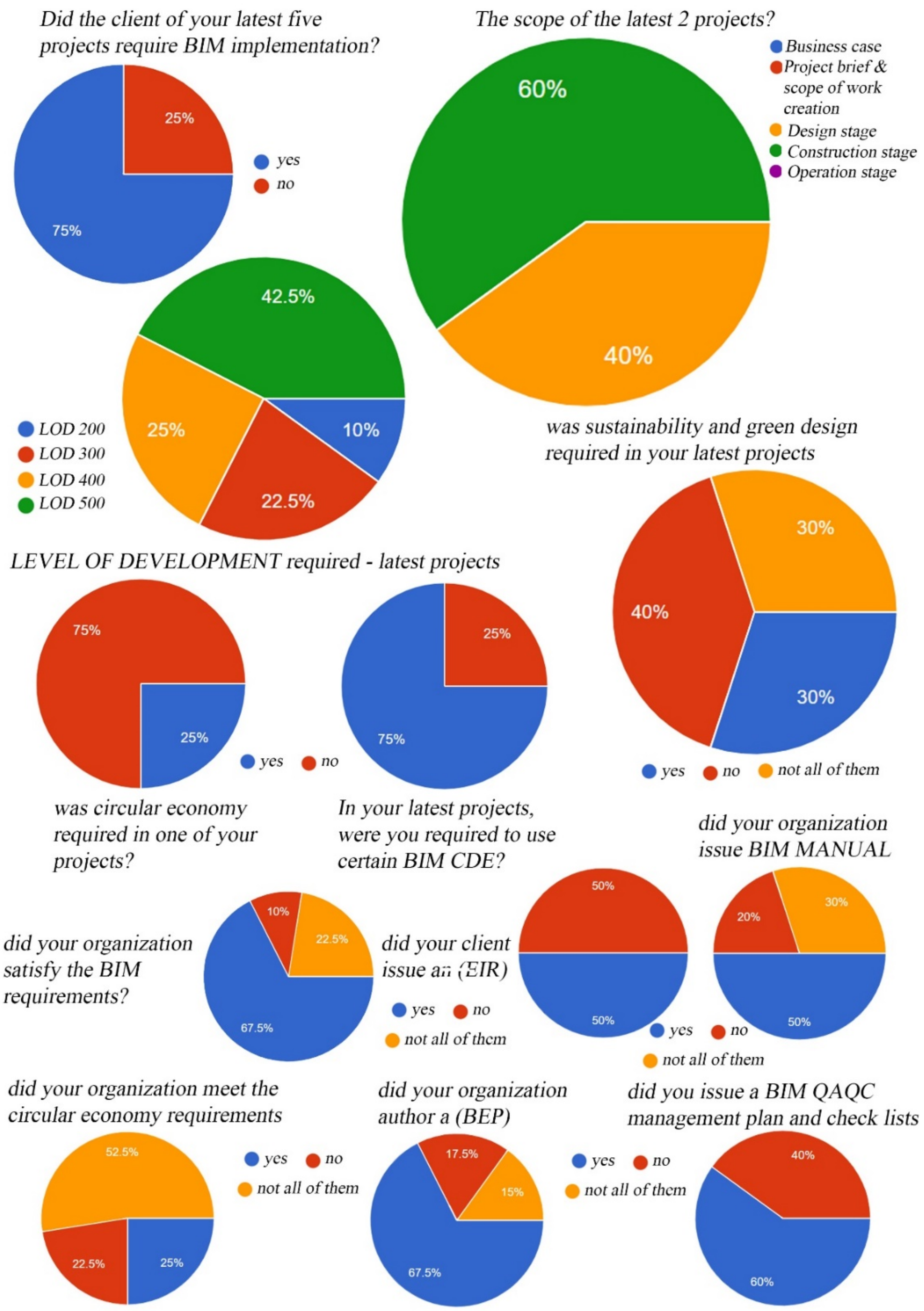


Figure 69 Participants BIM Practice in the Construction Industry

Following to the previously discussed results of the second section of the survey, it has also focused on investigating the most used software for the purpose of BIM modeling and interface conflicts and clash detection in construction projects. It was found that Autodesk Revit was the most common used modeling software. Autodesk

Navisworks is the one used for the clash detection task. Some of the participants has stated that they use Autodesk civil 3D, Autodesk robot structure, rhino, dynamo, sketchup and Autodesk Infraworks. The use of each software trade wise is, architecture, structure, mechanical, electrical and plumbing when it comes to Autodesk Revit. For the landscape and roads professionals use Autodesk civil 3Ds. For underground utilities the use Autodesk infraworks. Structural engineers usually use robot structure. And architects use sketchup and AUTODESK Revit for architecture and interior design. While they use rhino and dynamo for the parametric design.

The survey has also asked about the implementation and authoring of material passports and COBie parameters. Resulting in 22.5% of the companies' professionals had stated that they had material passports requirements, and 50% had COBie spreadsheets issued, as shown in the Fig. 70 - 71.

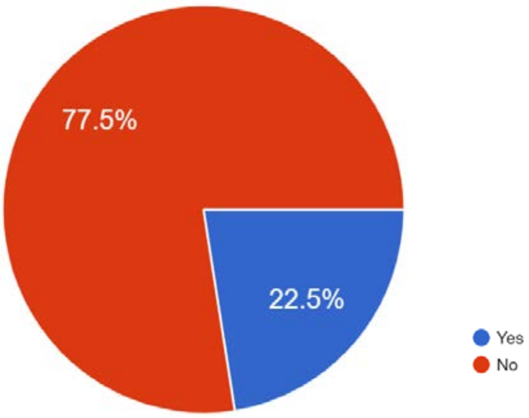


Figure 70 In your latest project, were material passports required to be issued?

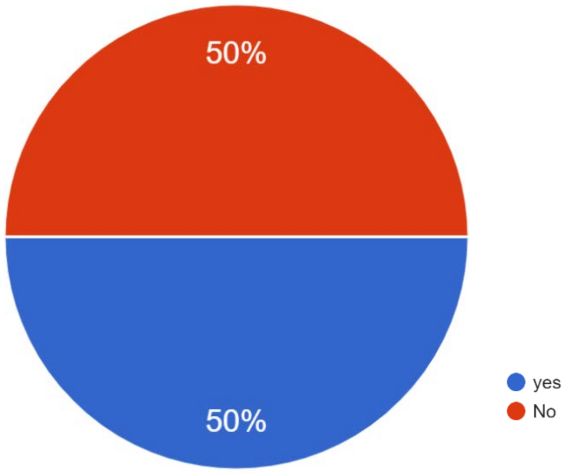


Figure 71 In your latest projects, was COBie parameters spread sheets issued?

Moving to the third section of the survey which was focusing on the BIM workflow challenges in real projects. Participants were asked 13 questions about the impact of specific aspects on the project success. The results were as follows:

1- The team experience has a high to significant impact on the project success when it comes to achieving BIM and sustainability requirements. But it has a moderate impact when it comes to circular economy requirements.
2- The software infrastructure factor has a major impact on achieving BIM requirements, moderate to major impact on achieving sustainability requirements and a low to moderate impact when it comes to circular economy.
3- The existence of the project BIM exchange\employer information requirements (EIR) has a moderate to high impact on achieving BIM, sustainability and circular economy requirements of the project.
4- The production of the project BIM execution plan (BEP) has a major to high impact on achieving BIM, sustainability, and circular economy requirements of the project.

5- The production of the project BIM manual has a major to high impact on achieving BIM, sustainability, and circular economy requirements of the project.

6- Production of BIM QAQC management plan and checklists has a major to high impact on achieving BIM, sustainability, and circular economy requirements of the project.

7- Material passports production has a major impact on achieving circular economy requirements of the project.

8- The production of the COBie parameters spread sheets has a major to high impact on achieving BIM and circular economy requirements of the project.

9- Existence of a well-structured common data environment (CDE) has a major to high impact on achieving BIM, sustainability, and circular economy requirements of the project.

Fig. 72 - 84 show the representation of section three results.

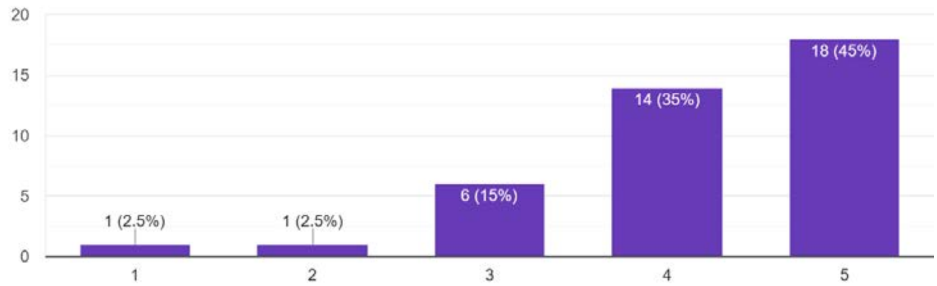


Figure 72 The rank of the impact of the experience of the project team on the project success in achieving BIM project requirements

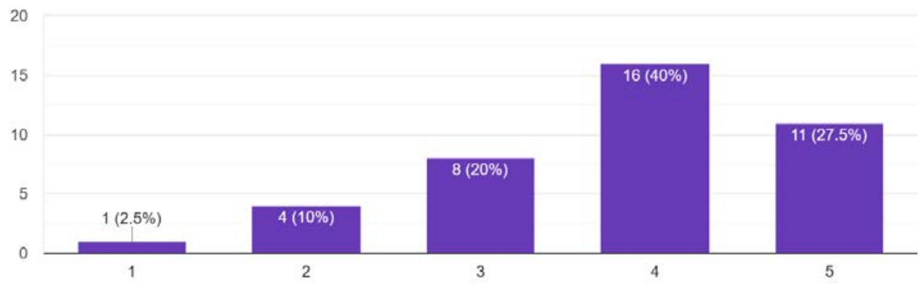


Figure 73 The rank of the impact of the experience of the project team on the project success in achieving Sustainability project requirements

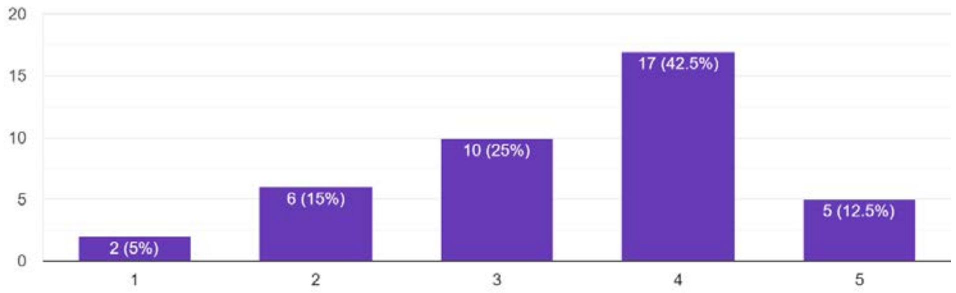


Figure 74 The rank of the impact of the experience of the project team on the project success in achieving circular economy project requirements

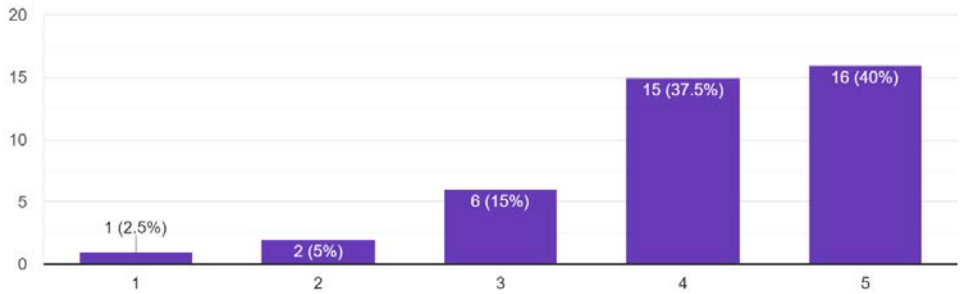


Figure 75 The rank of the impact of the software infrastructure on the project success in achieving BIM project requirements

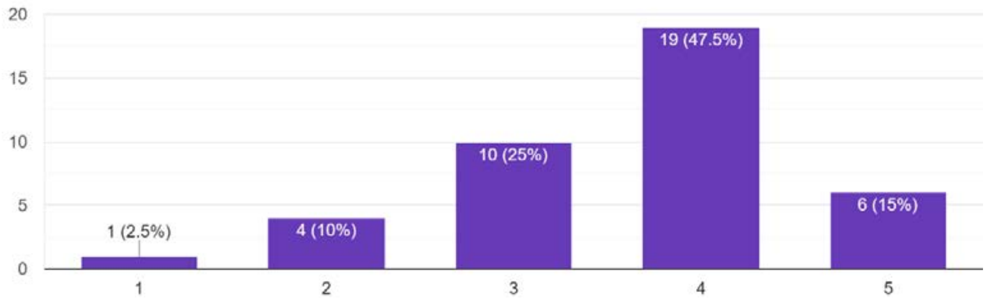


Figure 76 The rank of the impact of the software infrastructure on the project success in achieving sustainability project requirements

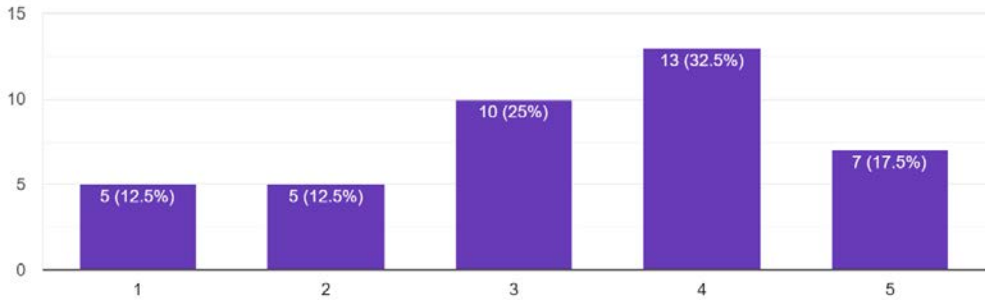


Figure 77 The rank of the impact of the software infrastructure on the project success in achieving circular economy project requirements

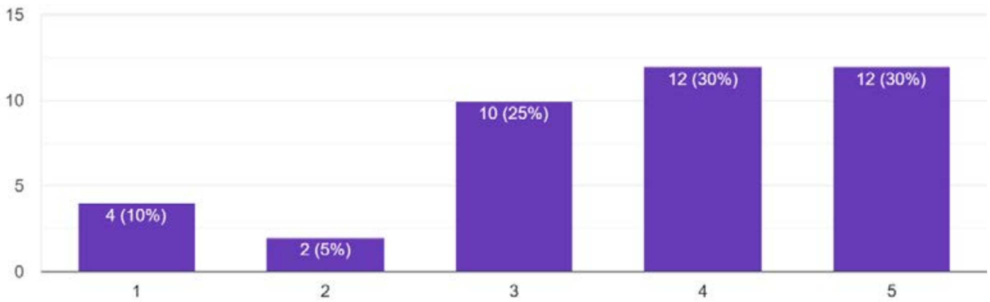


Figure 78 The rank of the impact of the existence of BIM exchange\employer information requirements (EIR) on the project success in achieving BIM, sustainability, and circular economy project requirements

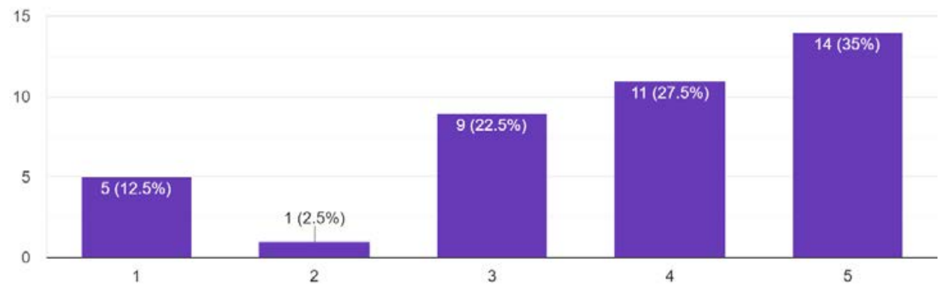


Figure 79 The rank of the impact of the existence of BIM execution plan (BEP) on the project success in achieving BIM, sustainability, and circular economy project requirements

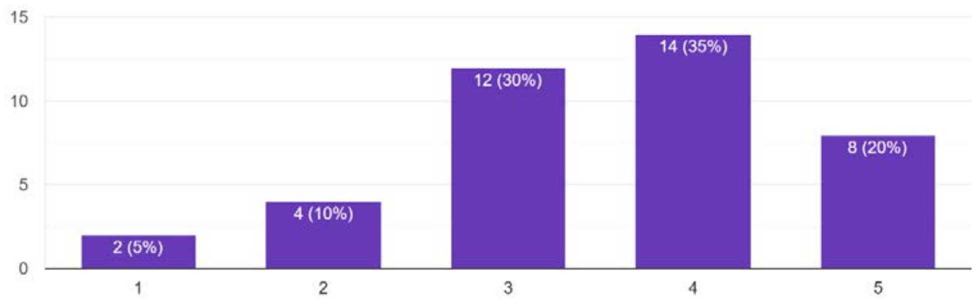


Figure 80 The rank of the impact of the existence of BIM manual on the project success in achieving BIM, sustainability, and circular economy project requirements

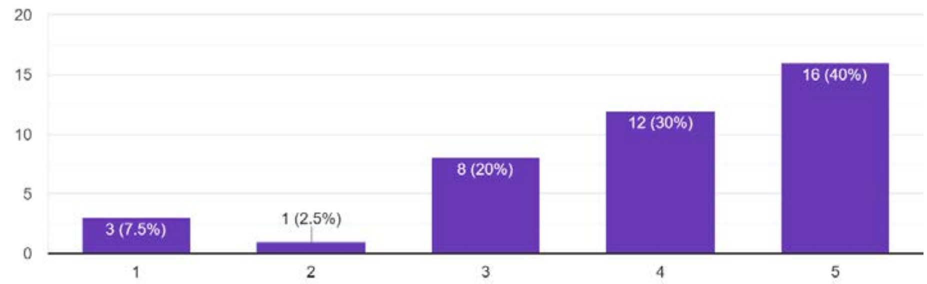


Figure 81 The rank of the impact of the existence of BIM QAQC management plan and checklists on the project success in achieving BIM, sustainability, and circular economy project requirements

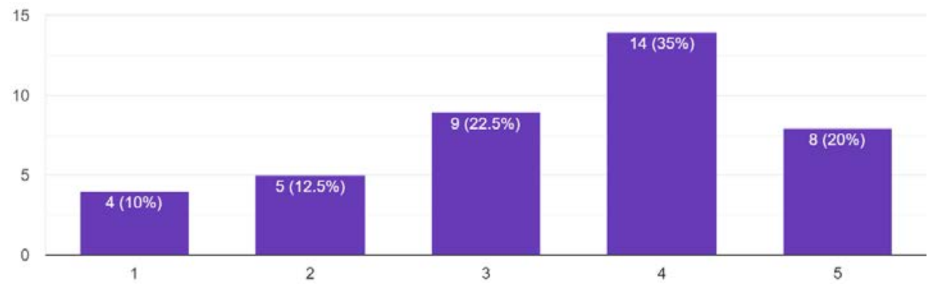


Figure 82 The rank of the impact of the existence of material passports on the project success in achieving circular economy project requirements

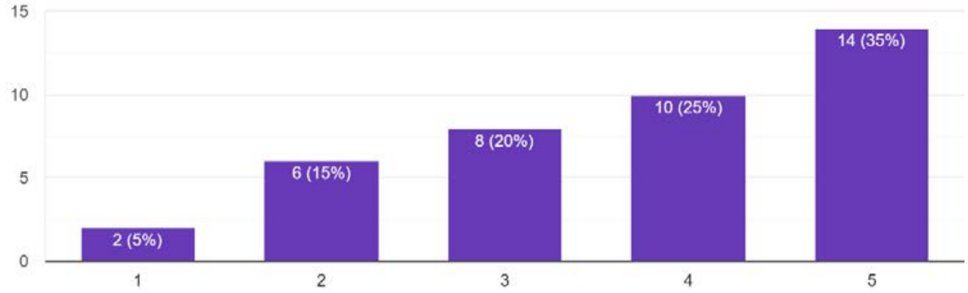


Figure 83 The rank of the impact of the production of COBie Parameters spread sheets on the project success in achieving BIM and circular economy project requirements

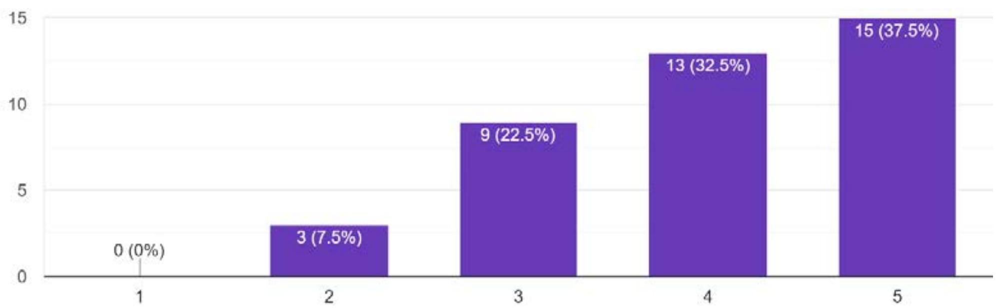


Figure 84 The rank of the impact of the production of well-structured common data environment (CDE) on the project success in achieving BIM, sustainability, and circular economy project requirements

The next (fourth) section of this proposal survey was designed to dig deeper into the benefits of following a proper BIM workflow in the construction industry. This section is designed to get the best out of the process, by asking the participants straight to the point five questions. These questions are measuring the benefits of using a proper BIM workflow on different aspects like, getting the best productivity and efficiency of the performing teams, aligning the project's outcomes with the employer requirements, most important factors affecting achieving BIM, sustainability, and circular economy requirements properly. It has also investigated on the benefits of using a properly structured common data environment (CDE) for the project success on achieving the requirements of BIM, sustainability, and circular economy. It also touches on the importance of using Autodesk Revit shared parameters option to add the needed parameters; to serve the circularity of the building. Finally, it has asked about the importance of COBie parameters implementation within the BIM models in order to specify and identify the rank of the circularity of the project components.

Analyzing the results and graphs from section four from the proposed survey, the author has noticed that 25 participants out of 40 have mentioned that the proper BIM workflow has a major impact. The responds have given it the highest grade on the used linear scale, which corresponds to the highest impact grade (Grade 05) on achieving BIM project requirements. 10 professionals have stated that it is on grade 04 on the importance scale, which makes it with a high impact. 4 of the engineers have graded this factor with grade 3 on the importance scale. Only one of the 40 participants had given it grade 01 (very low importance). Which makes the proper BIM workflow on the top on the important factors pyramid when it comes to achieving the rank of benefits on getting the most productivity and efficiency out of the performing teams.

The same question and answer structure was used to evaluate the importance and the rank of the benefits of using a proper BIM workflow on aligning the project outcomes to the employer requirements and project objectives. The results ranked it as a major to highest importance and impact. Below charts in Fig. 85 - 86 summarize the results gained from questions 01 and 02 in section 04 of the survey.

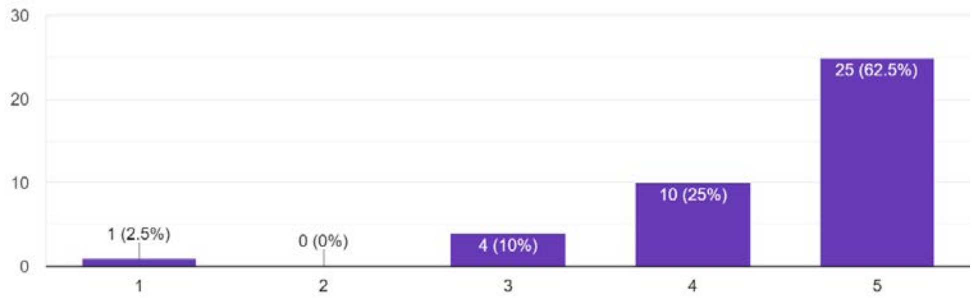


Figure 85 The rank of benefits of using proper BIM workflow on getting the best productivity and efficiency of the performing teams.

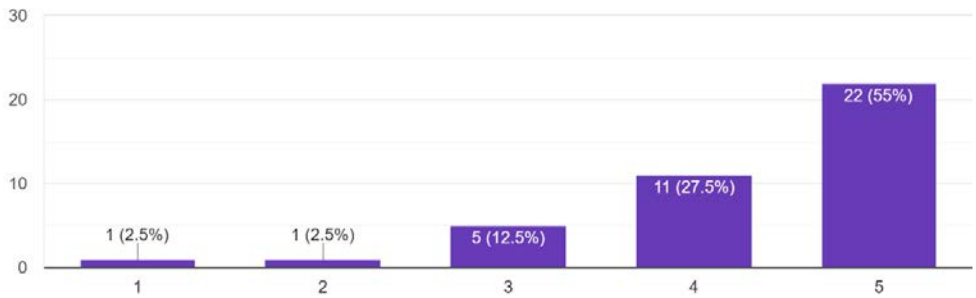


Figure 86 The rank of benefits of using proper BIM workflow on aligning the project's outcomes to the employer requirements and project objectives.

When the survey asked the participating professionals about the most important factor to be taken into consideration to properly achieve BIM in the real projects, it was found that the answers varies from 12.5% stating that the BIM exchange\employer information requirements (EIR) documents are on the highest importance, while another 12.5% have stated that the BIM execution plan (BEP) is the most important, on the other hand 15% of the answers went with selecting that none of the mentioned factors among the available options can be neglected. 45% of the participants has stated that all the available factors among the answers are on the highest importance to achieving BIM requirements on the project properly. Having 60% of the participants voted for all the options makes them all on the top of the important factors to be taken into consideration when implementing BIM on the projects. Having 12.5% of the participants voting for the EIR and the remaining 12.5% for the BEP will prioritize both the BEP and the EIR among the other factors without neglecting any of them. The two charts in Fig. 87 - 88 show the results on the survey – section 04 – questions 03 & 04.

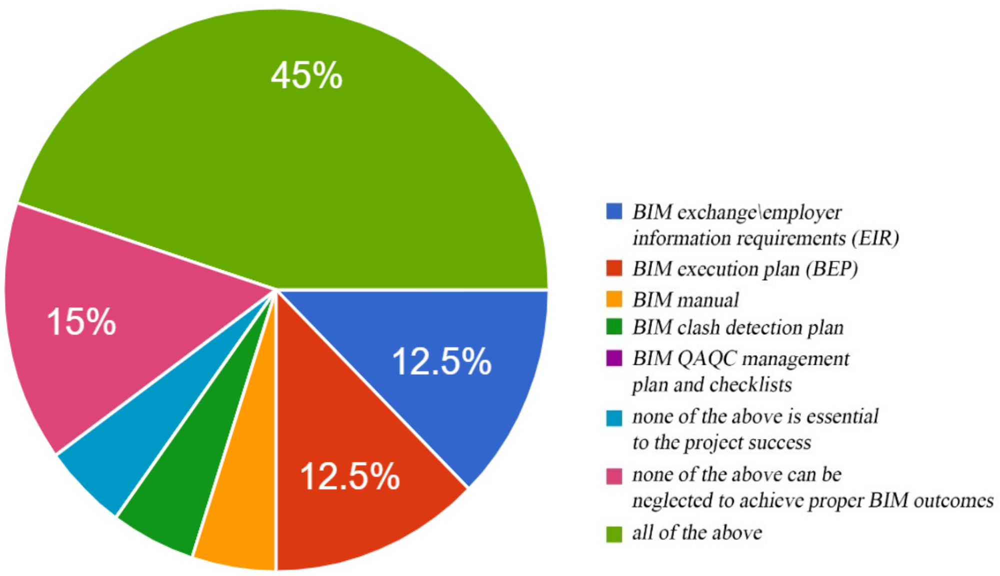


Figure 87 The most important factor to be taken into consideration to achieving BIM properly

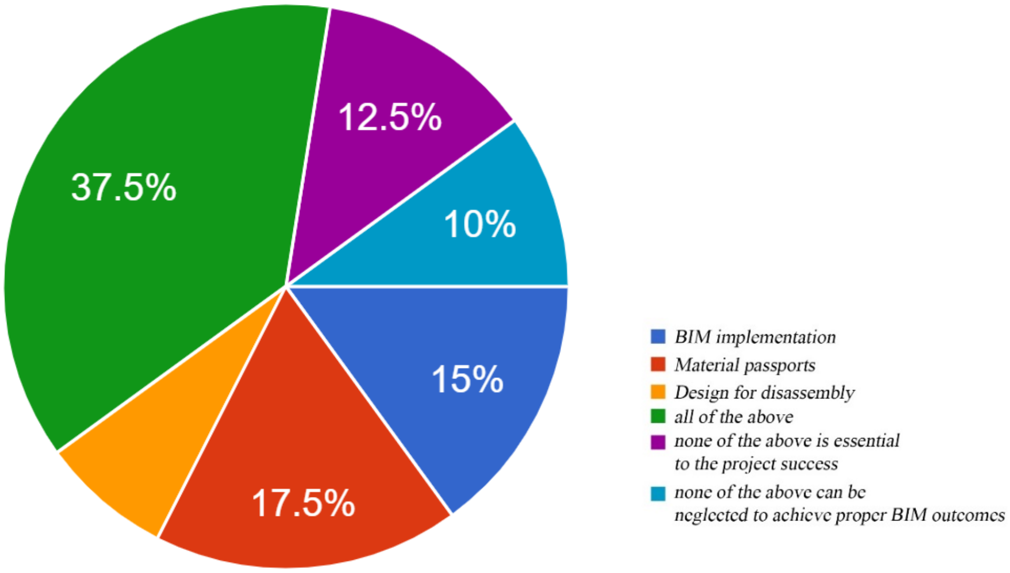


Figure 88 The most important factor to be taken into consideration to achieving sustainability properly

In this section of the survey the fifth question investigated on the importance of using a well-structured common data environment (CDE) to support the objective of achieving the project requirements of BIM, Sustainability, and circular economy effectively. It was found that 15 professionals stated that it is of a very high importance. 12 of the professionals had stated that it is on a grade 4 out of 5 on a linear scale, where 1 is the lowest importance and 5 is the highest. 8 of the participating engineers find that it is on a moderate importance and voted for a grade 3 out of 5. With 3 and 2 participants have voted for 2 out of 5 and 1 out of 5 on the same scale. The results put the CDE on a major high important factor to support the BIM, Sustainability, and circular economy requirements achievement of the projects. Fig. 89 represents a graphical representation of the results.

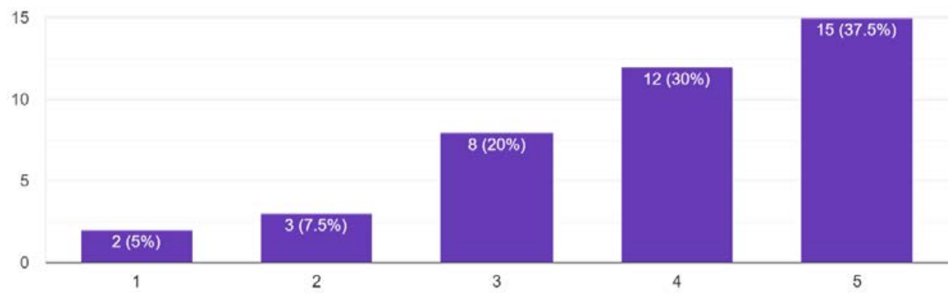


Figure 89 The importance of using a well-structured common data environment to support the achievement of BIM, sustainability, and circular economy project requirements

While the previously mentioned survey sections discussed very important topics, the fifth section has discussed the BIM benefits to implement circular economy concepts in construction industry, through asking 6 sensitive questions, and has found the following results:

1- 30% of the participating professionals believes that the material passports is the most important factor to be taken into consideration to achieve circular economy concepts, while 22.5% voted for the design for disassembly and dismantling factor.

2- Regarding the reusability, recyclability, and re-manufacturing ability inside the model to be able to rank the project components circularity, 25% of the participants put Autodesk Revit additional shared parameters on the top of the linear scale (1-5 where 5 is the highest importance), and 52.5% of the professionals has put it on the grade 4 out of 5 on the same importance linear scale.

3- When the participating engineers have been asked, how do you Rank the use of Revit interoperability and COBie parameters extension plugin to add component information regarding the reusability, recyclability and remanufacturing ability, and operation and maintenance information, inside the model to be able to rank the project components circularity among the projects? 47.5% have voted for the rank 4 out of 5. 22.5% have voted for the rank 5 out of five putting this factor on the highest importance rank. 20% have put it on a moderate importance rank (3 out of 5 on the same linear scale)

4- The next question touched on the design and BIM uses, selecting design analysis and constructability studies in the main frame of the questions. Questions asked about the rank of design for disassembly and dismantling method, and its impact on achieving higher ranking for building circularity. The results show that most of the participants have voted for the importance ranks of 4 out of 5 and 5 out of 5, with a percentage of 50% and 20% respectively. This makes this factor a major and highest importance one, to achieve higher circularity rank.

5- The fifth question of this section has knocked the door of project design, BIM design validation, value engineering and engineering analysis tasks. The question asked about the rank of using steel\wooden structure design over the traditional Concrete structure design IMPACT on the project components circularity at the end-of-life stage of the project asset. It was found that it is ranked as moderate to high importance, with 37.5% of the participants ranked them with a 4 out of 5 on the importance linear scale. 32.5% of the professionals have ranked them with a grade of 3 out of 5 on the same scale.

6- The last question of this section of the survey have asked about the most important factor \ document existence on making sure that the project team is achieving the project BIM requirements. The results have shown that the existence of project specific BEP, project BIM manuals, EIR, LOD clear definition, and project master information delivery plan (MIDP) and task information delivery plan (TIDP), model element definition matrix (MED), and BIM QAQC management plan and checklists are the most important documents to be authored and issued at the initiation phase of the project stage. with percentages of 80%, 70%, 67.5%, 62.5%, 57.5%, 52.5% and 52.5% respectively. It is important to note that percentages are cumulative due to the ability of select more than one factor \ document in the answer.

The charts shown in Fig. 90 - 95 shows a graphical illustration of the above-mentioned questions, for a better understanding of the answers analysis.

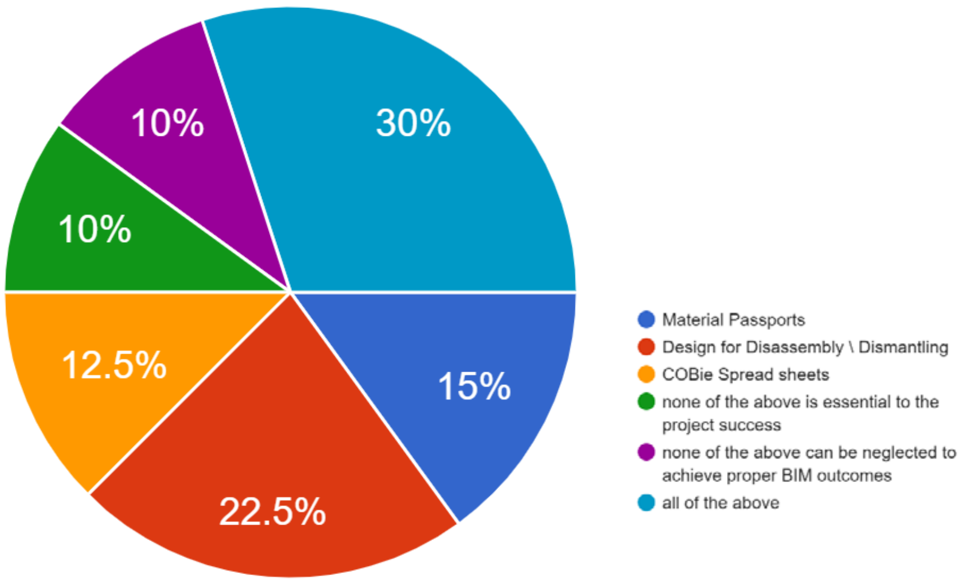


Figure 90 The most important factor to be taken into consideration to achieving circular economy properly

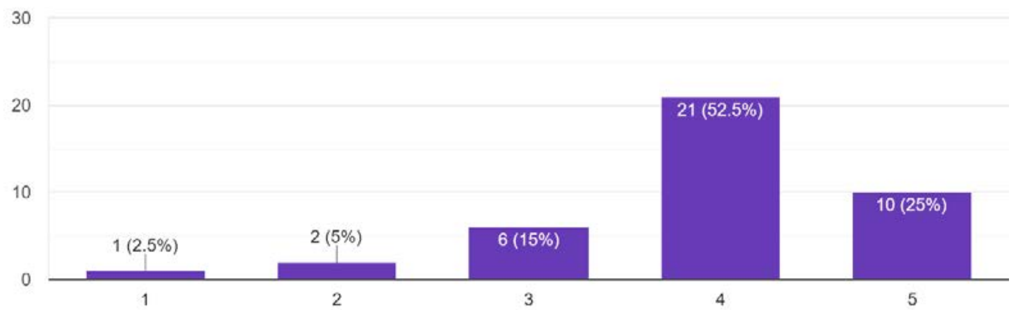


Figure 91 The Rank of importance of the use of Revit additional shared parameters to add component information regarding the re usability, recyclability, and re-

manufacturing ability inside the model to be able to rank the project components circularity

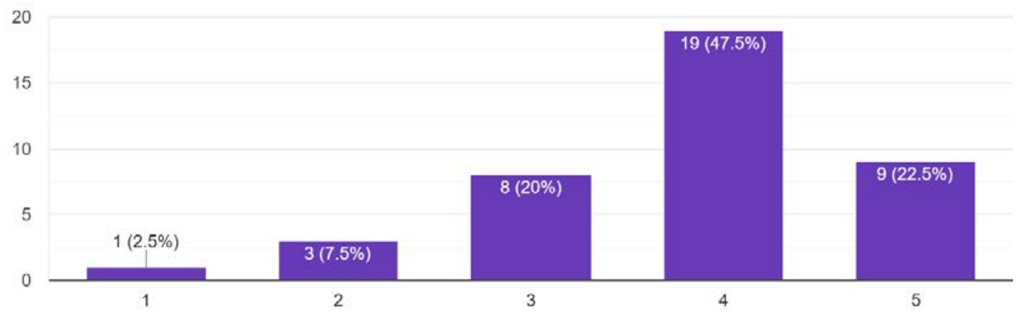


Figure 92 The Rank of the importance of the use of Revit interoperability and COBie parameters extension plugin to add component information regarding the reusability, recyclability and re-manufacturing ability, and operation and maintenance information inside the model to be able to rank the project components circularity among the projects

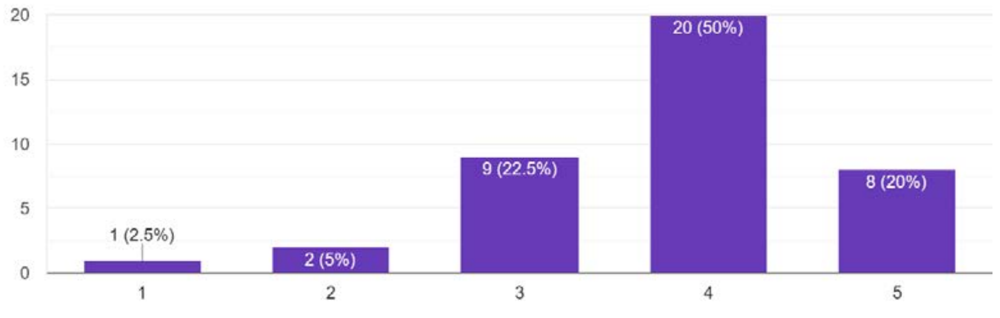


Figure 93 The Rank of importance of the use of the Design for Disassembly or Design for Dismantling practice\orientation IMPACT on achieving\building higher ranked circular Buildings considering project design and BIM uses of the Design analysis and constructability studies and evaluation

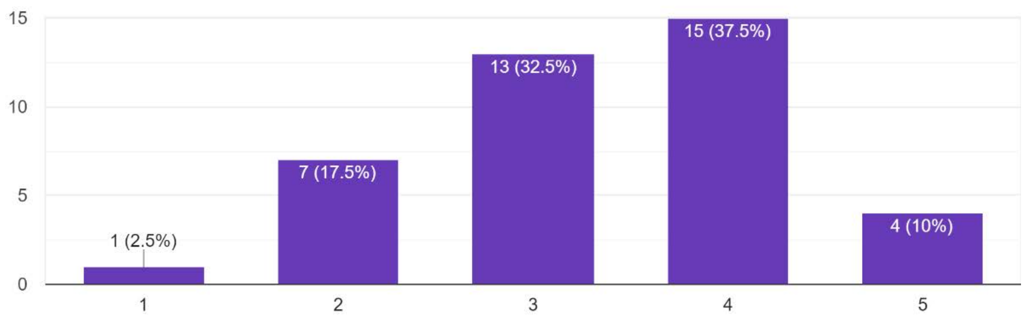


Figure 94 The Rank of importance of the use of Steel\wooden Structure design over the traditional Concrete structure design IMPACT on the project components circularity at the end-of-life stage of the project asset considering Project Design and BIM Design Validation, Value Engineering and Engineering Analysis among the BIM uses

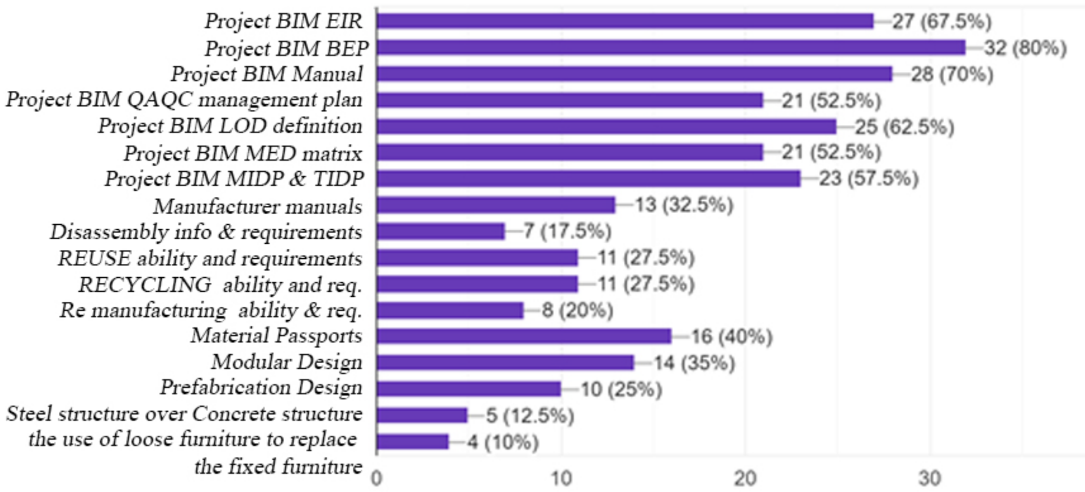


Figure 95 The rank of parameters which should be implemented\used\imported\authored\created\exported inside\from the BIM models of the project to make sure that the team is achieving the project BIM requirements

In the sixth survey investigating section, the questions went deeper into asking the participants on their point of view from the practical experience they have gained through their last working years in the construction industry on the gaps found in practice when it comes to BIM, sustainability, and circular economy concepts and practices. This was achieved by asking main four questions namely:

1- When it comes to practice how do you evaluate the GAP between what is required to be achieved to get the BEST BIM outcomes and what is being REALLY DONE in the REAL PROJECTS in the INDUSTRY considering the stakeholder \ client knowledge and awareness of the BIM scopes, uses, benefits, and required appropriate deliverable?
2- When it comes to practice how do you evaluate the GAP between what is required to be achieved to get the BEST BIM outcomes aligned with the project exchange information requirements (EIR) and requirements, and what is being REALLY DONE in the REAL PROJECTS in the INDUSTRY?
3- When it comes to practice and authoring MATERIAL PASSPORTS TO BOOST CIRCULARITY and SUSTAINABILITY of the built asset, how do you evaluate the GAP between what is required to be achieved to get the BEST CIRCULARITY, outcomes and what is being REALLY DONE in the REAL PROJECTS in the INDUSTRY?
4- When it comes to practice and authoring COBie PARAMETERS SPREAD SHEETS TO BOOST CIRCULARITY and SUSTAINABILITY and BIM use in the operation and maintenance phase of the built asset, how do you evaluate the GAP between what is required to be achieved to get the BEST CIRCULARITY, SUSTAINABILITY AND OPERATION PHASE OUTCOMES and what is being REALLY DONE in the REAL PROJECTS in the INDUSTRY?

The first question is trying to connect the project team practice, productivity, and outcomes to the client knowledge and level of awareness of BIM scopes and uses, his expectations, needs and requirements in real projects. The question is also trying to measure how satisfied the professionals are, and how they rank the gap found in this area of practice. While the second question is focusing on ranking the gap between the project teams' BIM outcomes and the employer\exchange information requirements (EIR) officially issued at the beginning of a real project where BIM is required and part of the contractual obligations of either the design consultant in the design phase or the construction contractor in the construction phase. In the third question the author has preferred to focus on the material passports production to support the circular economy implementation, and to measure the gap between the requirements to be achieved to produce the best circularity VS. what is being really done in real projects. Moving to the fourth question of this section of the survey, the proposed survey has asked about COBie parameters and its role in supporting sustainability, construction circularity, and BIM in the operation and maintenance phase of an asset. The question tried to measure the gap between the real requirements to achieve the best rank in this phase VS. what real project teams produce and achieve.

To better understand the results of this section a graphical representation shown in Fig. 96 - 99 represents the ranking of each factor among the options provided in each question.

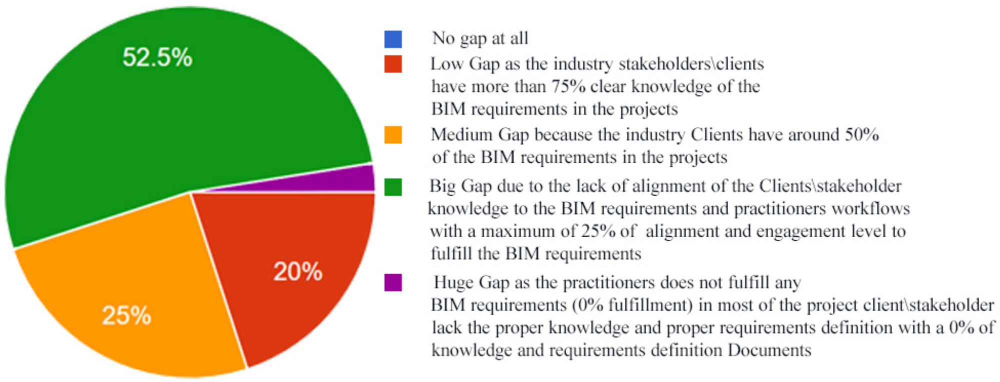


Figure 96 Question 01 results representation graph

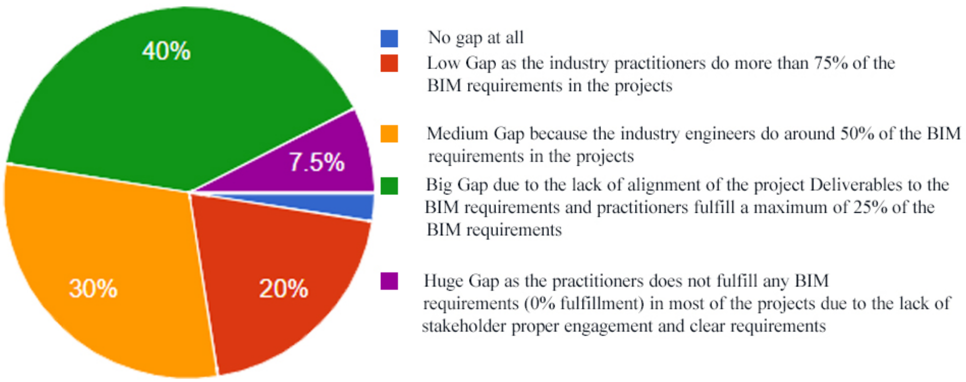


Figure 97 Question 02 results representation graph

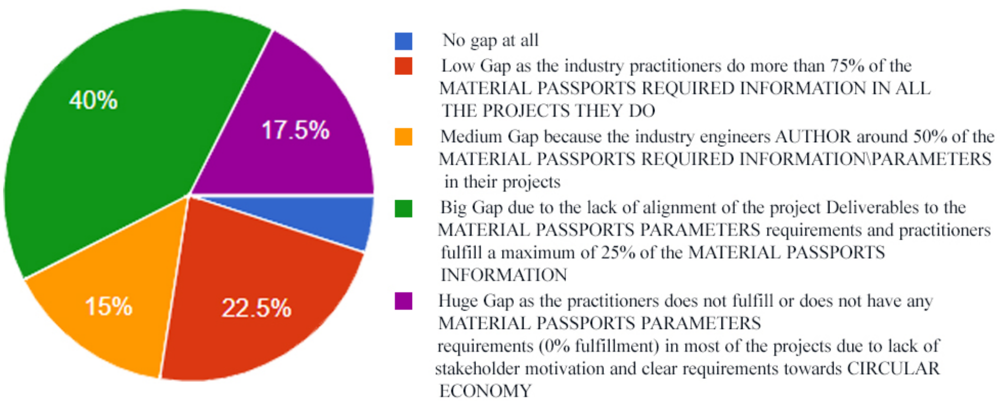


Figure 98 Question 03 results representation graph

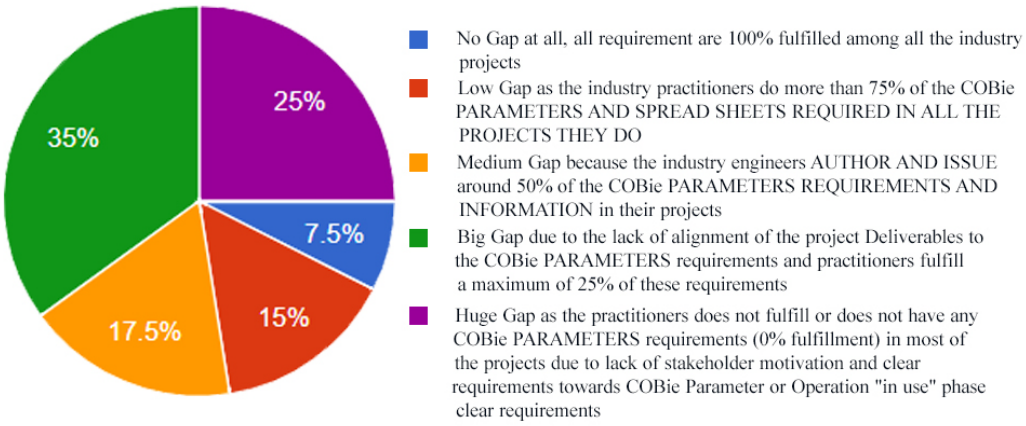


Figure 99 Question 04 results representation graph

The results of the section of the survey show that in the four areas investigated; there is always a big to a huge gap between what should be done as per standards and engineering common sense and what is being done in the real project due to many issues and circumstances which might vary from a project to another.

In the very last section of this thesis proposed survey, it was mandatory to ask the participants for their recommendations to deliver a better circular economy using BIM technology in construction projects where 40% of the professionals have stated that they have recommendations, and the provided ones are as follows:

1- Professional 01 recommendations:
    a. The best solution is incorporating all engineering teams (procurement, technical, QS and QA/QC) in the BIM experience rather than only architects
2- Professional 02 recommendations:
    a. Incorporate BIM data models while implementing Circular economy using BIM software.
    b. Train more professionals to use circular economy principles in the early stages of the design process.

    c. enhance the Common Data Environment to apply Circular economy framework while creating BIM models in different levels of development.

3- Professional 03 recommendations:

    a. Raise the awareness of BIM practitioners regarding the new updates in BIM-related technologies; to get the most benefits of BIM in the construction industry and to fulfill circular economy requirements.

4- Professional 04 recommendations:

    a. As project management point of view, to understand the LOD along with the feasibility, moreover, not overdoing BIM more than required for the benefit of the project.

5- Professional 05 recommendations:

    a. Contractor should understand the uses of BIM and give priority to achieve 100% good quality outcome, which reduces the time in coordination.

6- Professional 06 Recommendations:

    a. Production of EIR.
    b. Production of BEP.
    c. Production of Material passports.

7- Professional 07 Recommendations:

    a. More training for the team.
    b. Providing the needed standards by the authorities.

8- Professional 08 Recommendations:

a. Client/Contractor should have his own parameters, the work is collaborative and should not be in a waterfall process, otherwise it's robotic and will fail to deliver smaller scale projects.

9- Professional 09 Recommendations:

a. Proper setup of a well-structured CDE.

b. Proper production of a proper BEP.

c. Existence of proper and well defined EIR should be better guided and created at the beginning of the project by more experienced practitioners.

d. The circular economy is a common goal for all and there should be standards to rate and achieve a minimum level.

10- Professional 10 Recommendations:

a. Prompt the use and interact all related people including consultants, manufactures, with BIM Teams.

b. Another thing is to give a deep understanding for the use of BIM.

11- Professional 11 Recommendations:

a. We can start by giving fair timeline to prepare a decent BIM model with high accuracy. And to try to add as much info as needed.

b. Starting from the right model we can manage to prevent the loss of materials and energy.

12- Professional 12 Recommendations:

a. Measures such as waste prevention while executing the BIM Model on the site (will lead to less material waste).

b. material cost is directly proportional to the project cost. In larger picture less production of construction materials will subside the environmental pollution. Reducing pressure on the environment, improving the security of the supply of raw materials, quantity take off/Bill of material that can be easily acquired by BIM Implementation.

c. Explore the feasibility of defining a Safe Operating Space for natural resource use. By Cobie, data things can use operate to its outmost extent.

13- Professional 13 Recommendations:

a. Use of Digital Twin to maintain the digital information of the asset in the moment of disassembly.

14- Professional 14 Recommendations:

a. BIM requirements fulfillment.
b. Inclusion of CE requirements in the EIR.
c. Hiring a well experienced team.
d. Communication and integration on higher levels.
e. Training of teams.
f. Communication between all teams and BIM teams.
g. Well experienced project manager with high level of experience in BIM and CE, Design for disassembly approach.
h. Engaging all stakeholders.

15- Professional 15 Recommendations:

a. Focus on design for disassembly.
b. Start authoring material passports from the initiation stage and concept design of the projects.
c. Involve all stakeholders.
d. Supply chain assessment in the process from the start.

16- Professional 16 Recommendations:

a. Design for disassembly.
b. record and author material passports.
c. BIM implementation.
d. Proper BIM planning.
e. Existence of clear BIM EIR.

4.4.Best Practice Model Framework

In the last section of the discussion part of the thesis proposal, the author is providing the best practice model framework and methodology recommendations based on the methodology structure three main parts, namely:

1- Real project case study management documents and model analysis.
2- Proposal specific built and developed model and results analysis.
3- Specific survey results and analysis findings.

It is clearly found that there is a gap in the literature and the professional field practice when it comes to using building information modeling management methodologies and workflows to sustainability and circular economy concepts and requirements. On the other hand, it was found that there is a lack of knowledge of the employer requirements, participating teams, and engineering professionals. In addition to a gap between what is required and what is being built inside the BIM models, as found in the three sections of the discussion chapter. To cover the gap identified, the author is suggesting the step-by-step workflow below:

1- Work on awareness sessions of the circular economy, sustainability, and BIM management and modeling workflow, for all the construction industry organizations. These awareness sessions should cover the client organizations, design consultants, main contractors, subcontractors, supplies, specialists, and academia doctors and professors. Sessions should be done by providing specialized training material customized to each organization team needs.

2- Governments, public sector, and private sector clients should encourage their teams to include the requirements of circular economy, sustainability and BIM modeling and management in their employer information requirements and project scope definition in the tender stage. They should also educate the bidders about theses specific requirements.

3- Implement a supply chain assessment methodology during the bids evaluation and make it an essential part of the technical evaluation for the appointed party.

4- The employer to issue a well-structured employer\exchange information requitement document (EIR). The EIR should be built based on the strategic needs of the owner, aligned to the organization information requirements and asset information requirements documents, which should include the circular economy and sustainability vision.

5- Make the BIM execution plan, BIM management plan, BIM manual and all other BIM management documents part of the appointed party contractual obligations which should be part of the main project execution and management plan.

6- All the participating appointed parties to be knowledgeable and fully aware of circular economy, sustainability, and BIM workflow.

7- The implementation and use of a well-structured common data environment with identified permissions suitable for the use of the project and all appointed parties.

8- Involvement of the manufacturers, suppliers, and specialists from the early stages of the project initiation stage and design stage.

9- The implementation of the design for disassembly and dismantling concepts and procedures.
10- Start the importing of the circularity parameters from the early design stage of the project inside the BIM models, and the creation of the circularity schedules and parameters from the beginning of the design stage of the project.
11- Keep the stakeholders engaged and informed on the circularity and sustainability ranking of the project components during every project stage; to enable them to take the best circular and sustainable decisions.
12- Keep all the BIM models up to date during every project stage.
13- Keep all the project BIM documents up to date with each mile stone deliverables submission.

It is highly recommended to expand the proposal study results and finding in the future and to develop the model with the most up to date technology and software updates in addition to the latest engineering and sustainability trends. In addition to expand more research studies on the training needs and requirements updates; to cover all the new trends and technology standards. On the other hand, it is highly recommended to pay more attention to update the industry standards and regulations to cover wider range of sustainability, circular economy, and the role of BIM; to easily manage the requirements covered.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1.Research Summary and Conclusion

This research thesis proposal focuses on studying the role of BIM in supporting the measurement, analysis, record and calculate the circularity ranking of the designed asset. The objective was achieved through the deep analysis of real-world project case study and developing a workflow model that serves the purpose of helping the decision makers on enhancing the sustainability and circular economy implementation during the design and construction stages of the project.

The process started by studying the literature available on the concepts of sustainability, circular economy and the use of building information management and modeling in the construction industry. An enormous number of papers, thesis proposals and research reports, in addition to industry practitioner reports were read and analyzed; to find the gaps in both the literature and professional practice. Followed by analyzing real project case study from Qatar construction industry sector. Then the use of findings and results of the analysis to build and upgrade a project model for the purpose of the study; to experience and find a recommended workflow model to support the objective of the thesis. On the other hand, a well-structured survey was built specifically to support this thesis with the findings and recommendations form the professional field practitioners.

5.2.Research Findings

5.2.1. Literature Review Analysis

From the analysis of the literature read and reviewed the author has found a gap in the literature in the areas that connect CE & BIM. This was clearly defined after the deep analysis of the gathered documents, reports, papers, and thesis proposals related to the areas of sustainability, CE, & BIM. It was also clearly noticed that the literature lacks the technical practical orientation, that will help practitioners to create a developed BIM management model that serves the circulatrity of assets.

5.2.2. Real Project Case Study

From the analysis of the case study results, many observations and findings have been noticed. The findings may impact the decision of authoring the best management plan and model in the practice. Firstly, the type and content of each management document needed to manage projects that aims to implement sustainability and circular economy. Secondly, the best practice to utilize BIM management to support the purpose of managing such projects. Thirdly the use of BIM software and common data environment to get the best results for the efficiency, productivity and liability of the built models, drawings, and documents, for all the project stages.

5.2.3. Proposed Project BIM Model Development

Moving to the next part of the methodology used for this thesis, the author has developed a model with the implementation and creation of the needed parameters and schedules to support the decision making with real calculated percentages for the reusability, recyclability, ability to remanufacture, ability to dismantle, and total circularity ranking for each project component. Moving to the survey part of this thesis, which has involved the practitioners of the professional construction field in providing the input to find the gaps in the practice related to the implementation of sustainability, circular economy, and BIM management in construction projects.

5.2.4. Thesis Well-Structured Survey

In addition to supporting the best practice model with professional recommendations and methodology work frame. The built survey was conducted to build a comprehensive understanding of each parameter. It also investigated each parameter impact on the built model workflow. It has been very clear that the use of the powerful BIM management and modeling methodologies and workflows has the most impact on the efficiency of measuring the sustainability and circularity ranking of the asset used components for both the design and construction project phases. So, the accuracy and efficiency of the decisions made on the project touches the highest levels required as they are built on real and accurate data.

5.3.Limitations and Recommendations

Lately, the topic of this thesis became very significant and important, especially with the booming interest by environmentalists, industry professionals, and governments on the same subject. However, to the best knowledge of the author, very limited research studies have been conducted to cover the connection between sustainability, circular economy, and the use of BIM related areas specially in Qatar and the region. This led to facing many challenges and complications specially during the data gathering and collection phase. The challenges increase because the use of BIM, the requirements for implementation of circular economy model, and the sustainability requirements are limited in the construction projects. This was not only noticed in Qatar, but in the gulf region and the world as highlighted by the thesis survey participants. As a result, external resources from practitioners and industry related regulations and standards, were used to perform analysis and finding results.

Therefore, it is highly recommended that the governments and project owners include the sustainability, circular economy, and the utilization of BIM in their projects from the early stages. Those requirements should be studied to be aligned with the sustainability development goals by the UN, circular economy model in construction industry, and the implementation of BIM standards to support this industry orientation.

5.4.Future Works

This thesis focuses on studying the use of BIM technology and management model and its impact on supporting the decision making, measurement, and recording of sustainability and circular economy ranking on construction projects. Due to the time constraint, it has focused on analyzing limited amount of the collected data, management documents, and BIM models. on the other hand, it has focused on one part of the benefits of information stored in the built BIM model, the resulting schedules, and the used parameters. In the future, this can be extended to cover the analysis of the remaining part of BIM management documents, BIM models and the remaining uses and benefits of the embedded model parameters, resulting schedules, calculated parameters and enhance the used formulas to calculate the circularity of project components and the whole asset circularity ranking. Therefore, more efforts can be dedicated to analyzing real project management documents, used workflows, gaps and errors identification, and developing and updating the recommended workflow model and evaluate all environmental, social, economic, sustainability and BIM utilization. This will help for obtaining a better decision making by the industry stakeholders. Moreover, expanding the research to find more developed model on engaging governments, project owners, consultants, contractors, and all appointed and related parties in the whole project life cycle. Although design and construction project phases were the focus of this research, it can be expanded to cover the complete project life cycle stages starting from the project brief and feasibility studies, through all the project life cycle stages, and the in use and operation phase. In addition to cover the end-of-life decision making criteria.

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