Integrating BIM and GIS for Design Collaboration in Railway Projects

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Dedication

“In the name of Allah, the Most merciful, the most compassionate”

This thesis is dedicated to:

To the soul of my father

To my love, my mother

My life companion, my husband, Mahmoud

My lovely brothers and sisters

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I would like to thank my God (Allah) for making all these happen and accepting my prayer, for choosing me to take this new adventure, entirely new life, for the support, patience and energy to pass every sad and difficult moment and continue to complete my study

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Abstract

Collaboration is essential to achieve project targets and minimising rework in any project including railway projects. The railway project is considered as megaproject that requires effective collaboration in order to achieve efficiency and effectiveness. To ensure that the railway continues to provide safe, reliable, cost-effective services, and remains environmentally friendly while driving economic growth, engaging new technologies and new types of work models are required. Among these technologies, Building Information Modelling (BIM) and Geographic Information Systems (GIS) are recent technologies that support collaboration. However, using these technologies to achieve effective collaboration is challenging, especially in railway projects as they are amongst the most complicated projects and often numerous parties are involved in making important decisions. Currently, there is a lack of evidence-based guidelines or processes for effective collaboration in railway projects throughout their design stage. Therefore, this thesis has focused on developing a process model to improve collaboration in the design stage of railway projects using BIM and GIS. This research adopted a mixed-methods approach to examine and identify the issues that hinder collaboration in railway projects to assist in developing theBIM and GIS-enabled collaboration process model. An online questionnaire was designed and distributed to professionals to assess the state-of-the-art in BIM and GIS followed by two rounds of in-depth interviews with experts. The first round aimed to identify collaboration issues and consisted of 15 in-depth, face to face and videoconference/telephone interviews; while the second round consisted of 10 in-depth interviews to identify the process model components of the collaborative process using IDEF technique.

The questionnaire data were analysed using descriptive statistics and statistical tests (for example, Regression analysis, Wilcoxon Signed Ranks and Kruskal-Wallis Test). The results showed a lack of training in BIM and GIS and identified collaboration as a significant factor for railway projects, but there were many challenges to achieve effective collaboration. These challenges

have been further investigated during the first round of interviews using content and thematic analysis. The results revealed that the most common challenges were getting the right information at the right time for the right purposes followed by resistance to change. Furthermore, the findings indicated that developing a process model, based on a clear plan of work demonstrating the collaboration process, is a potential solution to tackle these challenges. Thus, a Collaborative Plan of Work (CPW) has been developed through combining the RIBA (Royal Institute of British Architects) Plan of Work and the GRIP (Governance for Railway Investment Projects) stages. This CPW will be the basis to develop a process model for BIM and GIS-enabled collaboration. The results from the second round of the interviews identified the process model components which are: key players' roles and responsibilities, tasks (BIM and GIS Uses), BIM and GIS-based deliverables, and critical decision points for collaborative process design. Moreover, this process model was formulated utilising Integrated DEFinition (IDEF) structured diagramming techniques (IDEF0 and IDEF3).

In conclusion, the process model of the collaboration process and the integrated implementation of BIM and GIS sets out role and responsibilities, deliverables, and key decision points. Finally, the research outcomes have been validated through a focus group and interviews with professionals in the biggest Railway company where the proposed process model was operationalised using a commercial Common Data Environment platform (viewpoint 4project). From their discussion, feedback and recommendations the IDEF processes model have been refined. It is concluded that such a process is crucial for effective collaboration in railway projects as it enables the management of the design process in terms of technologies used, activities, deliverables, and decision points. Therefore, the research findings support the notion that BIM and GIS can help to achieve effective collaboration by delivering the right information at the right time for the right purposes. As a result, they help to achieve the projects' objectives efficiently in terms of time, cost and effort.

Keywords: Collaboration, Railway projects, BIM, GIS, RIBA, GRIP, IDEF0, IDEF3 and process model.

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List of Abbreviations

3D	Three dimensional
4D	3D + time sequencing
5D	4D + cost
AEC/O	Architecture, Engineering, Construction and Operation
ANOVA	Analysis of Variance
AM	Annotation Model AM
ANSI	American National Standards Institute
APM	Association of Project Management
ASE	Analysis-Synthesis-Evaluation
BEP	BIM Execution Planning
BIM	Building Information Modelling
BOS	Bristol Online Survey
BRE	Building Research Establishment
BS	British Standard
BSI	British Standards Institution
CAD	Computer-Aided Drafting (or Design)
CapEx	Capital Expenditure
CCE	Cost Control Engineer
CDE	Common Data Environment
CIC	Construction Industry Council
CIOB	Chartered Institute of Building
CIOB	Chartered Institute Of Building
CityGML	City Geography Markup Language
CME	Construction Manager Engineer
COBie	Construction Operations Building Information Exchange
Con Man	Construction Manager
CPA	Critical Path Analysis
CPIC	Construction Project Information Committee
CPW	Collaborative Plan of Work
CPW	Collaborative Plan of Work
CSCD	Computer Supported Collaborative Design
dng	Digital Negative (DNG) Filename extension.
DPoW	Digital Plan of Work
DTI	Department of Trade and Industry
dwg	Drawing Database (file extension)
EIR	Employers Information Requirements
FBS	Function-Behaviour-Structure
FHWA	Federal Highway Administration
FM	Facilities Management
gbXML	The Green Building XML (Extensible Markup Language) scheme
GDCPP	Generic Design and Construction Process Protocol
GIS	Geographic Information Systems
GRIP	Governance for Railway Investment Projects
GSL	Government Soft Landings
GST	General Systems Theory

HRM	Human Resources Manager
ICOM	Input, Control, Output, and Mechanism
ICT	Integrated Collaborative Technologies
IDEF	Integrated DEFinition
IFC	Industry Foundation Classes
IM	Information Management
IPD	Integrated Project Delivery
ISO	International Organization for Standardization
IT	Information Technology
ITS	Intelligent Transport Systems
KM	Information/Knowledge Management
LOD	Level of Detail/Development/Design
MEP	Mechanical, Electrical, and Plumbing services
MEP	Mechanical, Electrical, and Plumbing services
NASA	National Aeronautics and Space Administration
NBIMS	National Building Information Modelling Standard
NBS	National Building Specification
NBS	National Building Specification
NEDO	National Economic Development Office
OCP	Online Collaboration Platforms
OpEx	Operational Expenditure
PAS	Publicly Available Specification
PD	Project Director
PE	Planner Engineer
PERT	Programme Evaluation and Review Technique
PM	Project Manager
QCE	Quality Control Engineer
QS	Quantity Surveyor
RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
SADT	Structured Analysis and Design Technique
SNA	Social Network Analysis
SPSS	Statistical Package for the Social Sciences
SRTS	Safe Routes To School
SSM	Soft Systems Methodology
TOE	Technical Office Engineer
UBM	Unified Building Model
UOB	Units of Behaviour
VIF	Variance Inflation Factor
WIP	Work In Progress

Chapter 1 : Introduction

1.1 Introduction

This chapter reviews the background of the research to identify the research gap and justify it. Then presents the research scope and design. Finally, presents the outline of the research and chapter summary.

1.2 Research Background

The railway plays a significant role in human life by providing safe, reliable, cost-effective services, which are environmental-friendly and drive economic growth. It is the most common transportation system for many societies. It needs a continuous upgrade in different operational activity due to technological advances, environmental change and increasing demands of customers. Railway infrastructure plays its role in terms of safety, reliability, sufficient capacity and availability over its lifecycle (Patra, 2009). In order to fulfil this requirement effectively, various phases of the lifecycle need to be examined, from feasibility until operation and maintenance.

Today's railway transport should offer speed, efficiency and safety, in addition to the necessity of providing its passengers with exceptional comfort and service (Huber and Suhner, 2014). The role of railways in the transport sector has declined following continuous development of the road and air transport industries. Finally, to keep the rail service sustainable, in most countries, railway organisations have been nationalised. This is owing to the significant role that the railway is played in the movement of population and national economy. However, railways nationalisation causes several negative effects on the organisations of the railway. These include lack of flexibility, non-cost effectiveness, low quality of rail service, lack of punctuality. Nonetheless, railway organisations have succeeded to improve the railway(Profillidis, 2007). This necessitated to find solutions to tackle these issues to make sure to deliver a sustainable railway and serve the purposes it built for.

Although the railway is considered as a safe, efficient, eco-friendly transport mode, however, recently, there has been a decline in the public perception of the railway (Berrado, Cherkaoui and Khaddour, 2010). Due to rapid advances in technology, the construction industry, and infrastructure in general and railway specifically needs to keep up with these developments. The demands of passengers are increased to provide better services for the railway in terms of safety, reliability and comfort. So, to reach these objectives there is a need to improve and maintain the quality of the infrastructure(Park, 2013). This improvement can be achieved by providing effective collaboration. Collaboration means working together to achieve a common goal of the project. However, collaboration needs efficient tools for the best results, which can be provided via a BIM platform (Building Information Modelling- detail in the next chapter). BIM enables participants to collaborate in a best collaborative environment work to share information, different thoughts, and better decision making throughout the project lifecycle(AGC, 2006).

Indeed, there is less information about BIM for infrastructure compared to BIM for buildings(Graça, 2014). BIM became mandatory in 2016 for UK public sector projects and most countries are expected to follow suit(NBS, 2015). BIM can be said to lack the ability to analyse spatial data beyond the building footprint, while GIS tools have the ability to deal with spatial and geographic information (Karan et al., 2015, Wang, Pan and Luo, 2019). Therefore, integrating BIM with GIS can provide a complete tool to support collaboration between participants throughout the lifecycle of any project. This research argues that formulating a framework to demonstrate the collaboration process will lead to an effective collaboration which will assist in achieving the project objectives more efficiently. This research attempts to assess the current practice of railway projects. It is intended to identify the collaboration issues and develop a process model to address these issues.

1.3 Research Problem

In recent years, the importance of collaboration has increased with advances in Information and Communication Technologies. Collaboration increases the opportunities for better decision making, accesses the information easily and shares risks and responsibilities (Prahalad and Hamel, 1990; Tu, Li and Bian, 2018). A consequence of this is reducing time and costs and increasing productivity in addition to the availability of information at any time and everywhere.

There is research about attempting to use different techniques and methods to achieve collaboration for several purposes. BIM and GIS are the two technologies that are used for providing a collaborative environment. To realise the full potential of BIM, it is essential to integrate it with other technologies such as GIS because BIM and GIS complement one another, which offers huge advantages and opportunities. Elbeltagi and Dawood, 2011; Zhang et al., 2009) claimed that achieving real integration of BIM and GIS can be obtained by using the strengths of each BIM and GIS and combining them in an integrated way.

Although the integration of BIM with GIS will produce a powerful toolkit for collaboration in railway projects, there are a few studies for this purpose. This could be because the challenges may occur due to the different worlds for both BIM and GIS such as interoperability or lack of knowledge about them.

However, several studies have been conducted in order to determine the key to success in collaboration whether using BIM and GIS separately or using other applications. Van Den Bergh et al., (2009) developed a novel human/computer interaction tool allowing stockholders to visualise information from several screens in order to interact with a huge amount of information. However, they found that the system is as not strong as it should be and more demonstration is required to allow the system to enable many users to react with many screens at the same time. Shim et al., (2008) and Moon et al., (2004) suggested using a RIIM (Railway Infrastructure Information Model) in order to provide integration and interoperability during the whole lifecycle of the railway infrastructure from planning until maintenance. BIM can offer a high level of efficiency in communication and collaboration (Bryde, Broquetas and Volm, 2013; Grilo and Jardim-Goncalves, 2010; Olatunji, 2011). Sebastian (2011) emphasises that using BIM optimally leads to achieving a multi-disciplinary collaboration. Nevertheless, to reach that there are challenges that need to be overcome such as the re-organising collaborative processes, and the changing of key parties’ roles, the relationships of a new contract, clients’ role, architects and contractors. there is a lack of practical knowledge on how to manage the actors of building in role order to collaborate effectively in their changing roles and to promote and using BIM as a collaborative optimal ICT support (Sebastian, 2011).

Similarly, GIS is also used individually in railway projects. Guler, Akad and Ergun (2004) found that through GIS, better decisions could be made by using it to identify the event or asset to another event or asset and determining if the relationship between them may be considered as a crucial factor for deciding the design, construction and maintenance. For the same purpose, Wei (1996) developed a new GIS technology to select an optimum railway line. He found that there is not much difference in results between using a computer and using a traditional method, but the computer is more efficient and saved much more time.

Nyerges and Jankowski, (1997) suggested a theoretical framework for human decision-making collaboratively based on GIS. One of the practical aspects of integrating BIM and GIS explored by Kim et al., in 2015 was to provide a program for a safe path for the pupils to the school called Safe Routes To School (SRTS). The purpose of this program is to reduce the consumption of energy and emissions of CO_2, resulting in improving the conditions in terms of safety and health for the children. This program consists of integrating BIM with GIS in providing visualisation for the weather and monitoring this information via participants.

There are many studies regarding railway sector using different techniques such as BIM and GIS separately (Guler, Akad and Ergun, 2004; Shim et al., 2008; and Moon et al., 2004). However, there is a lack of integration of BIM and GIS for collaboration in this sector. Combining them may provide a significant role in every stage of railway life. Integration of BIM and GIS face many challenges. One of the most important obstacles is mismatching information between BIM and GIS. Furthermore, there are differences between BIM and GIS in terms of "users", "application focuses", "developmental stages", "spatial scales", "coordinate system", "semantic" and "geometric representations", and "information storage and access methods". Therefore, the key points success of integrating BIM and GIS is openness and collaboration (Liu et al., 2017). Thereby, this study will bridge this gap and a process model will be developed to facilitate the use of integrated BIM and GIS by participants after recognising the most important phase, which this integration will be useful.

1.2 Research Questions

The main research question addressed by this research are:
What are the requirements for collaboration among participants in railway projects?
The above central question can be decomposed into more precise questions:

- What is the current practice of BIM and GIS in railway design?
- What is the current status of collaboration in railway projects and how it can be improved?
- What is the current practice of integrating BIM and GIS between participants in general and in railway projects?
- What is the potential for integrating BIM and GIS in railway projects?
- How can integrated BIM and GIS be used to improve collaboration?

1.4 Research Justification

Collaboration is essential for achieving targets and minimising rework in any project. The railway is one of the most important transport sectors needing attention and development. Planning and delivery of large infrastructure solutions consuming a lot of time, money, and human capital were considered as the most challenging in the construction industry (Bundgaard, Klazinga and Visser, 2011; Törneman, 2015).

Collaborative work is a core theme of the UK Government Strategy - and for an infrastructure project this involves convergence of Computer-aided design (CAD), BIM and GIS information with other types of project information, within a digital setting, such that the right information is available to the right person, in the right form, at the right time (May, Taylor and Irwin, 2017) . Collaboration may be considered as an opportunity to solve many problems such as clash detection, rework, and better decision making (Oke et al., 2018). Furthermore, collaboration would help in achieving the moving target wanted from railway projects, for example, reducing time, cost, better quality, increase the project performance and productivity, sharing information, risk, responsibilities, and availability of project information at any time. Finally, collaboration would help in sharing knowledge, skills and managing relationships within the project team to work together (Wang, Pan and Luo, 2019; Zeng et al., 2012; Kjartansdóttir et al., 2015).

There are rare studies focusing on collaborating in the design phase of construction projects which are aimed at bridging the gap between project phases and encouraging parties to collaborate together (Koutsikouri, Austin and Dainty, 2008). However, a great collaboration among participants of the projects is required while using BIM in order to utilise its features to serve the design and construction processes effectively (Oke et al., 2018). Thus to obtain as many possible advantages from BIM, it needs to integrate with other new technology such as GIS because GIS presents the outdoor environment while BIM present indoor (Amirebrahimi et al., 2015). As well, BIM lacks the ability to analyse spatial data that GIS provided (Karan, 2014).

BIM and GIS have been recently used for industry by big companies for railway projects such as Crossrail and HS2. Crossrail has a collaboration platform called “eB”, but it is specific for Crossrail to organise and manage their information in a centralised location (Crossrail Limited, 2017). Furthermore, although in Crossrail the document can directly linked to GIS, the focus of the BIM environment tend to be on “technical information” which start as employers requirements as a shape in outline designs form, granularity development by developing design and resulting in assets and related data that will be delivered over to the Infrastructure Manager (Crossrail Limited, 2017). While in HS2 they do not have any specific platform for collaboration even with using BIM and GIS in their company.

Suchocki (2014) argues that utilising BIM and GIS has great advantages and makes a difference globally, such as by enabling informed decisions, exploring design alternatives, and providing real-world context. Therefore, due to the significance of BIM and GIS, there is a need for a process model for collaboration which can be used in industry.

One of the challenges of using BIM is the existence of several businesses and legal issues affecting the processes of collaborative BIM (Sebastian, 2010). Moreover, other challenges include organisational issues such as competencies of BIM individually, the high cost of adoption of BIM (Akin, 2010); a fragmented way of working involving stakeholders in different projects phases or lifecycle assessment; lack of collaboration between involved parties. Furthermore, most recent research studies on BIM and GIS focus on technologies more than process and people (Zanni, 2016). Moreover, there is a lack of coordination among people, tools, deliverables, and information requirements (Succar, Sher and Williams, 2012). BIM is not merely a tool or a solution, it requires new process and communication channels (Talebi, 2014). Therefore, this research attempts to develop a process model to improve collaboration among project participants.

1.5 Scope of Research

The design stage of the railway project needs an effective collaboration process to avoid rework. According to a report by Network Rail, collaboration is one of the most effective factors to deliver better railway in terms of safety, reliability, capacity, cost-effectiveness, quality and productivity (NetworkRail, 2014). The importance of collaboration has recently increased in the Architecture, Engineering, and Construction (AEC) Industry (Leicht, Messner and Anumba, 2009). Even though, collaboration cannot be achieved without using information and communication technologies (Shelbourn et al., 2007b). Moreover, collaboration needs effective tools, for example, BIM and GIS. Although they are recent technologies that, while important for collaboration, are recent innovations (Zeiss, 2013), which mean the experience of using them is low and need more training and knowledge. Consequently, changing from traditional ways to new trends face many challenges, for example, BIM and GIS suffer from interoperability and format issues. Moreover, collaboration requires guidance and awareness to demonstrate the process of collaboration (Shelbourn et al., 2007b).

BIM enables participants to collaborate in a shared software platform to share information, enabling better decision making throughout the project lifecycle (AGC, 2006). Hence, BIM lacks the ability to analyse spatial data. GIS tools have the ability to deal with spatial and geographic information (Karan, Irizarry and Haymaker, 2016). Therefore, integrating BIM with GIS can provide a complete toolset to support collaboration between participants for better collaborative decision making throughout the lifecycle of the railway project. Nevertheless, the most important decisions made at early stages which requires more attention to avoid reworking, and saving time, cost, and efforts. Thus, the focus of this research was on the early stages (design stages). Despite this potential merit, data on the application of BIM and GIS integration in infrastructure is rather lacking when compared with buildings. This is expected to change as countries such as the UK are now mandating that their public sector projects use BIM, with other countries are expected to follow suit (Karan, Irizarry and Haymaker, 2016). In many publications, many BIM frameworks have been developed including different categories such as people, tools, processes, technology, and competence (Succar, Sher and Williams, 2012; Succar, 2009; Chen and Luo, 2014; Succar and Kassem, 2015). Nevertheless, the framework that was developed by (Succar, 2009) was the most comprehensive one. It consists of three categories of BIM fields: policy, technology, and the process field. Therefore, the scope of this research is integrating BIM with GIS to improve collaboration in the design stage of railway projects, as the most important decisions have been taken in this stage. Therefore, a process model will be developed to clarify the design process in a collaborative manner for railway infrastructure (Railway track, Civil engineering structures, and systems) (section 2.2).

1.6 Aim and Objectives

The aim of this research was to improve collaboration by developing a process model for the design stage of railway projects to integrate BIM and

GIS and manage the information among stakeholders to get the right information to the right stakeholder at the right time for the right purposes.

To achieve the aim of this research the following objectives have been set out:

1- To review collaborative working in the railway sector and explore the current practice of BIM and GIS in railway design to identify the main problems in collaborative design management.

2- To examine the use of technological advancements state of the art in BIM and GIS to identify the gaps in knowledge for collaborative design.

3- To assess the current practice of integrating BIM and GIS in railway projects.

4- To develop a 'BIM-GIS' process model for effective collaboration for the design stage of railway projects.

5- To validate the proposed process through engagement with participants and to develop guidelines for implementation of this process model.

1.7 Research Design

In order to meet the research objectives, a triangulation approach is adopted (qualitative and quantitative) (Creswell, Plano Clark and Hanson, 2010). The *"iterative theory-building process"* (Drongelen, 2001) consisted of the following tasks:

1- A comprehensive literature survey to review the related books, scientific journals, and publications and attending conferences and workshops concerning collaboration and its theories in addition to background review of BIM and GIS to identify exactly the research problem.

2- Based upon the findings from the literature review, a quantitative questionnaire survey was designed to examine and assess the current status of using BIM and GIS in railway and explore the potential use of BIM and GIS together for collaboration.

3- The first round of qualitative face-to-face and semi-structured interviews were employed to further investigate issues related to collaboration and potential suggestion to overcome them which were developing a Collaborative Plan of Work and a process model.

4- From the findings of the first round of the interviews, the second round of qualitative face-to-face and semi-structured interviews were conducted to identify the components of the process model.

5- From the quantitative and qualitative results, a process model was designed (using IDEF0 and IDEF3, Integrated DEFinition) to improve collaboration in the design stage of railway projects.

6- A validation process was conducted to check the workability of the process model and refine it. A commercial Common Data Environment called Viewpoint (formerly 4Projects) was used as a platform to implement the process model. A focus group and qualitative methods used with experts in a railway company were used to assess the Viewpoint implementation and validate the underlying process model.

1.8 Thesis Outline

The thesis has been divided into eight chapters and a brief summary is provided below for each chapter and the outline of the research process is shown in Figure 1-1:

Chapter 1- Introduction

This chapter presents the background of research, research problem and provides justifications for its importance. Also, in this chapter, the aim and objectives are presented to guide to the thesis.

Chapter two: A literature review on railway, design stage, and collaboration

In this chapter, the first part of the literature is presented. It focuses on providing an overview of the infrastructure, railway projects, and design process definition. Furthermore, the definition of collaboration and its strategies, process and drivers are reviewed.

Chapter Three: A literature review on BIM, and GIS

This chapter contains the second part of the literature. The focus of this chapter is to provide an overview on BIM (It defines the existing definitions of BIM (e.g. "Building Information Modelling" and "Building Information Management") and discusses the policy, technology, and process aspects of BIM) and GIS (definition and applications). Furthermore, the integration of them to improve collaboration. Moreover, this chapter provides previous studies about implementing BIM and GIS, benefits and challenges.

Chapter Four: Research Methodology

This chapter discussed the methodology in terms of theoretical concepts, the design of the research, methods and strategies. Qualitative and quantitative approaches were reviewed, and the chosen research design justified (techniques and procedures).

Chapter Five: Results and Data Analysis of the Questionnaire and the Interviews

This chapter describes the formulation of the questionnaire and the analysis of it. The findings from the questionnaire results are also presented and discussed. At the end of the questionnaire analysis, the key findings presented. Furthermore, the first round of the interviewers presented to examine the collaboration issues and the suggestions to overcome them. As well as in this chapter the components that constitute the BIM and GIS-enable collaboration presented and the needed process model has been outlined.

Chapter Six: Development of collaborative process model

This chapter presents the development of the process model for BIM and GIS-enabled collaboration upon Interviews and survey have been used to develop the process model, using various types of IDEF (Integrated DEFinition) notation. This chapter consists of presenting the high-level decompositions, detailed decompositions, and analysis of the second set of the interviews. Finally, summarises of the findings of this chapter.

Chapter Seven: Discussion

This Chapter discusses the main findings drawn from the research outcomes, which relate the findings to the context of the literature.

Chapter Eight: Validation of research outputs and model

This chapter presents the validation process of the process model to establish the trustworthiness of the research outcomes through conducting focus group, interviews with industrial experts, and documentation. The chapter presents the validation process and the way to present the IDEF to the participants. Followed by presenting the received feedback from the focus group followed by the interviews. Furthermore, presenting amended the IDEF process model for BIM-GIS enabled collaboration upon the recommendations made by the industrial participants. Finally, the main findings are summarised.

Chapter Nine: Conclusion and Recommendation

This chapter presents an outline of the main conclusions. In addition to presenting the recommendations for future work from the research findings and how to fulfil the achievement of the research aim and objectives. In addition, this chapter discussed the limitations of the study.

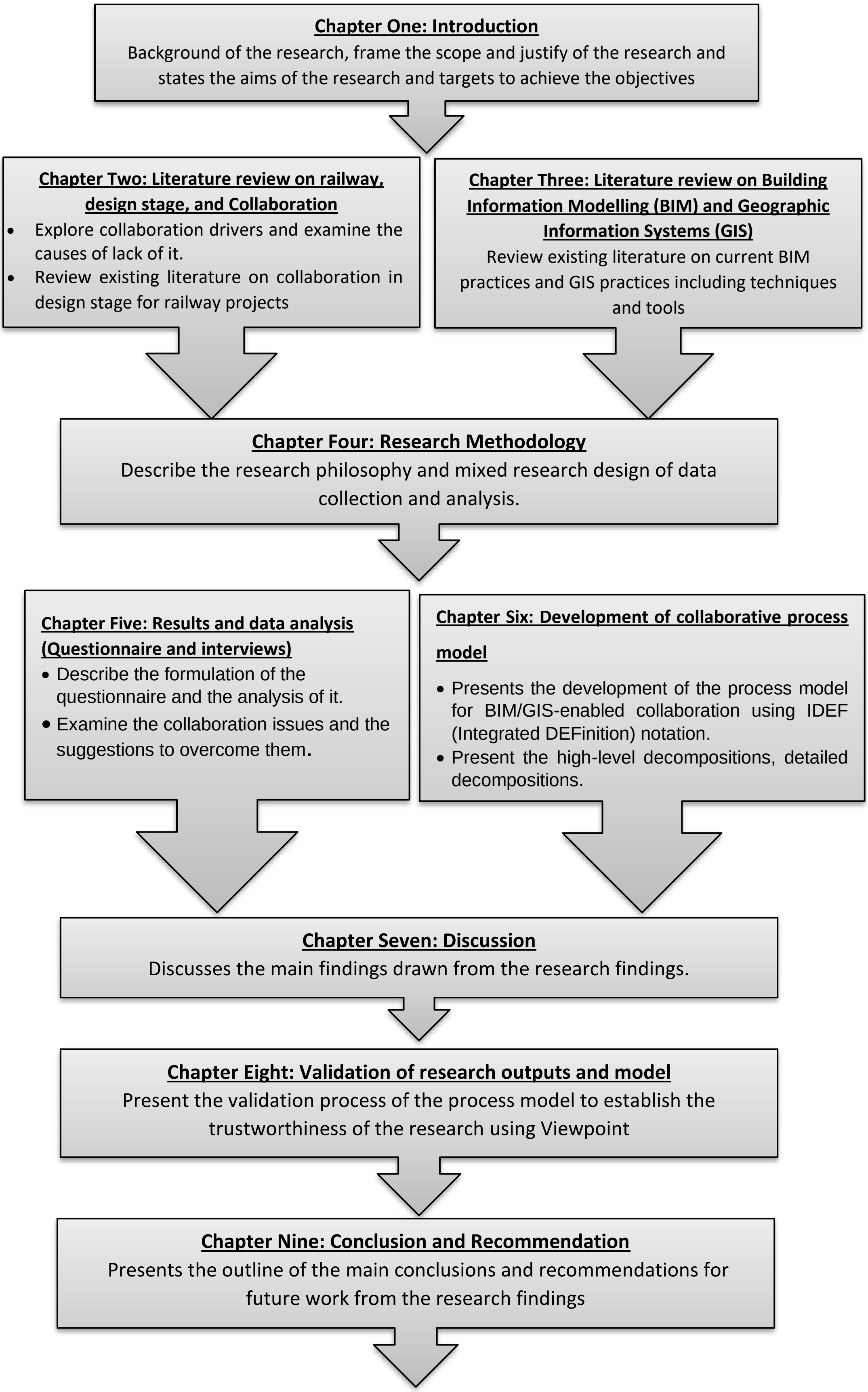


Figure 1-1: Research process outline

1.9 Summary

This Chapter has provided a discussion of the background of the research area and provided justifications for the problems' significance. Furthermore, it presented the research aim and objectives along with the research methodology. Finally, the structure of the thesis has been illustrated and explained.

Chapter 2 : Literature Review on Railway, Design Stage, and Collaboration

2.1 Introduction

This chapter presents the first part of the literature review. First of all, it reviews the background of this study and its importance to be considered. Then a presents a background regarding collaboration. Therefore, generate an overview of the infrastructure, railway projects, and design process definition. Furthermore, ideas about the definition of collaboration and its strategies, process and drivers are reviewed to narrow down the research problem and presented in detail (chapter 3)

2.2 Background of the Study

There is a need for new information technology in the construction industry to manage, share, and store information. Any construction project is designed to deliver high-quality work for a specific purpose with minimum cost and time through the collaborative efforts of the various professions (Elleithy, 2010; Foster, 2008). However, several factors could act as barriers to achieving these objectives. One such factor is using of traditional ways of communication, such as exchange of non-electronic drawings (paper), that is often associated with an inefficient use of time and money (Gallaher et al., 2004; Sommerville, Craig and McCarney, 2004).

2.3 Importance of Railway Infrastructure

Studies defined infrastructure in different ways and classified it to different categories. Shou et al., (2015, p292) defined it as is "basic physical and organisational structures for social work" which are owned and managed by governments. Shou et al., (2015) stated that each type of infrastructure transport which includes an airport, bridge, road and rail has its own methods of construction and own characteristics. While Keskinen (2007) grouped infrastructure into two board types; economic infrastructure (public utilities) and physical infrastructure. The physical infrastructure is considered as the actual set of connected structural elements that offer the framework to support the whole structure in terms of basic services. While, public utilities are necessary for the sectors producing these goods for an economy (Keskinen, 2007). Railway as a type of infrastructure was the main focus of this research due to its significant role in any country economy.

Transportation is known as a fundamental activity for humankind and it involves the movement of people, goods and information from one place to another (Dincer, Hogerwaard and Zamfirescu, 2016). It refers to the existing complex interrelationships between physical environments and patterns of activity in terms of social and political levels of a developed economy. The purpose of transport is to make a journey for a specific purpose Nutley (1998). Economic gain is the main demand driver for transport, for which the transport demand is derived (White and Senior, 1983).

Railway infrastructure is one of the most important transport sectors needing attention and development. It plays a crucial role in developed and developing countries. It is crucial in linking people and communities and providing people and goods with a means of transportation (Walker and Price, 2013, Keskinen, 2007). Railway transport is considered a mature industry in the developed world. The railway transports passengers and freight. Its capability can extend to cover any distance in any environment (urban, suburban, peri-urban, regional and interurban). Its range for passengers' transportation is usually suited to approximately 1,500 km, while for freight the distances can be much greater. From a transport system point of view, it is by default considered to comprise three constituents as shown in Figure 2-1 (Pyrgidis, 2016):

- Railway infrastructure
- Rolling stock
- Railway operation

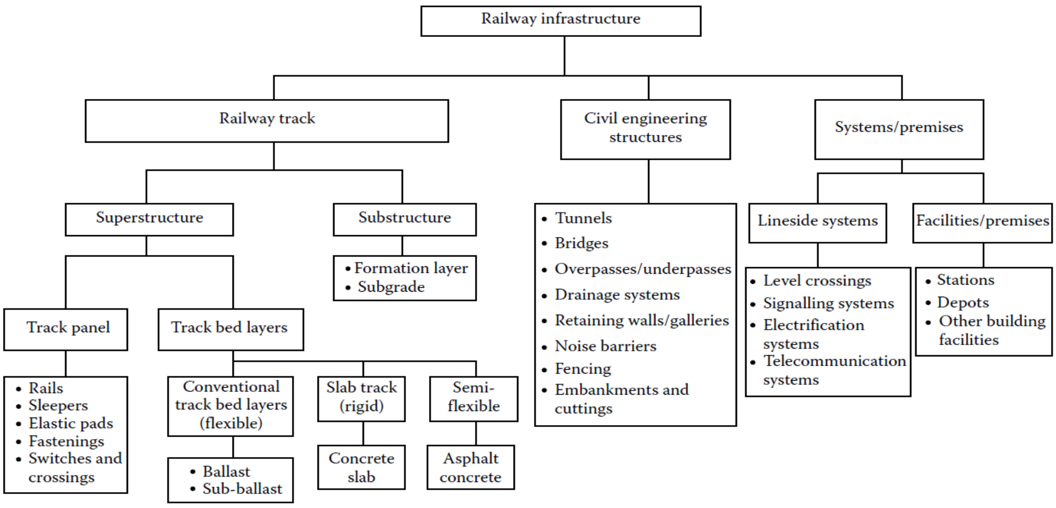


Figure 2-1: Components of the railway infrastructure

These components were the focus of this research because of the most important decisions related to these components at the early stages of design processes.

The railway is showing a remarkable comeback after a period of decline in the developed world. The obvious revival of the railways is boosted through its ability to move enormous amounts of freight or passengers from place to place in an efficient way in terms of energy and emissions. However, railways in many countries are still struggling to be more efficient and commercially viable, instead of depending on government subsidy and legacy companies (African Development Bank, 2015). Ali (2012) argued that the importance and success of the railway transport depend on how to prove its abilities to compete with road and air transport in the market to serve long-distance passenger. Furthermore, Bo (2012) stated that because of the gradual improvement of the economy, there is an intense market competition in railway construction. This is because railway construction includes complex procedures and complicated construct techniques.

On the other hand, attention is required for the railway for several reasons. For example, Walker and Price (2013) demonstrated that rail is the most significant type of transport in human life. It has strengths which need to be exploited and weaknesses that need to be reduced or avoided (Table 2-1). It is safer and more economical than the road to transport heavy freight such as coal and aggregate. Its advantages include high-speed operation, long-distance range, large capacity, less energy consumption, low environmental impact, safety, consistent punctuality. This provides an opportunity for railway transport to grow massively across the world (Park, 2013).

Table 2-1: Strength and weakness of railway transportation: (Sameni, 2012)

	Item	Main reasons
Strengths	Safety	Restriction in movement to just one axis - Very controlled
	Energy efficiency	Low friction due to steel wheels running on steel rail - Higher passenger/freight km per kilo equivalent of petrol
	Environment friendly	Low CO_2 emissions due to higher passenger/freight km per kilo equivalent of petrol – Low friction and adhesion
	Load handling	Enormous traction power and energy efficiency
	Less land use	High carrying capacity per square metre of infrastructure
Weaknesses	Not door-to-door	Not practical
	Capital intensive industry	Rolling stock, signalling and infrastructure are expensive.
	Extreme dependency on the infrastructure	Trains can only go where the rails go and only have one degree of freedom for movement along the rails.
	Long braking distance	Low friction due to steel wheels running on steel rails
	Noise	Steel wheels running on steel rails

Rail transport is crucial for human life and economic growth; it requires great attention. To ensure that the railway continues to fulfil its role in terms of providing safe, reliable, cost-effective, environmentally friendly as well as driving economic growth, implementing new technologies and new types of work are needed. To achieve that, involved parties should work in a collaborative environment. Geospatial software specialist Geoff Zeiss reported in August 2013 that integrating both engineering and a geospatial database has a crucial role to improve communication and coordination between whole stakeholders in a project, particularly for the makers of non-technical decisions (Zeiss, 2013).

Collaboration considered as a crucial factor to improve the railway especially at design stage for several reasons. Through collaboration, project participants will be able to share a single model for visualisation, coordination, communication, assessment, analysis, simulation or discipline design (Harrison and Zealand, 2015). Eastman et al. (2008) reported that through collaboration, each firm would be able to reduce the project's change orders when firstly planning the project cost. Therefore, the project will be better understood, and a clash-free design may be sought in the future planning of the project. Furthermore, collaboration enhances sharing information and making critical decisions effectively (Tu, Li and Bian, 2018). Moreover, collaboration has become an important issue in the AEC Industry in recent years (Leicht, Messner and Anumba, 2009). Thus, collaboration is the key success to deliver better railway in terms of cost, time and productivity. The construction industry is moving toward using the collaboration process (Aziz et al., 2004). Despite this, to achieve collaboration technologies need to be utilised precisely (Shelbourn et al., 2007a). From these technologies, BIM and GIS are recent ones that particularly enable collaboration (Zeiss, 2013).

BIM and GIS as new technologies can realise the huge benefits of infrastructure through its lifecycle. For example, Fanning et al., (2015) reported that by using BIM in infrastructure a significant increase will appear in efficiency, sustainability, and the waste would be minimised during all phases of projects. While, GIS has the ability to transform the information from planning to design, operation and maintenance. This would increase productivity and the performance of the transportation system due to the capability of GIS uniquely to integrate with other technologies as reported by commercial software brochure (Esri, 2011). Within a certain framework, for instance, building a new railway station, GIS is used to link, process, and integrate different datasets (Blainey and Preston, 2013).

2.4 Theoretical Drivers for the Design Process in Railway Projects

2.4.1 Definitions of the Design Process

There are several definitions for the concept of designing such as that by Pahl and Beitz, (1988) who defined it as the process of optimising a certain group of objectives within a range of inconsistent constraints. They added that designing's requirements always change in order to attain an applicable and optimised solution for a certain group of circumstances. In view of that, the process of design requires a strong degree of collaboration with people from different areas and majors. Besides, there should be an operable amount of information administrated and encouraged by a sound and well-built organization (Hassan, 1996). With that, design optimisation as a process is achieved through the step of decision-making based on the most recent restructured version of design information.

As for building design, Hassan (1996) defined it as

> *"a key process sets the client's and end user's clear necessities to create and produce, relying on his or her knowledge and experience concerning a certain topic. In other words, it is a group of documents that give an account and justifies a project that would meet the related requirements, along with other types of requirements, namely: statutory and implicit imposed by a certain domain, context and/or the environment".*

Likewise, Vakili-Ardebili (2005) defines it as

> "*concerning the process of building design, it is mainly regarded an active process that includes an improvement taking into consideration that the design stage is a continuously developing system whose level of advancement and progress compared with previous experiences are constructed in the primary stages of design building through effective strategies and innovations".*

Accordingly, from these definitions above, with the intention of achieving a cooperative process of design, requirements of objectives and compliance should be clearly formulated before the design's process starts. Yet, the cooperative process should preserve a certain degree of flexibility and plainness to encourage the atmosphere of innovations.

2.4.2 Prescriptive and Descriptive Design Models

The history of the Design Methods Movement dates back to 1960s in Britain, where all its members believe that design is not mainly constructed on intuition and experience, but it should be carefully and deeply revised by a more organized and scientific process that could be set (Goldschmidt, 2014). This is considered the first effort to construct the design process. Hubka (2013) suggested that a large number of models structured in the course of that period were flowcharts, particularly the Analysis-Synthesis-Evaluation (ASE) that were suggested by Asimow (1962) as models of the design process and were widely accepted. The structure of the ASE model stemmed from the problem-solving paradigm as information processing; it is the same paradigm that founded artificial intelligence and cognitive science.

Moreover, to elucidate the iterative nature, of design researchers use a spiral metaphor, from abstract to a concrete solution (Watts, 1966). With that, Alexander (1964) suggested a prescriptive method where the designer has no choice but to adapt previously rigid programmed steps contrary to the paradigm of creative thinking. Still, this model is considered to be ineffective, leading researchers to rethink and recommend a novel paradigm concerning descriptive design models. Moreover, it is found that descriptive design models related to real design behaviour are necessary to develop the actions of understanding and thinking as it exists in our real-life situations (Goldschmidt, 2014). Consequently, an action of partnership is effectively created between designer and computer (Kalay et al., 1987). With that, the design has been simplified rather than being restricted to the standard solutions, and thus, that enable the design team to attain innovative solutions in the design of the buildings. Accordingly, this research relies on the descriptive paradigm for collaborative and collective partnership and process leading to map striving not to limit the creativity of design.

Besides, Gupta and Murthy (1980) maintained that the cognitive design process consists of three phases (cited in Hassan, 1996): (i) Exploratory Phase, (ii) Transforming Phase, and (iii) Convergence Phase. As for the exploratory Phase, it is constructed on the data provided in the brief. Throughout this phase, the designer's task lies in attaining an adequate understanding concerning the problem in research (collaboration issues in the case of this research). In the Transformation Phase, the process of creation begins where the designer, with the help of knowledge, skills and certain talents recommends effective and alternative solutions to the problem (explore solutions through interviews in the case if this research). During the Convergence stage, the designer's main function is to assess the proposed solutions in terms of feasibility and applicability in an attempt to reach a decision regarding the optimal choice. It should be noted that numerous researchers have adopted a parallel approach, concentrating on the designer's thought process (Austin et al., 2001; Evans, Powell and Talbot, 1982). However, it is still possible to consider the cognitive process of design evolution as subjective and different between individuals.

Organisational design process has been described according to Laseau (2001) as a "architectural practice" enclosing the following steps: (i) building programme, (ii) schematic design, (iii) preliminary design, (iv) design development, (v) contract documents, (vi) shop drawings, and (vii) construction". Regarding the aforementioned steps, Laseau recommended a 5-step linear process model that included these five steps, namely: problem definition, developing alternatives, evaluation, selection and communication. So far, the current design process's generic descriptive model can merely be applied as a framework, centring on the required organisational and contractual arrangements. Thus, this kind of approach to map the design process has been adopted by numerous researchers (e.g. Ahuja and Nandakumar, 1986).

2.4.3 Modelling the Conceptual Stage

It is argued that the conceptual design stage lies more in "problem finding" and less about "problem-solving" Sebastian (2007). Still, if the goals of the design are not initially established, it is possible that design team members will work towards inconsistent objectives. Researchers can elucidate this statement in the sense that the design process is no longer administrated in a restrictive manner (offering prescriptive solutions without any flexibility). Thus,

the design problem’s analysis is considered an essential step to the process, as practical design problems are variable, distinctive and uneasy to comprehend a recognise (Laseau, 2001).
As for the creativity and cognitive information processing elements, it is noted that they make the conceptual design stage the most problematic part to automate the design process (Newsome, Spillers and Finger, 1989). For instance, in railway design, the complexity of its work is getting high due to the introduction of new additional design criteria in the related system. Indeed, the scope of the concept design remains to explore the numerous existing solutions to a problem until the best design solution arises (Chakrabarti and Bligh, 1994). it has been concluded that there is no universal term for concept design. Nevertheless, a process that enables the transparency of the collaborative workflows can facilitate the development of a common definition between stakeholders in order to reduce uncertain (Steele, 2000). As a matter of fact, the concept design’s scope aims to explore several current solutions to a certain problem until the top design solution is achieved (Chakrabarti and Bligh, 1994). The latest has been followed to explore the suggestions to overcome the collaboration issues.

2.5 Collaborative Design Process

In most industries, both design and engineering are collaborative processes which include different participants coming with diverse skills in different technical areas. According to Eastman et al. (2008); Gerbov (2014), there are several stages into which the design phase in construction projects can be divided.

- **Pre-design**

The pre-design stage is usually the first stage of construction projects. This stage involves an assessment of the need for construction. The preliminary building requirements are articulated. In projects involving infrastructure, stakeholders involved in this stage include consultants, the public, and customers. The stage is usually merged with the second stage of design.

- **Conceptual design**

Both terms *schematic* and *conceptual* design can be used to name this phase which is aiming to come up with solutions for the design, shape and space definitions, materials and systems of the building. In projects of an infrastructure nature, the process of conducting a feasibility study usually happens at the same time at this stage in order to assess the undertaker of the economic feasibility.

- **General design**

This stage, which is sometimes referred to as design development, the level of detail regarding plans for the building, main materials needed, and key building systems is taken a notch higher. This is the stage at which the essence of costs involved in construction and design solutions are defined.

- **Construction-level design**

This is the stage of design where the ultimate set of documents which are highly detailed is created for use in the construction project. Such documents include detailed plans of all the building elements which are complete, material and systems specifications, site work plans, and the building systems acceptance criteria (Eastman et al., 2008: 151-152).

For one to comprehend the factors impacting on efficiency and effectiveness of collaboration design there is a need to do a closer view of the character of design and collaboration.

Design can be viewed as an activity for humans which seeks to create an environmental improvement through creating artefacts. To do this, it needs to formulate the functions and then create a design to reach these functions. This is a view supported by Gero (1990) who says that the activity of design is purposeful and has the goal of transforming the desires into an artefact’s design description. This is the description which is then used to produce the artefact. The key outcome of the design is a description of the designed artefact.

Based on Gero's (1990) Function-Behaviour-Structure (FBS) framework, the following sub-processes are involved in the design.

- **Formulation**: The designer creates an idea of the behaviour of the structure to enable to perform the needed function.
- **Synthesis**: The structure is generated by the designer.
- **Evaluation**: The designer assesses the structure behaves in keeping with the expected behaviour.
- **Reformulation**: In instances where the manner in which the structure behaves differs from what it is expected to behave like, the designer has three choices: Type 1, reformulation of the structure, Type 2, reformulation of the behaviour, Type 3, reformulation of the function.
- **Documentation**: This is a process of creating a design description of the structure. According to Gero (1990), there are two contexts under which design is performed: where the designer operates, and the context produced by the process of developing the design. One of the outstanding frameworks which have been in strides related to design in various areas is the FBS framework. The designer decisions may be affected by the environmental state Which may encourage them to change their concepts; which itself is linked to that which they have done (Gero and Kannengiesser, 2004)

These are important concepts because they deliver a view which is generalised on the process of design as an iterative process where change, reformulation, and re-documentation are present. The design environment which the designer creates influences how that designer perceives the design at a later stage and the actions that the designer takes going forward. In collaborative design, it is not just the actions of the designer that influence them, but also those of other designers.

When a design is created by a group of individuals, there is a requirement for a shared vision of structure and function which is only possible through communication. The separate inputs of the designers have to be coordinated in design so that the shared vision can be shared and so that the elements of the design can be fitted together. Collaboration means that bringing together specialised knowledge held by different designers creates results that may not have been possible if each of the participants worked on their own (Kvan, 2000).

A process view on collaboration has been provided through the concept of transactive memory, developed by (Wegner, 1995). Transactive memory happens when one individual becomes external storage of information for another. The individuals depend on common memory restore the information, which is not known for each of them, from other individuals. Transactive memory allows the memory of all the group members to be combined (Wegner, 1995). This is the same idea of this research that collaboration allows all the participants to share their knowledge and needed information to approach the project goals.

The goal of the collaboration is the integration of knowledge. Collaborative design is defined by Kleinsmann and Valkenburg (2008), as a process which involves actors from varying disciplines sharing knowledge about both the process and content of the design. The same authors note that this is done with the aim of creating a shared understanding of both elements. This makes it possible for the integration and exploration of their knowledge and for the broader common goal to be achieved: which is the new product.

When used in information systems, the idea of memory does not necessarily refer to events which happened in the past, as may be implied by intuitive understanding. Rather, it refers to information which is stored in certain storage (Wegner, 1995). In this context, this storage would be the mind of the individual. Hence, transactive memory incorporates even the memory, which was there before the design process commenced, including the experience and professional knowledge of individuals. In this case, the idea of memory can be equated to knowledge.

It is important to identify the location of the knowledge that required to be retrieved transactive memory. This means having an idea as to who can provide that information. However, it is not always possible for each person to always know what is known by others. Everyone’s familiarity with the knowledge holding system is from their own perspective. However, Wegner (1995) notes that the system is bigger and more complicated than that of separate individuals. Hence, Kleinsmann and Valkenburg (2008) says that there is a need for knowledge of the state of knowledge at any given time to facilitate an effective exchange of information.

Apart from developing a shared understanding of the design, collaborative designers develop a shared comprehension of the system which holds knowledge. Shared understanding is defined by Kleinsmann and Valkenburg (2008) as the similarity in how individuals perceive actors about either the conceptualisation of the design content of the way the transactive memory system works.

The ideas of transactive memory and shared understanding provide a foundation for the observation that collaborative design as a process is chronological, where environmental changes that the designers make are impacted on by the sum of past actions which are responsible for the existing state of the environment.

Added to this, the knowledge existing before the project was initiated and the state of the environment affect the design. For example, several communication challenges emanate from differences inherent among the actors even before the project started. Several elements can be credited for these differences: skills, professional values and goals, and vocabulary (Kleinsmann, Buijs and Valkenburg, 2010; Pei, Campbell and Evans, 2009).

Using the point of view which sees communication as a self-organised and self-steered system with high levels of vagueness, Maier, Eckert and Clarkson (2005) advance the argument that there is limited control over any kind of communication. The same authors, however, note that there is potential for influence where there are comprehension and connection to the *internal logic of a system*. This refers to components and their connections and the precise rules on which they operate. They note that the desirable solution involves raising the awareness and ensure that the designers have access to opportunities for continuous learning.

The idea of transactive memory has been followed in this research. This is because the idea of the *internal system* and its *logic* in the above statement implies a resemblance to the idea of shared understanding and transactive memory discussed earlier. The ideas of shared understanding, transactive memory, and communication as a social system imply that the design is impacted by the knowledge of the team that designers have (the knowledge holding system) and the process of teamwork, as opposed to just comprehension of the design object.

2.6 Collaboration

New technologies for collaboration redefine the way of working simultaneously and sharing information between every domain. Through this collaboration, traditional lines will be blurred, for instance, organisational boundaries, professional areas, and geographic borders. Collaboration provides participants working together with huge advantages. For example, sharing is one of the collaboration benefits which enables people to reach a huge amount of stored knowledge; obtaining this information in past would have been difficult or even impossible, as well as sharing ideas to make more informed decisions (Laituri, College and Dangermond, 2010).

There is a discussion about the term's *collaboration* and *cooperation*. It is important to distinguish between the terms collaboration and cooperation as they are different (Kozar, 2010). Cooperation means working together toward shared goals, while collaboration means working together towards common goals while respecting the contribution of each individual to the whole (Kozar, 2010; Kymmell, 2008). Cooperative work is to complete the task by dividing it among the participants and each person is responsible for a part of the problem-solving. While collaboration is "the mutual engagement of participants in a coordinated effort to solve the problem together" (Roschellel and Teasley, 1995; Kozar, 2010).

The key difference between cooperation and collaboration is that cooperation can be achieved if all participants work separately on their assigned part and bring their results to the table. While collaboration requires direct interaction among individuals to create a product depending on negotiations, discussions and accommodating the perspectives of others (Kozar, 2010). Coordination is given as to "first. bring the different elements of (a complex activity or organisation) into an efficient relationship and second negotiate with (others) in order to work together effectively" (Oxford University Press, 2001, p.189).

In this research, the term *collaboration* will be used because of railway projects working towards a similar goal(s). Furthermore, collaboration is required to achieve project targets and hoping aims by integrating BIM with GIS.

2.6.1 Collaboration Definition

Collaboration can be defined as working together to common goals. There are several definitions for collaboration according to the context and the author's perspective (Warnest, 2005). According to Lawrence, Hardy and Phillips, (2002), collaboration is a collaborative relationship within organisational based on negotiation for continuous communication without control from the market or hierarchical mechanisms. Whereas, Gray (1989) defines collaboration as a process which includes multiple parties searching for solutions to reach what is possible, far from their own limited vision.

Thus, organisational relationships take a vital value from collaboration, while on the contrary, phrases such as cooperation, partnership, coordination, and competition indicate a working relationship in an effective negotiating way in order to achieve an objective which is agreed on in a complex setting (Alshehri, 2011). From the above illustration and considering the aim of this study the collaboration can be defined as "professionals working together to reach the same goal far from their own interest".

2.6.2 Collaborative Design Management in Construction

Due to the iterative nature of design and the complexity of the outcome, especially in the case of railway projects as which are considered as megaprojects, the management of the collaborative design process becomes difficult from the early stages.

Thus, researchers have highlighted the importance of architectural management such as (Alharbi, Emmitt and Demian, 2015) as well as information management (Hassan, 1996) for eliminating design problems. Furthermore, it has been suggested that BIM and GIS can assist in efficient information management (Su, 2003; Demian and Walters, 2013). Hassan (1996) has categorised design problems into the following: (i) inherent nature of design (e.g. iterative nature), (ii) technical aspects of design (e.g. lack of technical knowledge), (iii) client-related (e.g. lack of appreciation of the impact of design changes), (iv) managing information (e.g. missing information), and (v) difficulties in planning design (e.g. inadequacy of planning techniques). This research focuses on addressing the information management and planning of design categories, also assisted by the current technological solutions (e.g. BIM and GIS). This socio-technical approach to design management encompasses a holistic consideration of the parameters that influence the design process and outcome without eliminating the critical aspects that contribute to a collaborative design process. This approach aligns with the notion that collaboration at a project level is a complex mechanism of social interaction and procurement (Cicmil and Marshall, 2005).

There are many issues in the current models in construction industry. The current business model in the construction industry remains highly fragmented, depending on paper-based models of communication, causing unanticipated errors, and as a result, time delays, and additional costs (Eastman et al., 2008). Especially in the case of environmental assessment, which is usually performed too late during the design phase, resulting in inconsistencies, compromises and lost opportunities. This process involves a large number of people and documents, which quickly become difficult to manage and coordinate (Bouchlaghem, 2012). Korkmaz, Riley and Horman (2010) have examined the association between project delivery attributes and project performance outcomes, finding that “Energy rate” is one of the significant variables that affect the project delivery outcome. So as to improve collaborative practice productivity in the construction industry, the focus needs to be on (Doherty and Fulford, 2006): (i) strengthening of relationships to create a network of organisations that share the same values; (ii) design processes to include value engineering and lifecycle costing; (iii) creating procedures and information needs standardisation; and (iv) performing value-adding project management activities. Soetanto et al. (2015) have identified the following as the key success factors for collaborative design projects: (i) Satisfying institutional requirements and aligning with professional guidelines; (ii) Designing activities for online collaborative design; (iii) Support for collaboration; (iv) Skills for collaboration; (v) Platforms for collaboration; (vi) Skills for online collaboration; and (vii) Skills for synchronous collaboration. A holistic socio-technical approach to BIM-enabled collaborative design management can address these issues.

2.6.2.1 Strategies of Collaborative Working

Effective use of technologies facilitates the process of collaboration. It should be known that both organizational and people issues can benefit from using technology for effective cooperation in construction projects (Shelbourn et al., 2007). Shelbourn et al., (2007) have identified the strategic areas for effective cooperation, namely: Business Strategy, Technology Strategy and People Strategy. Also, Bouchlaghem (2012) has identified effective collaboration as the formal and informal collaboration's function, along with strategic areas as follows: business strategy, technology strategy and people strategy. He added that there are six factors that link these three key areas of (i) vision - agreement on scope, aims and objectives; (ii) stakeholder engagement - all key participants must be consulted; (iii) trust - time and resources are the enablers; (iv) communication - a common means should be decided; (v) processes – the day to day workflows should be transparent and known to all key participants; and (vi) technologies – an agreement on technologies to be used is required to ensure collaboration.

2.6.2.2 The Social Aspect of Designing

For a successful outcome, it necessary to define a shared meaning of the problem along with the solutions of alternative design, from early stages of the design process. Fundamentally, the nature of team designing has been described as an activity that depends on supporting the team members to each other (Valkenburg and Dorst, 1998).

The design process is complex and requires several factors to achieve successful management. Blessing (1994) has found that design is complex not just in the technical process but also in the social process, and thus, "a model of the design process should include the notion of teamwork". For successful management of the interdisciplinary teamwork, the design processes must have a flexible structure which is shared among all the team members to contribute to the processes of negotiation and coordination (Peng, 1999). To make it effectively happen, there is a need to clarify the technical, social factors that affect the design, in conjunction with the way that the project team find a happy end to conflicts (Steele, 2000). In order to achieve an integrated practice to be a truly collaborative process, it needs to realise the value of its team members and utilises it to achieve an economic value process with high performance, achieve client's goals, and generate a managed process in a better way for future projects (Jernigan, 2008).

There are several types of design process models. The representation of common models of the design procedures has been reviewed by (Gebala and Eppinger, 1991) as, Direct Graphs; Matrices (such as the Design Structured Matrix, DSM); Programme Evaluation and Review Technique (PERT); and Structured Analysis and Design Technique (SADT). PERT and DSM diagrams are proper to determine activities that either parallel or sequential, but not suitable for mapping the iterative nature of building design process (Hassan, 1996). Furthermore, to reach final, workable designs, the iterations are required especially when ignoring the concerning complex and specialist services (Pryke, 2012). Chapter 4 provides a more detailed discussion of the mapping methods for process mapping. Therefore, a proper technique is required for mapping the process model that addresses the issues in other methods.

There are several techniques to facilitate the collaboration process and the interaction between parties. At present, the belief of prioritising the social aspects of collaboration has led many researchers to implement sociometry for construction research to systematically identify the relationships among actors within a certain organisation (Pryke, 2012). As for Social Network Analysis (SNA), it is derived from a branch of mathematics called graph theory (Prell, 2012). SNA qualifies a certain network to connect individuals, corporations with other entities applications in the area of social researches (see Table 4-5). The effectiveness of the SNA has not justified yet (Ruan et al., 2013). the SNA assumes the capability of the actors to perform their best capabilities, which means it does not provide quality control over the outcome of the design even it effectively predicts the interdependencies between actors of the project.

The complete design process has been defined by the Generic Design and Construction Process Protocol (GDCPP) (Cooper et al., 2008; Kagioglou et al., 2000; Zanni, 2016). Apart from providing a description of the processes' physical stages, the GDCPP model also deals with the management of design. Steele (2000) refers to the concept of the *Approval Gates* which need to be signed off before each stage commences, make it possible for the design output to be evaluated. In this way, they ensure that the process is controlled in a more efficient way. Putting the design on hold between stages is seen as a way of boosting communication and coordination among those taking part in projects through the stages of design (Zanni, 2016).

However, it lacks the gates of GDCPP stages which have been proven to enhance the coordination decision-making among the participants of the project (Sackey, 2014). Therefore, to combine the strengths of engineering and social modelling methods, a socio-technical approach will be the most applicable approach to structure the process of design (Sackey, 2014). The newly structured model developed in this research examines the aspects of teamwork by assigning tasks to competent team members and then supervising their interactions within a collaborative process in the railway design stage.

2.6.2.3 Communication Types for Collaboration

A structured process can provide assurance and improve the efficiency of communication during the collaboration for railway design. Graphic thinking is considered as communication in three contexts: individual, team, and public (Laseau, 2001). The ideas are shared when the focus is on better communication. Ewenstein and Whyte (2007) have examined the effect of types and artefacts of communication for collaboration within a multidisciplinary context. It has been found that the process of representation is imbued with power. Therefore, the decision what to show, when, how, and to whom, must be managed through careful conventions (Ewenstein and Whyte, 2007).

Communication in groups can vary in terms of channels available, the equality of information sharing through communication, and the degree of centralisation of the network (Freeman, 1979). Emmitt and Ruikar (2013) have categorised collaborative communication as (i) synchronous (same time) and asynchronous (different times); (ii) intrapersonal (more private) and mass communication (more public); and (iii) formal and informal channels. Asynchronous collaboration means working together in a separate temporal collaborative environment, in other words, the exchange of data will happen between various stakeholders without instant feedback (Johansen, 1988). While in synchronous collaboration, the teamwork together at the same time with direct responses to modify the proposed design but not necessarily at the same place.

Different types of collaboration are needed based on situations. Bouchlaghem (2012) has categorised the possible technologies for collaboration into four categories in relation to time and place: (i) same time - same place, (ii) same place - different times, (iii) different places - same time, and (iv) different places - different times as shown in Figure 2-2.

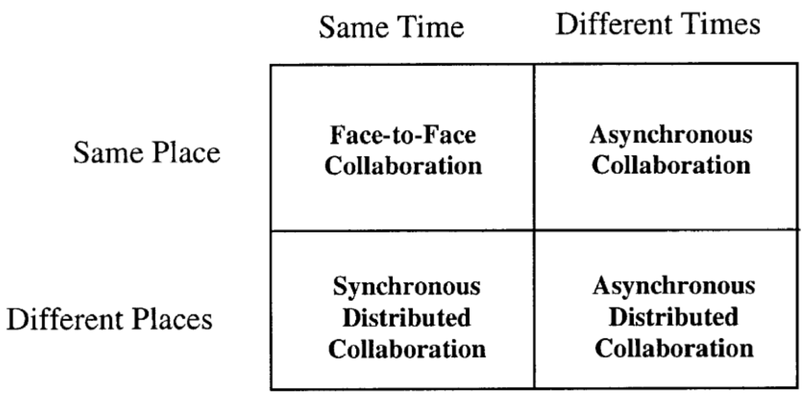


Figure 2-2: Types of collaboration (Shelbourn et al., 2004)

.A structured process for railway design workflow management can facilitate both synchronous and asynchronous communication for distributed teams' collaboration, which is the norm in construction.

The purpose of communication for collaboration is the exchange of information. Tunstall (2006) has defined three types of communication for building design: (i) talking (e.g. face to face, telephone, video conferencing), (ii) writing (e.g. emails, reports, and specifications through extranets), and (iii) images (e.g. 2D, 3D drawings, animated models, photographs). The type and accuracy of communication have significant implications for the progress of the decision-making process. A clearly defined execution planning of a collaborative process can assist in ensuring that the right information is delivered timely.

Communication problems can be addressed by providing an audit trail where except for the explicit knowledge (who did that) also accounts for the tacit knowledge (why it was done) (Cerovsek, 2011). There is a lack of research in the area of collaboration and the flow of information between design professionals. Most of the current process modelling tools in the AEC industry (Prasad et al., 2018). Furthermore, the capabilities of BIM are very limited concerning the "how", and absent concerning the "why", leading to inefficiency to solve the emerging problems within the BIM environment (Dossick and Neff, 2011). Furthermore, BIM limited to spatial data and need to be integrated with another technology deal effectively with spatial data such as GIS. To address this gap, this research project has developed a process model for collaborative design, which defines tasks and deliverables (explicit knowledge) and combining with GIS to provide a holistic process of collaboration.

2.6.2.4 Information/Knowledge Management (IM/KM) and Collaboration

At the start, based on reports by the National Economic Development Office (NEDO), it has been found that more than 50% of building sites are associated with poor design information (Building Economic Development Committee, 1987). With that, resultant problems are categorized as follows: (NEDC Report, 1990; cited in Hassan, 1996): (i) lack of information transfer, (ii) late information transfer, or (iii) unresolved conflict through lack of information transfer management. In his study, Manyanga (1993) has shown that the process is driven by related information and the decision-making process mainly depends on the related information that the designer is aware of when the decision is made, and if the information package is possible to be identified (Baldwin et al., 1998; Hassan, 1996).

The high quality of the information is lead to high-quality decision making. More tellingly, Knowledge Management (KM) does the best to ratify the method organisations use their knowledge through enhancing collaboration among groups and attaining lessons learned among other parties (Carrillo and Chinowsky, 2005). Still, creating models comprising only the required amount of information creates a substantial challenge (Jernigan, 2008). Plume and Mitchell (2007) maintain that this aspect is considered a critical one, especially amongst various experts with incompatible proposals. The capability and the skill to make primary and informed decisions built on facts is considered one of the key benefits of the BIM design process, but without the idea of information access and sharing, this benefit will not be achieved (Jernigan, 2008). For that reason, the decision-making's quality highly depends on the information quality received, along with the individuals' skills to process the required information. Mainly, Ruikar, Anumba and Carrillo (2006) considered KM a social system; leading to agree on the ontological commitment as KM provides the major challenge for conceptual design (Wang et al., 2002).

Based on the BIM Working Group's recommendations, in 2016, the British Government has mandated all involved parties to use the fully cooperative 3D BIM for its projects (BIS, 2011). The Government's Construction Strategy presents an excellent opportunity for both the Government (and the entire relevant research bodies) and the AEC/O industry to create novel forms of cooperation and work to provide better value for the projects 'money (Becerik-Gerber and Kensek, 2009).

In a nutshell, BIM is deemed to be a one-entity way to examine the problem of the profoundly rooted fragmentation in the AEC/O industry through being a computer intelligible approach to share building information in design among disciplines (Sacks et al., 2010). Consequently, it has been noted that big construction organisations are at the lead in term of KM because of the strategic methods and structured approaches to design implementation

(Robinson et al., 2005). Thus, this research has effectively worked to develop a structured approach for the so-called collaboration throughout the design stage implementation. In detail, a consistent and operable approach will strongly improve remote design teams' coordination through simplifying better alignment. Carrillo and Chinowsky, (2005) refer that there are other challenges for KM in construction, namely: (i) limited amount of time, (ii) organisation culture, (iii) lack of standard work processes and (iv) insufficient funding. The standards of BIM for collaboration are discussed in detail in chapter 3 (section **3.4.1.1).**

2.6.2.5 Systems Approach to Collaborative Building Design

The origins of the General Systems Theory (GST) can be traced back to the biological sciences even though it has since been discovered to be useful even in business organisations... Hence, it has been used to solve problems in other industries outside construction (Walker, 2007). The systems approach emphasises the contribution made by the interrelationships between the individual parts of a system and how the system adapts to the environment in which it finds itself for it to achieve its goals. Walker (2007) concluded that the organisational theory could be used in the process of describing and explaining the character of management processes in projects involving construction. In the view of (Erdogan et al., 2008), systems thinking is a method that can boost the process of learning in situations where systems are complicated and can basically be used across disciplines.

There is a connection between each of the elements. This connection can either be direct or indirect and there can never be a sub-set of elements which is not related to other elements. Ackoff (1960) defines a system as an entity which physically or conceptually made up of parts that are interdependent. Systems can be divided into two basic categories: open systems and closed systems. A closed system is not influenced by things that happen outside it; such as a machine. On the other hand, an open system responds to the environment around it. Walker (2007) notes that the boundaries of an open system are semipermeable and there is always an exchange between the system and the environment in which it operates. And so, the construction industry, like every other industry, happens to be an open system. As an open system, it relies on inputs that come from the environment. These are the inputs that are constantly been processed and changed into products which make their way back to the environment (Jennings and Wattam, 1998). In the view of Checkland (2000) GST is not a suitable tactic for managerial "*messy problems"*. Instead, the same scholar suggests that such problems require a Soft Systems Methodology (SSM). Nonetheless, by his own admission, there is no distinct separation between *soft* (as in fuzzy ill-defined) and *hard* (technological and well-defined) problems. All the same, when the design is performance-based and seeks to address quantitative sustainability goals, a system engineering process can be perceived as being suitable for its application.

Two scholars who have used systems thinking as a basis for their work are (Walker, 2007) and (Cleland and King,1983). In their work, they focus on the notions of complexity, interdependence, and change. They represent projects or other organisational forms as processes or concepts that link systems at three levels of obstruction. The work of Cleland and King (1983), has been heavily used as a basis for Walker's (2007) production of innovative approaches in the construction industry. The same author has advanced the argument that in the absence of a structured approach, the management theory fails to facilitate project management in the industry. Walker (2007) identifies issues on which the project management process functions should focus on (i) identification, communication, and adaption of the objectives of the system; (ii) making sure that the system's parts are effectively functioning; (iii) making sure that there is an establishment of appropriate links between the parts; (iv) triggering the system so that whatever established links work at their optimal; and (v) connecting the whole system to the environment and ensuring that the system is responsive to any alterations in the environment. Requirement analysis, or functional resources analysis, is also extremely important, notwithstanding the fact that it is itself not the foundation on which the organisation has a competitive advantage in the market (Jennings and Wattam, 1998). The requirements engineering process depends on the identification of the stakeholders within a particular system (the same idea followed by this research, together with their varying viewpoints and perceptions (Sharp, Finkelstein and Galal, 1999)

The systems approach has been followed by this research so that a structured process can be developed for collaborative design application and delivery. An argument is advanced that to achieve sustainability goals, the collaborative design process elements (human and technological resources) have to be performed at their optimal, while also being correctly coordinated. It is considered that the developed system is open, to be able to address the required flexibility so that it is able to adapt to flexible events. The idea is that such a practice delivers enhanced alignment of a team.

2.7 Plans of Work

2.7.1 RIBA Plan of Work: The UK Industry Standard for Design Management

The RIBA Plan of Work, in the United Kingdom, is founded on a descriptive approach for design process management. According to Cooper et al (2008), this Plan of Work has been broadly acknowledged as the operating standard. It separates the process of design into several stages such as briefing, design, construction, and operation. There are design tasks in all the stages, which are allocated to design roles. Based on its popularity and the fluency with which many building professionals have become with it, there have been some reviews of the RIBA Design Process (2013) (stage 0 *Strategic Definition* to stage 4 Technical Design), even though the early stages are the main focus of this research. Hence, this research's outcomes are based on a combination of the early three stages of the RIBA Plan of Work 2013 with GRIP Stages (discussed in the next section 2.7.2). The three stages are (i) 0: Strategic Definition, (ii) 1: Preparation and Brief, (iii) 2: Concept Design. Table 2-2 provides a graphic illustration of the evolution of the RIBA Plan of Work (1964-2013) and GRIP stages. RIBA Plan of Work provides a description of the parallel tasks to core design activities in more detail such as procurement, town planning and sustainability checkpoints (Wilson and Yariv, 2015).

Table 2-2: RIBA Plan of Work evolution milestones (RIBA, 2007, 2011, 2012, 2013a; Cooper et al., 2008, Zanni, 2016, Wilson and Yariv, 2015)

Versions	**RIBA Plan of Work (from 1964 to 1997)**	**RIBA Plan of Work 2007**	**Green Overlay to the RIBA Outline Plan of Work (2011)**	**BIM Overlay to the RIBA Outline Plan of Work (2012)**	**RIBA Plan of Work 2013**	**GRIP stages**
Stakeholders roles	Role of the Architect as Design Leader coordinating the various designers			Introduces the term Integrated Collaborating Team and the BIM Model	Introduces new roles in the Collaborative Project Team	Define the internal manager as a sponsor to manage the whole project.
Information definition	Inform of documents			Introduces BIM Data Drops, Integrated Project Delivery, Interoperability	Information Exchanges, UK Government Information Exchange	Objective, scope, timing, and specification,
Design Stages	A: Inception B: Feasibility C: Outline proposals D: Scheme design E: Detail design F: Production info G: Bills of Qualities H: Tender action J: Project planning K: Operation on site L: Completion M: Feedback	**Preparation** - A: Appraisal, B: Design Brief **Design** - C: Concept, D: Developed Design, E: Technical Design **Pre-construction** - F: Production Information, G: Tender Documentation, H: Tender Action **Construction** – J: Mobilisation, K: Construction to Practical Completion **Use** – L: Post Practical Completion **R and D** – M: Model Maintenance and Development			0: Strategic Definition 1: Preparation and Brief 2: Concept Design 3: Developed Design 4: Technical Design 5: Construction 6: Handover and Close 7: In Use	1- Output definition 2- Feasibility 3- Option selection 4- Single option development 5- Detailed design 6- Construction & commission 7- Scheme hand back *8*- Project Closeout
Procurement routes	Aligns with only one procurement route				Offers flexibility to more routes	Follow detail design and construct contract

Accompanying the RIBA Plan of Work 2013 (RIBA, 2013a) is the RIBA Plan of Work Toolbox, with the aim of bringing integration to the project team (Sinclair, 2013). Nonetheless, this toolkit is not made to cater for any issues that have to do with sustainability. A flexible model which is not only more dynamic but also caters for the tasks of stakeholders simultaneously is required. In the RIBA Plan of Work 2013 the attempt to address poor coordination and design team fragmentation is accomplished merely by suggesting emergent technologies such as BIM and GIS should be used. Nonetheless, within the process, the know-how (how to collaborate and use the integration of BIM and GIS to achieve effective collaboration) is still absent (Zanni, 2016). There needs to be a definition of the implementation of a new paradigm in the design process, and it should also be understood before it can become the common practice in the industry. Slaughter (2000) argues that the strategies and means used for implementing the strategies required better understanding. For example, according to Sinclair (2012) states that shifting from BIM level 0 to level 3 required working within collaborative and integrated method and teamwork. A comprehensive and systematic collaborative design process can assimilate the considerations of managing information timely from the beginning of design (planning, briefing, and concept stages).

2.7.2 GRIP Stages

GRIP Stages is a plan of work to facilitate project delivery. With the aim of delivering projects on the operational railway, the Network Rail developed the Governance for Railway Investment Projects (GRIP), a management and control process. The GRIP Policy Standard's (NR/L1/INI/PM/GRIP/100) issue two was promulgated in March 2012. The aim of developing GRIP was to lessen and alleviate the risk linked to projects. It would facilitate the renewal of the railway and projects in a high street environment. It is founded on best practice in industries dealing with huge infrastructure projects and practice endorsed by such bodies as the Chartered Institute of Building (CIOB) and Association of Project Management (APM). (Langford and Dyer, 2007; NetwokRail, 2015; Dyck, 2017)

GRIP should be seen as a product as opposed to being a process. It divides projects into eight separate stages (Figure 2-3).

1-Output definition.

2- Feasibility.

3-Option selection.

4-Single option development.

5-Detailed design.

6-Construction test and commission.

7-Scheme hand back.

8-Project closeout.

The project, at its different critical stages, is assessed using formal reviews so that there is an assurance that the project will move successfully to the following stage. GRIP Stages focus on the product (output) (Plume and Mitchell, 2007), not on the process of developing a railway process (see section 5.4.3). Furthermore, the schedule performance is poor in early GRIP stages which lead to unwanted impact to deliver the project smoothly and need to be improved (Plume and Mitchell, 2007). That means a process model focusing on the process in detail is required to clarify in order to manage the information and identify the issues may occur through the design process. However, GRIP Stage customised for a railway project to identify the feasibility of conducting a project, but it is not mandatory for the projects to follow it which cause inconsistency to applied across the projects and programmes (Plume and Mitchell, 2007). Therefore, utilising this plan of work on collaboration-based will add value to the railway project to facilitate the collaboration process. Nevertheless, to achieve that is required to be combined with another plan of work such as RIBA as discussed in section 5.4.3.

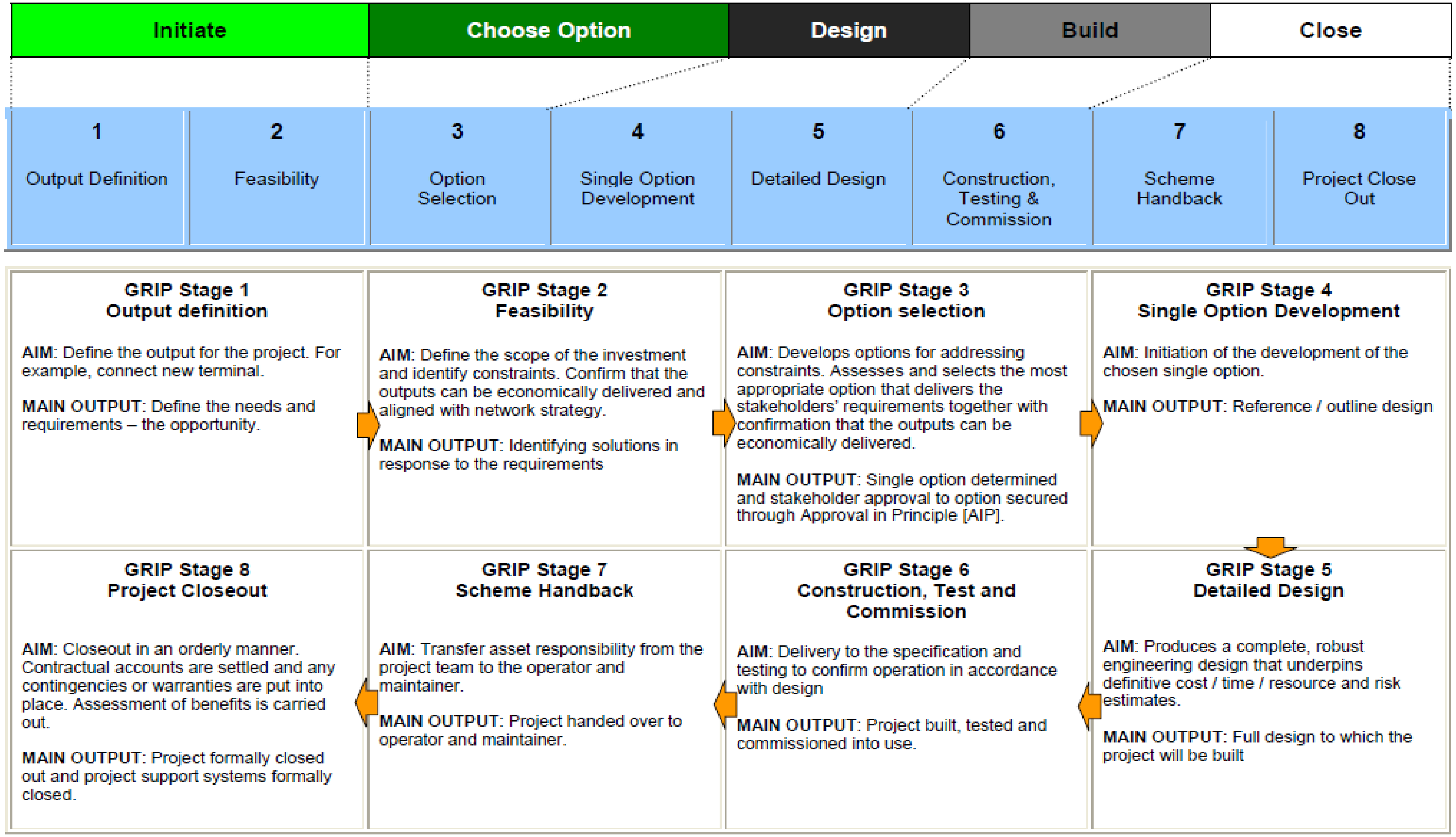


Figure 2-3: GRIP Stage (NetwokRail, 2015)

2.8 Collaboration Drivers

There are several factors that drive the collaboration and affect it. The role that collaboration plays is significant in the infrastructure development of developing countries (World Bank, 2008). Indeed, increased private sector involvement in infrastructure management resulted in more procurement mechanisms such as service contracts, leasing, joint ventures (Bing et al., 2005). Klijn and Teisman (2003) revealed that the failure to develop good partnerships depends on a combination of three factors: the actor composition complexity, institutional factors, and public and private sector strategic choices. The major problems and issues which are associated widely with collaborative engagement approach to delivering sustainable infrastructure projects can be classified broadly as risk allocation, globalisation, legal and regulatory framework, finance, technology, relationships, trust, market maturity, skills/ competence, and communication. (Adetola, 2014)

All the following factors are important in somehow to facilitate the collaboration process throughout the lifecycle of the railway project. However, the most critical factors that required consideration and related to the aim of this research to provide a clear process model for BIM and GIS-enabled collaboration are risk allocation, legal and regulatory framework, technology, relationships, trust, skills/ competence, and communication. This is because of railway projects performed by several different parties to deliver a sustainable railway. Therefore, risk factor will be high and need to be allocated and clear framework about legal, regulatory need to be formulated. Furthermore, collaboration is about trust, communication, and skills/competence. Moreover, technologies required to bring this collaboration to the real and implemented effectively.

2.8.1 Risk Allocation

This factor considered as the most important driver of collaboration. Risk is caused by external or internal factors which can be described as a possibility or damage threat, injury, responsibility, loss or any other negative event, which by preventative action, maybe avoided (Ward, Chapman and Curtis, 1991; Bing et al. 2005). Therefore, if an investor reaches a conclusion that the probability of actual return on his investment is lower than expected, he may treat this as a financial risk and should explain this to all stakeholders, accordingly. This manifests the importance of understanding the circumstances that give rise to such eventualities and to identify them, as early as possible in the life of the project. When projects are of a public-private collaboration type. Then it is obvious that such risks should be identified and consequently shared, somehow, in an optimal manner, on top of the shared responsibilities. As a rule of thumb, and according to (Ward, Chapman and Curtis, 1991; Edwards, 1995; Flanagan and Norman, 1993) identification, the guiding principle for such collaborative work is to divide the responsibilities and the eventual related rewards and/or losses (after identifying the associated risks) according to what each party could offer financially or technically.

Therefore, a private-sector party (or parties) could be delegated the job that relates to the whole life-cycle process of the project, such as, design, construction, operation and maintenance and their eventual disposal, leaving the public sector to deal with such issues of land acquisitions, inflation, environment, infrastructure-related issues, etc.

2.8.2 Globalisation

Globalisation opens the chance of connecting the world through better international communication, transport, new technology and trade links. It is defined by McGrew (1992) as the “multiple links and interconnections that exceed the national state to form the modern global system".

Collaboration is more comprehensive to include all affairs for either public or private. This means that the public and private sector sharing some responsibility for the actual achievements (Collin, 1998). Grant (1996) focus on that the driving force for collaboration includes authority and cooperative responsibility, joint investment, shared risk/commitment, shared resources and rewards, and mutual benefit. The approaches for an early collaborative engagement used traditional model (Design-Bid-Build) to deliver infrastructure which primary responsibility for the public sector will be authorized (Yakowenko, 2004). However, the distinctive of traditional aspects of project procurement are: contracts excessive, the commercial dispute among parties, non-essential overrun in cost and time, inability customers to get the value for money, delay in completion and occupation of the project, using materials with low quality, which cause various errors in construction, and building destroy eventually (National Economic Development Office, 1986)

2.8.3 Legal and Regulatory Framework

Efficient, effective and fair conducts for tenders need a comprehensive, legal, regulatory framework which characterised by clarity, transparency and predictability (Thant, 1996; Harris, 2003). The readiness of the private sector affected by the legal environment to collaborate in developing the infrastructure project. Thus, the government should develop a suitable legal and regulatory framework, in addition to a compatible financial environment for investment and appeal foreign investors to encourage the private sector to participate (Kumaraswamy and Zhang, 2001). There is a clash that the accomplishment of collaboration for the public-private based on adequate and authorize legal and regulatory plan which analyses services critically, partners and value for money the approach for purchases (Zhang, 2005a; Bing et al., 2005). This is necessary to avoid potential conflicts and delay in delivery services (Institute of Public-Private Partnerships, 2000).

2.8.4 Finance

Naturally, infrastructure projects are known by large, complicated and require capital intensive, which in necessarily, innovative strategies for finance are needed. Financing the project that is an independent legal entity is one of the innovative financial engineering technique which is repaid by the generated cash flows for the project itself (Merna and Dubey, 1998). For example, in Hong Kong for the BOT tunnel project, three groups of criteria are set by the government for tenders' evaluation weighted according to the importance of criteria. The results showed by the assigned weight are 65% finance, 20% engineering, 15% for operation and transport planning. It seems that project finance and exist a financial plan is crucial for an infrastructure project successful (Kumaraswamy and Zhang, 2001). By using new technology, such as BIM and GIS successfully and efficiently will provide a better financial plan for the project and reduce the cost needed for the whole project. In a similar way, Zhang (2005a) measured the financial ability for the concessionaire through four dimensions: strong financial engineering strategies, affordable finance sources and low costs for services. The funded partnership projects usually be with both stock and debt.

2.8.5 Technology

Technology has been known as the knowledge and information that used as an application purposefully in the design, goods and services production and hiring, and in human activities organisation (Das and Van de Ven, 2000). It is considered as an essential tool to improve people and goods movement to achieve the modern economy and society needs, Intelligent Transport Systems (ITS), technology tools facilitate the management of the infrastructure including road safety (Brussels, 1999). Industries have been shown rapid development in construction because of appearing new technologies such as BIM and GIS that change the perception of the way to build and make it much complex and larger as stated by Domich and Friedland (2005), so new innovation will be necessary to be adopted to achieve this major advanced.

2.8.6 Relationships

There is a controversial issue regarding the relationship between public and private investment and attracted attention since the early 1980s and still (Khan and Reinhart, 1990). Therefore, the successful management of the project is affected by the interaction between the participants of the project. To ensure facilitate coordination effectively throughout the lifecycle of the project, the process of interaction must involve planning, communication, monitoring and control and the organisation of the project (Kapogiannis, 2014). The partnership based on trust both inside and outside the organisation, which absence of confidence between the organisation and its own people may face difficulties to build trusting relationships with other institutional (Khalfan, McDermott and Swan, 2007). Internal organisational conflicts may affect negatively on the performance of the project in the construction project (Mohsini and Davidson, 1992). For this, the roles and responsibilities of the government are vital to develop and manage the partnership of the project.

The project may fail if the government incapable to manage the partnership of the projects (Kwak, 2002).

There are key factors to ensure a successful application of the partnership projects in public-private, which they are: trust and communicating openly, readiness for making concession and collaboration, and respect (Jacobson and Choi, 2008). Innes and Booher (2004) supported that by emphasising that in order to avoid difficulties and resolve them before they become worst, building trust between project stakeholders is needed.

In addition, the World Bank illustrated the possible reasons that cause the delay in delivering the project in participant projects. From of these: wide gaps in expectations between public-private sector, the objectives and commitments of the government are not clear, the making decision is complicated; the definition of the sector policies is poor; lack of adequate legal/ regulatory framework; poorly of managing risk; low credibility of the policies of the government. Also, lack of local capital markets; absence of mechanisms for attracting finance of long-term from private sources with acceptable rates; absence of transparency and competition (Asian Business, 1996). In the end, just the government will be responsible for the failure in cost. To increase the possibility of success of the project participants, it needs to work simultaneously in a team and having previously identified goals, objectives and obvious procedures for collaborative engagement (Larson, 1995). Moreover, to reduce the risk and increase the certainty of public procurement and having the ability to execute the specific role, the partners for both public and private sector may have to share a common goal. From these roles; availability of assessment or costs and needs, skills for public-private partnership managing and negotiation, and ability to monitor and apply contracts (Zhang, 2005b). Thereby, collaboration is very important to guarantee the project success with best features such as saving time, cost and quality. However, an absence of existing private participants having the ability to do business may consider as an obstacle to successful collaboration between public and private.

2.8.7 Trust

Trust and relationship are very crucial to reach and facilitate effective collaboration. It has been illustrated that trust is considered as a distinguishing feature of effective organisations which the organisations and their members take significant benefits from it (Bies, Sheppard and Lewicki, 1995; Kramer and Tyler, 1996). Trust leads to a high of collaboration and performance level (Jones et al., 1998). In addition, Mayer, Davis and Schoorman (1995) stated that the individuals tend to take a risk in a relationship due to their beliefs about the ability, benevolence and integrity of others. The expectation of applying the behaviour of taking risk is increasing the outcomes and high performance in social perspective such as groups working, collaboration, negotiation, communication and exchanging information (Dirks and Ferrin, 2001). Therefore, trust is an essential condition for collaboration because by trust individuals more likely to share more information with their superior or work partner confidently (Hwang and Burgers, 1997). As a result, the collaboration between participants and reach the group goal will be easier when the individual work with dependable on other, which the individuals will not be worried about the potential behaviour of their partners (Dirks and Ferrin, 2001).

The theory of trust highlights three vital antecedents of individual trust: capability, benevolence and integrity (Mayer, Davis and Schoorman, 1995). In a complex project such as railway, trust plays a very crucial role. Sometimes not everyone understands specialist deals which dependable on the expertise of other persons are needed which can be achieved through collaboration confidently. The appearing of trust across reliable information, fulfilment promises, and the outcomes reach or exceed the expectations of people. Whilst, the doubt sets when the trust is breaking down and the expectations of the people are dashed. The building of trust may be during sharing goals, solving problems, experience, behaving reasonably and reciprocity (Khalfan, McDermott and Swan, 2007). Thus, trust has an important on the outcomes of the project positively (Laan et al., 2011).

2.8.8 Market Maturity

A market is an effective place for the buyers and sellers to exercise business trade goods, services or contracts to gain money, in other words, is the place for demand and supply (Royal Institute of Chartered Surveyors, 2011). Nowadays, both developed and developing countries have shown the increasing and effective use of collaboration in public-private to gain services in the infrastructure sector from 1992 until now. Deloitte (2006) claimed that the UK has a most active market in the world for collaborative public-private that is known as PFI and support the strategic expansion through developing a structure characterised as a most developed organisational, legal, regulatory and business (Deloitte, 2006).

2.8.9 Skills / Competence

Executing and implementing a project need careful management to tackle conflicts and possible problems. Decisions making are a necessary part of any project that is taken by the experts and may affect other people. Attention to details carefully and predictability of possible problems are required for managing any project. These skills consist of planning, organisation, monitoring, coordination, motivation, communication, procuring, leading, delegation and negotiation (Fayol, 1949) to emphasise on the optimum resources usage. These skills and techniques should be applied to the organisation monitor of all aspects of every project by managing the project. Consequently, producing a well-designed facility, well-constructed, having sufficient functionality and financial that satisfy the requirements of the clients in terms of quality, safety, budgeting cost and time, and maintenance in the future (The Chartered Institute of Building, 2002)

2.8.10 Communication

Project communication can be managed as a zone of knowledge which uses the required process to generate, collect, distribute, store, retrieve and ultimately dispose of the project information properly and timely (ANSI, 2008). Communication means that more than one person involves in a collaborative process (Adetola, 2014). Communication effectively may facilitate work activities coordination, managing information, and deciding. Management based on the clarity of communication, and effective and quick sharing thoughts and ideas with other people with different technical skills and interest. There are two ways for effective communication: informal and formal. The informal way uses telephone conversations, oral or face-to-face to express personal relationships, solving problems effectively and speedy as well as workflow decisions. The formal one is required for informal decisions acceptance to clarify the main reasons for the decision and inform non-participate people in the decision by the related information (Cleland and Gareis, 2006).

The weakness of the coordination in the construction project process due to poor communication between the project team (Kagioglou et al., 2000). Despite the many construction projects formed a special team to develop a specific project easily, there is no chance to work together again on other projects. As a result, the interaction and performance of the project team may affect as illustrated by (Sommerville and Stocks, 1996). Additionally, the project team may not gain benefit from shared best practice due to fragmentation in every new project. The success of a project needs the right people with the right skills and information at the right time. Therefore, to provide a collaborate environment, encourage communication and making a decision at the proper time required from the participants to involving effectively at the early project stages (Kagioglou et al., 2000).

2.9 Integrated Collaborative Technologies

According to the statement by Wainhouse Research & First Virtual Communications (2002), using existing computers and network infrastructure for providing integrated collaborative environments allows participants to achieve enormous competitive benefits for collaborating both personality and group. These environments are fully new and offer the best features taken from combing both traditional video conferencing and web collaboration to provide teams with an interactive environment while working together through an interface-based browser (Kapogiannis, 2014). Working in a collaborative environment provides a secure sharing of data and information (May, Taylor and Irwin, 2017). Through collaboration, the data and information will be shared through one single system, same standards instead everyone using their own system and standards. This lead to increase the security of the system during exchanging information or any other operation.

Integrated Collaborative Technologies involve the following as mentioned by Stevens et al., 2009; Kapogiannis, 2014; and Kiviniemi, 2005):

- **Collaborative software**: Support sharing and information flow in order to improve the team's performance. It uses for collaborating in real-time, conferencing and asynchronous.
- **Workflow systems**: Facilitating the automation and managing of business processes through.
- **Systems of managing documents:** Manage documents during all the stages of its processing.
- **Peer-to-peer collaboration software**: To allow users to share files and communicate in real-time with no need for a central server.
- **Systems of managing knowledge**: Support the knowledge capture, organise, distribute (know-how). Also known as Information Technology (IT) systems.
- **Systems for the social network**: Are IT systems which link people that know each other with people that their contacts know.
- **Collaborative Design**: enables stakeholders to design construction projects (collected or distributed).
- **Cloud system**: consist of components of computing (hardware, software and infrastructure) the facilitate the cloud computing services delivery through a network (internet) such as SaaS (software as a service), PaaS (platform as a service) and IaaS (infrastructure as service) (Abedi, Fathi and Rawai, 2011)

Collaborative tools assist communication, collaboration, and problem-solving process which lead to facilitate teams working together across geographic distances. Integration of technology means technology tools using in businesses general content areas to enable stakeholders to apply skills of computer and technology to learning and problem-solving (Adetola, 2014).

Anyway, collaboration needs individuals working together in a coordinated manner, to achieve a common goal. It can be argued that Integrated Collaborative Technologies are those tools that assist stakeholders to work together for problem-solving with no consideration of geographic distance (Kapogiannis, 2014). These technologies can work in two modes of working synchronous (real-time) or asynchronous (not real-time) manner, which enable stakeholders or team members to share information (documents or files) at any time from anywhere (Figure 2-4).

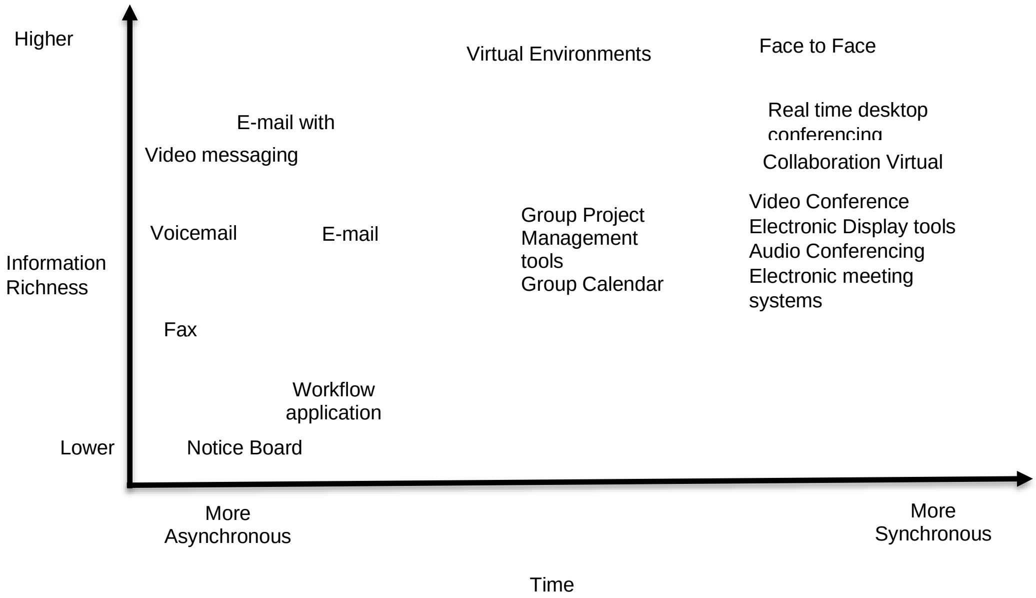


Figure 2-4: Technologies comparison adapted from D70 (cited from Kapogiannis, 2014)

There is a high demand from the construction industry to provide integrated collaborative environments and according to the roadmap of building information of the UK government shown in Figure 2-5, the Level 2 of BIM implementation is compulsory by 2016. that is mean that ERP (Enterprise Resource Planning Systems) need to manage the use of construction commercial data which develop required to mandate the integrated collaborative environments (Kapogiannis, 2014).

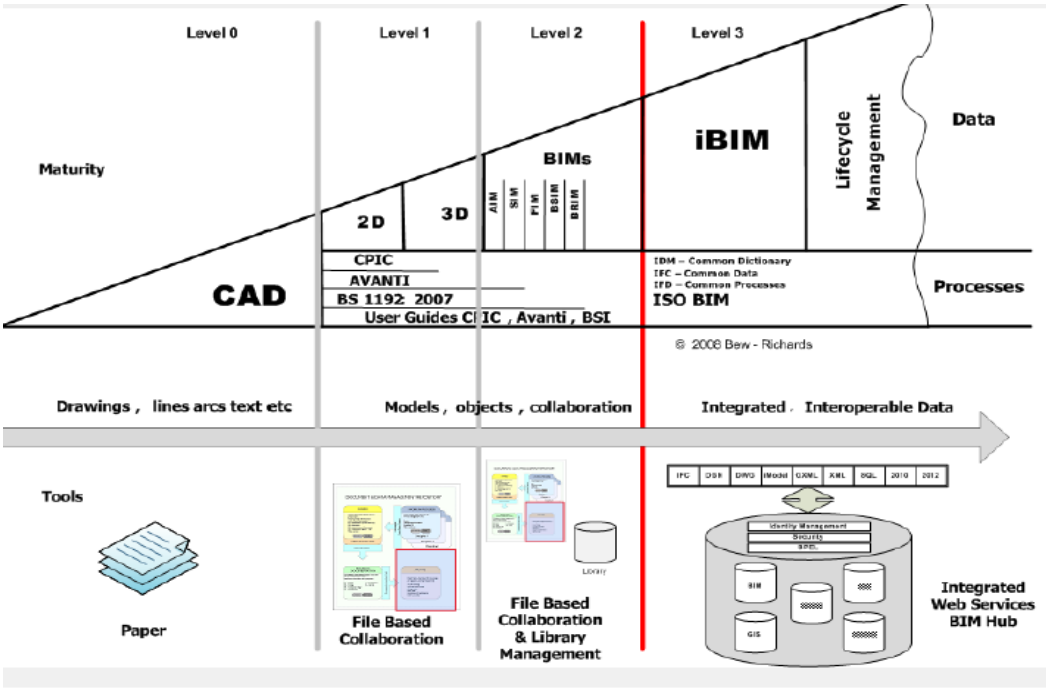


Figure 2-5: Roadmap of Building Information Modelling (BIM) (BIM Industry Working Group, 2011, p16)

Planning and delivering of large infrastructure solutions consumed a lot of time, money, and human capital and considered as the most challenging in the construction industry (Bundgaard, Klazinga and Visser, 2011; Törneman, 2015). Using Building Information Modelling (BIM) is very rare in infrastructure especially in railway. Furthermore, Norberg (2012) argued that the railway is built horizontally not like vertical building which the need for 3D modelling not very necessary which make the implementing of BIM is rare in infrastructure. While in fact, 3D is very significant either in building or infrastructure because BIM offers many advantages. For example, any clashes will be detected, risks will be reduced, the models will be better visualised, in addition to increase the quality and the productivity of the project. Therefore, change is needed in every sector of infrastructure because using new technologies such as BIM and GIS may be beneficial.

2.10 Integrating BIM and GIS for Collaboration

Integration of BIM with GIS used in various areas which combine these two technologies to provide a strong synergy. Real integration comes from exploiting both BIM's and GIS's strengths in relation to one another (Elbeltagi and Dawood, 2011; Zhang et al., 2009). For example, Tobiáš (2015) reveals in his research the main fields that could benefit from BIM and GIS collaboration. In his study, he concluded that the most important areas are the facility management of complex and large buildings and creating models of buildings, whether existing or heritage. However, it is necessary to monitor the BIM field carefully by GIS and allowing geometrics experts to ensure they are kept abreast of the developments for the future (Tobiáš, 2015). Furthermore, Laat and Berlo (2011) identified the integrating BIM and GIS mutual benefits which BIM can be used for storing data for built environments models. While, in contrast, GIS can be used as a source for new building design and integration in the geospatial context. Moreover, Corcoran et al. (2015) explored developing a collaborative exercise to use BIM and GIS collaboratively to provide a practice community, which in the results, they found that collaborative environments enable participants to share thoughts, skills, similar aspirations and learn from each other, even with having different standpoints between them.

BIM and GIS have been used in a collaborative manner in a different project life cycle. Bansal (2014) utilised cooperative BIM and GIS for planning construction safety. Sebastian, Böhms and Helm (2013) found out that 3D BIM and 3D GIS map can be connected to the PANTURA approach (the title of EU collaborative research project) which CAD/BIM can be used to generate the BIM model with IFC export functionality. Therefore, they suggested that this approach is available to implement in other projects by other parties. They stated that more research is required to support the proposed approach or reject it.

There are wider applications and discussions regarding collaboration. However, until now there is no real consensus in the meaning of this term (Törneman, 2015). Furthermore, Wognum and Faber (2002) argued that there is a lack of understanding in managing collaboration among organisations. Consequently, this leads to a lack of methodology to support collaborating management. This may because collaboration needs several factors to succeed. To illustrate that, Eriksson and Pesämaa (2007) pointed out that moving towards collaboration in the construction projects relationships and delivery methods requires a comprehensive change in structures, processes and attitudes. Moon et al. (2004) stated that in order to provide an active collaboration environment, a single integrated model would be required for the design, construction and maintenance process.

Overall, it can be summarised that collaboration is very important and required in order to deliver any project effectively in terms of time, cost and efforts. Furthermore, through collaboration, the process of the work will be easier, more secure, and a single model can be shared at the same time among different parties which lead to effective decision making and share risks. However, to achieve effective collaboration, professional use of effective technologies is required such as BIM and GIS (next chapter). Unfortunately, there is a lack of studies addressing the use of integration of BIM with GIS to improve collaboration. However, both technologies are used independently to address several issues and some collaboration issues, but not specifically for collaboration in railway. Therefore, this gap needs to be filled, because the significance and necessity of collaboration to be followed in the railway project.

2.11 Summary

This chapter provided a comprehensive literature review on the background of the study and shapes the problem statement. Also, presented a background on the definition of the infrastructure, transport and railway. Then collaboration is reviewed in terms of definition, types, drivers, and technologies. The outcomes of the literature highlighted the importance of railway projects in economic growth and need more attention to keep safe and effective. Furthermore, the railway required to be delivered on time without reworks to save time, cost and effort. Hence, collaboration is the key point to achieves these targets because collaboration facilitates decisions making effectively and avoiding reworks. Moreover, the chapter also presented that to achieve effective collaboration technologies that enable it is needed. The literature outlined that there is a lack of research considering collaboration as a process. Additionally, BIM and GIS are the two most proper technologies to achieve effective collaboration.

Chapter 3 : Building Information Modelling (BIM) and Geographic Information Systems (GIS)

3.1 Introduction

After reviewing the literature about collaboration and the needs of technologies to achieve it, this chapter presents the second part of the literature review. It starts with reviewing background of Building Information Modelling in terms of definitions, policy, process aspects of BIM, and areas of implementing BIM. Followed by presenting GIS, its definitions, benefits, and application. Furthermore, this chapter presents the applications of integration BIM with GIS in different areas in order to identify the key gaps to fill it by suitable methods (chapter 4). Finally, the chapter summarised the key findings.

3.2 Building Information Modelling in Context

Building Information Modelling has several advantages in different stages for any project and in many aspects. Improving the quality of both the collaborative process and the end product of building design have been emphasised in several reports (HM Government, 2013; DTI, 2007). It has been argued that BIM enables the implementation of quality management which results in more sustainable outcomes (Chen & Luo, 2014). BIM has the ability to improve the performance of the AEC industry and enhance coordination and collaboration between different project parties (Elhendawi, Smith and Elbeltagi, 2019). Furthermore, integrating BIM in railway has many benefits such as improving decision making, planning and assist in the management, operation and maintenance, which facilitate new work's evolution in future and their adoption with new needs or environmental evolution (Bensalah, Elouadi and Mharzi, 2018)

BIM has several benefits, for example, it is used for visualising, clash detection also, as a system of communication to increase efficiency, quality such as sharing, preserving, querying the model, organising and maintaining (Ahmad, Demian and Price, 2012; NBIMS, 2007; Lina Ahmed AbuHamra, 2015)

The early application of Computer-Aided Drafting/Design, (CAD) has been generally "*geometric centric*" (Choi, Barash and Anderson, 1984). In the 1990s, there was a shift in focus with the acknowledgement of the significance of incorporating textual and graphical information (Linderoth, 2010). Now, building models can incorporate a variety of engineering analysis from a broad array of professionals within the industry (Richards, 2010). Hence, to achieve efficient implementation of BIM, the construction industry needs to consider and reshape its current way of works to move from fragmented processes to collaborative procedures (Mao, Zhu and Ahmad, 2007; Zanni, 2016).

Based on the recommendations made by the BIM Working Group, the United Kingdom Government has mandated that its projects should use a fully collaborative 3D BIM as of 2016 (BIS, 2011). The Government's Construction Strategy creates a great chance for both the government (and other pertinent bodies of research) and the AEC/O industry to introduce fresh methods of collaborative working to deliver optimal value for money projects (Becerik-Gerber and Kensek, 2009). BIM has the ability to resolve the deep-rooted problem of fragmentation in the AEC/O industry, that as it is considered as a computer intelligible approach to exchange building information between disciplines in design (Sacks et al., 2010).

Notwithstanding the reality that well-organised coordination between people, technology, and tools has the potential to result in great benefits in both building quality and performance, there are still a number of challenges to be addressed. suggest that to mitigate these challenges, there is a need for an integrated design process is, collaboratively across disciplines, complicated design analysis, vigilant system and material optimisation. Generally, it is recognised that despite the noticeable advantages of collaborative BIM and GIS, they are still not widely used. Therefore, the major issue among researchers is the willingness of construction companies to adopt new technologies (Abuelmaatti and Ahmed, 2014; Ruikar, Anumba and Carrillo, 2006; Succar & Kassem, 2015). Particularly in the context of high-performance buildings, there is an increase in the need to boost coordination and collaboration between architectural, structural, electrical, mechanical, and envelop systems. For this interaction to happen successfully, it needs such attributes like early participant involvement, teams which are experienced, methods and levels of communication and comparability between teams working on a project (Nofera & Korkmaz, 2010). The significance of managing the process of decision making has been acknowledged by several authors when various experts have conflicting proposals (Plume and Mitchell, 2007). To address these communication problems, an audit trail can be provided also for recognising explicit knowledge (who did what when) and tacit knowledge (why was it done) (Cerovsek, 2011). Recent research has shown that BIM capabilities currently are very limited regarding the "how" and that leads to the inefficiency during solving the emerging design problems (Plume and Mitchell, 2007). Nonetheless, the quantity of generating information makes the process substantially complicated. This results in the coordination of design becoming even more challenging. A systematic process of BIM and GIS-enabled collaborative design has been developed by this study. It can be employed as a design, implementation guideline.

3.2.1 Definition of BIM

BIM defined by many researchers based on their use and understanding of the term BIM. BIM has been defined by the NBIMS (2007) as:

> *"A digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward."*

Another definition is provided by NBS (2017):

> *“BIM describes the means by which everyone can understand a building using a digital model which draws on a range of data assembled collaboratively, before during and after construction. Creating a digital Building Information Model enables those who interact with the building to optimize their actions, resulting in a greater whole life value for the asset.”*

What is implied by the definitions above is that there must be some form of electronic connection between every piece of information and the BIM. This makes it possible for the information to be retrieved when required. Hence, BIM software can be used to accomplish several tasks: planning, designing, construction, operation, and building maintenance in a collaborative manner using standardised approaches. It has been suggested that value can be created by BIM through bringing together people, technology, and process (RIBA Enterprises Ltd and NBS, 2016; NBS, 2017). Nonetheless, an understanding of the way information can be integrated within BIM is still limited. BIM is a tool or a process which facilitates participants to interact among them to manage, share, store the information to achieve the project objectives.

3.2.2 From Drafting to BIM

Building design illustrations have been traditionally been drawn by hand using instruments such as pens, irregular curves, paper, drawing boards, and T-squares (Henderson, 1994). Up until now, hand drawings are still being created, by architects who want to communicate with the entire team involved in the design, particularly in the initial stages of the synthesis. There are firm supporters on hand drawing when they focus on the significance of maintaining it as a part of the design education curriculum, and also in professional practice by merging it with digital technologies (Have and Toorn, 2012).

The weaknesses of paper drawings have been to an extent mitigated by the introduction of CAD. Elements that have been improved include taking less time and ensuring that alterations can be done easily. According to Sackey (2014), 2D CAD became widely adopted in the 1990s, which is the same decade when it was improved to 3D CAD. Later, Van Nederveen and Tolman (1992) coined the term "*Building Information Model*". As time passed, different software companies came up with their own names (Graphisoft, "Virtual Building"; Bentley Systems, "Integrated Project Models"; Autodesk and Vectorworks, "Building Information Modelling"). These technological advances were a great benefit to design implementation as the technologies allow the designer to communicate their intent in a more efficient way.

It has been recognised that since the introduction of 2D CAD, BIM has possibly been the most important change in the infrastructure and construction industry. Hence, its implementation process is still not fully understood. BIM is fundamentally different and constitutes a paradigm shift toward parametric modelling compared to traditional drawings. The suggestion made by the new paradigm is that a database of relationships and information can represent the design product instead of using an abstract set of representations (lines) that are subject to interpretation (Denzer and Hedges, 2008). Also, the increase in the quantity of information makes the management process even more complicated (Krygiel and Nies, 2008). Hence, if there is any hope of addressing this step-change in an effective manner, there is a need to define and formalise the new processes and methods.

3.2.3 Building Information Management

No matter the definition used of BIM because information is the heart of BIM. *BIM* can sometimes be referred to as "*Building Information Management"*. According to Crotty (2012), poor information causes significant problems during the design process. This is also recognised by the Building Economic Development Committee (1987) which indicates that the leading reason for failures has been either insufficient or missing information. Crotty (2012) agrees and reports that poor communication among members of a design team is also a common deficiency. A number of scholars such as (Demian and Walters 2013; Finch et al., 2007; and Erdogan et al., 2008) consider collaborative information management one of the important issues in the construction projects management. Attia et al. (2013) report that there have been limited studies which try to model the process of designing high-performance buildings with a team that is integrated. However, a sequential process is their suggested solution. With regards to concept design, it is essential to have a more detailed definition, since there is a substantial increase in complexity.

3.2.4 BIM Maturity

BIM maturity definitions are still in a process of evolving (Kassem, Succar and Dawood, 2015; Succar, Sher and Williams, 2012), delivery of non-graphical and coordinated graphical information is still the main subject. There have been a number of attempts at benchmarking BIM implementation maturity (Succar, Sher and Williams, 2012; NBIMS, 2007; Succar, 2009). In the United Kingdom, the BIM maturity diagram, as represented in Figure 3.1 is the leading definition used (Richards, 2010). In the diagram, the four levels of BIM are defined from 0 to 3. The first level, 0, stands for a process that is unstructured and involves the exchange of paper-based documents and CAD files. The second level, 1, defines a process as a collaboration based on files and one which follows specified information management standard guides. While the third level, 2, is in alignment with similar standards it also suggests similar models from different role players are synchronized into common library management, or else a Common Data Environment (CDE) and the downloading files for collaboration. The fourth level, 3, is proposed to be fully interoperable and integrated data, which follow interoperability standards. It is the aim of this research to comprehend the prevailing practices for the implementation of BIM and GIS-enabled collaboration design and help to move its maturity from "*ad hoc*" to "*defined*", and then, to "*manage*", as Succar, Sher and Williams (2012) described it.

According to Richards (2010) Level 2, BIM Maturity relies on information exchange with a CDE following BS1192:2007, for information delivery (BSI, 2007). The CDE takes the role of being the model's central source, where the local copies are synchronised, as is represented in Figure 3-1. The name "Work in Progress" is given to these files. Sometimes they are called "Achieved", which follows a specific protocol for exchange. This makes it possible for project participants to access the files through controlled access. There is a need for checking, approval, and validation, before any sharing (as the BIM Project Strategy document defines) (Richards, 2010), so that they are ready for coordination. All external information should also be included in the CDE. In the United Kingdom, several BSI standards have been developed with the aim of defining Level 2 BIM maturity and generate a shared language for BIM and GIS-enabled collaborative design (see Section 3.4.1). This research depends on existing standards of BIM implementation in an attempt to consider an effective collaboration for the early stages throughout the design process (Building Research Establishment Ltd., 2016)

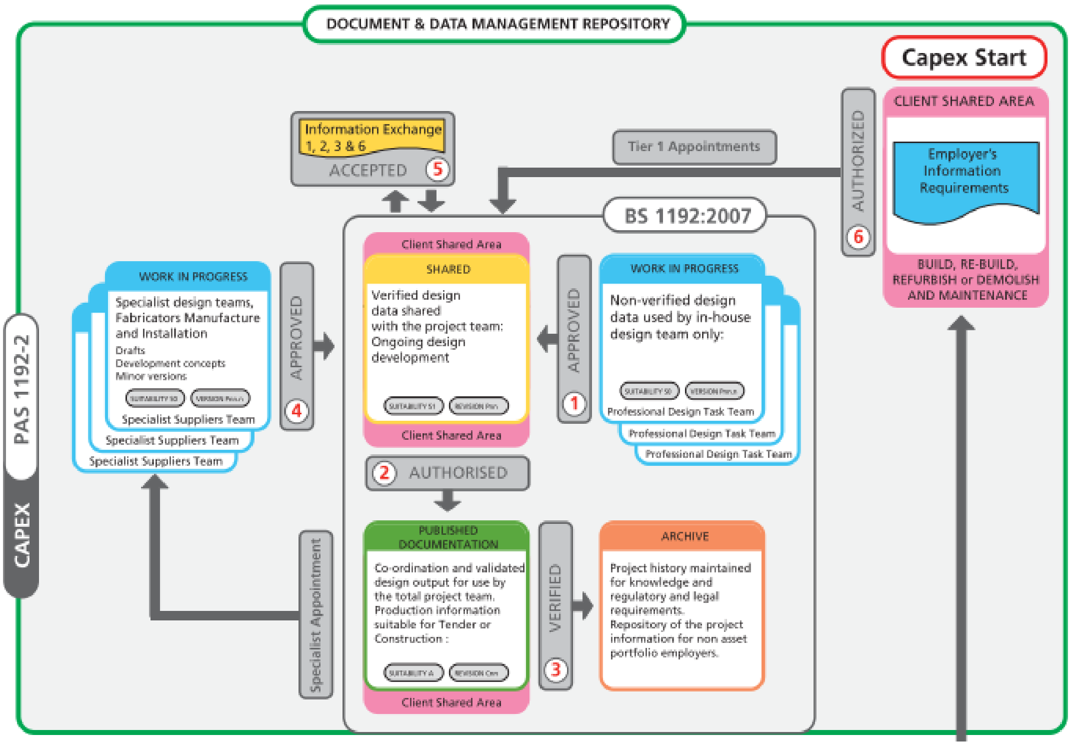


Figure 3-1: Managing the information within a CDE (BSI, 2013)

However, there is a need to clarify that Level 2 BIM maturity is neither a single database nor building model. It is rather a sequence of interrelated databases or models. Many forms can be taken by these models while preserving relationships and permitting for the extraction and sharing of information. One of the main confusions about the BIM is the single database or single model description, among the following (Jernigan, 2008): (i) BIM does not replace people, a lot of work is still involved, but people get to work smarter; (ii) it is not every process that will be automated by BIM, there is still a requirement for the employment of individual skills that involve problem-solving even though with less effort; (iii) BIM can help with the capturing of knowledge, lessen repetitive inputs, and makes it easier to find errors. BIM according to the "ISO 19650 series", a federated information model generated by using a mixture of manual and automated information management processes. All information containers delivered by task teams related to an asset or a project are included in the information model (BS EN ISO 19650-1, 2018).

3.3 Computer Supported Collaborative Design (CSCD)

The point-to-point model which has been traditionally used has proved not only to be complicated but also insufficient, and it has been suggested that a data-centric model is more ideal (Yu, 2014). Technology has been considered to be a tool that has the ability to aid the project manager role while also supporting process improvements (Cooper, 2005). Hence, because of the web-based technologies and the internet, CSCD is considered as a way to address the requirements of product development is increasingly complex (Shen, Hao and Li, 2008). Using Online Collaboration Platforms (OCPs) is vital for communicating information among members of a project, from the initial design stages (Anumba, Baugh and Khalfan, 2002). Suggestions have been made to the effect that all collaboration and communication needs to happen via BIM (Jernigan, 2008). Hence, using OCPs is crucial, because they facilitate both synchronous and asynchronous collaboration which is required by the collaborative process of BIM (Anumba, Baugh and Khalfan, 2002).

Available technological maturities such as server capacities, processing power computers, connections on the internet, and BIM, called for a redesigning of the current design process. As a result, enhancing the centrality of information, and exploiting the benefits of cloud computing (Ruikar, Anumba and Carrillo, 2003). With regards to building design for high-performance buildings, the need for efficient assimilation of information becomes even more important than it has ever been.

As BIM models become increasingly complicated and larger, two major concerns come about: task management and data coordination (Eastman et al., 2008). Issues that any 4D modelling planner needs to consider are discussed by Eastman et al. (2008): (i) model scope, (ii) level of detail, (iii) re-organisation of the model, (iv) temporary components, (v) decomposition and aggregation, and (vi) schedule properties. In order to specify the information requirements (EIR), the NBS BIM Toolkit Level 2 BIM package of standards are able to provide employers with it and also validate whether they have been provided to them. Nonetheless, several additions are still required to achieve real collaborative design. Robinson et al. (2005) suggest the management of knowledge should: (i) have a connection to all business objectives; (ii) be used across the entire organisation; (iii) be entrenched in the behaviour and culture of the employer, business processes, and the development of products; and (iv) be reported for its performance.

An approach to information management which is systematic would guarantee that participants in projects get the information they need at the right time. To reach that level of coordination, should keep the ad hoc processes that result in the diagram of spider web communication to a minimum, with enabling information centralisation in a CDE. The significance of managing assessment of knowledge has been emphasised by Thomson, El-Haram and Hardcastle (2009) who have also developed a methodology for the system.

3.4 BIM Execution Planning (BEP)

There is a lack of practical guidance for BIM implementation even with releasing different standards and protocols to define BIM (Hooper and Ekholm, 2012). Therefore, RIBA (2012); Sinclair (2013) established the need for developing a BIM execution plan before starting an actual design. The plan aims to define the roles, responsibilities, and duties of the different stakeholders upon the deliverables of BIM for each design stage. In order to assist organisations, the “BIM Project Execution Planning Guide” (CIC, 2011) has been developed to maximise the implementation of BIM and focus on the activities, messages, and events that are implemented to achieve a common goal.

In order to implement BEP, there are several elements suggested by different researchers. According to CIC (2011) there are six elements should be taken into account when an action plan for implementing BIM are developed are: (i) the strategy: consists of goals, objectives, and the management support; (ii) the uses – describe the specific BIM implementation method including creation, processing, communication, and information integrating; (iii) the process-focuses on the current workflows and adapting it to BIM; (iv) the information-identifies the information requirements (e.g. breakdown of the model elements, level of development, and data); (v) the infrastructure- includes the needed of the software, hardware, and workspaces; and (vi) the personnel- studies the roles and responsibilities, education and training. The definition of the roles, responsibilities, and deliverables should be first before attempting to re-engineering the process.

Similarly, Jernigan (2008) have suggested that a BEP should address the following as a minimum: (i) goals and uses- defining BIM objectives of the projects, its uses and ambitions as well as the workflows tasks required for delivery them; (ii) standards- it is used for the project and any deviations from the standards; (iii) software platform- identified the software of the BIM to be used and how the issues of the interoperability are addressed; (iv) stakeholders- define the leadership of the project and additional stakeholders, along with their role and responsibilities; (v) meetings – identify the frequency of the meeting attendees; (vi) project deliverables- identify the outputs and the format in which they are delivered; (vii) project characteristics- includes numbers of buildings, location etc; and work and schedule division; (viii) shared coordinates- identify the common systems of coordination for all BIM data (e.g. detailed modifications) (ix) data segregation - addressing the organisational structure of the model to assist the multi-discipline, multi-user access, project phasing and ownership of the data; (x) checking/validation- identify the process of checking and validation of the BIM drawing and data; (xi) data exchange - identify the protocols of communication as well as data exchange frequency and form; and (xii) dates of project review - identify the main dates for BIM reviews which include participating for both internal and external design teams.

3.5 Fields of BIM Implementation

Collaboration process should concern about three main elements: technology, process and people. BIM implementation is not only about technology but also about people and processes (Arayici et al., 2011; Ahmed, Opoku and Aziz, 2016). The tackling of process and people issues constitute 80% of the successful implementation of collaborative systems and the other 20% is consumed by finding solutions to issues linked to technology (Wilkinson, 2005). There are two broad areas to the resistance to technology (ibid.): the collaborative working principle, and technology adoption. To achieve successful collaboration, there is a need to bring together processes, people, and technologies. However, Soetanto et al. (2003) believe that the people aspect is the source of the biggest challenge.

The paradigm shift is required to achieve successful implementation of BIM in railway design. If the repeatable processes are standardised, there could be a facilitation of their automation which would lead to the streamlining of the collaborative design process. It required to refined contractual guidelines and terms, demand for individuals with new sets of skills, roles of management, green building design, workspaces where there is an interaction of information, verification tools that are automated, integration of BIM and construction management functions (Eastman et al., 2008). However, presently, there is a lack of methods for planning and information delivery in a collaborative manner which available for railway projects. This is the gap that this research seeks to address.

BIM frameworks have been developing by several publications. These frameworks include: (i) (i) tools, people, processes (DTI, 2007); (ii) technology, process, and competence (Rekola et al, 2010); (iii) process, technology, and people ;(Chen, 2014) and (v) technology, policy, and process (Succar, Sher and Williams, 2012; Succar, 2009; Succar and Kaseem, 2015). However, the most comprehensive frameworks are the one developed by Succar (2009). The framework had three BIM fields: (i) policy; (ii) technology; (iii) process (see Figure 3-2). In the policy field, participants include regulatory bodies and research centres among others. In the technology field, role players include software providers who make technology available to the bodies mentioned in the policy field. Finally, the process filed role players are the AEC/O stakeholders whose responsibility are right from the pre-design to the operation phase of the project. It is the scope of this research project to deliver a definition of the process of collaborative design and assessment.

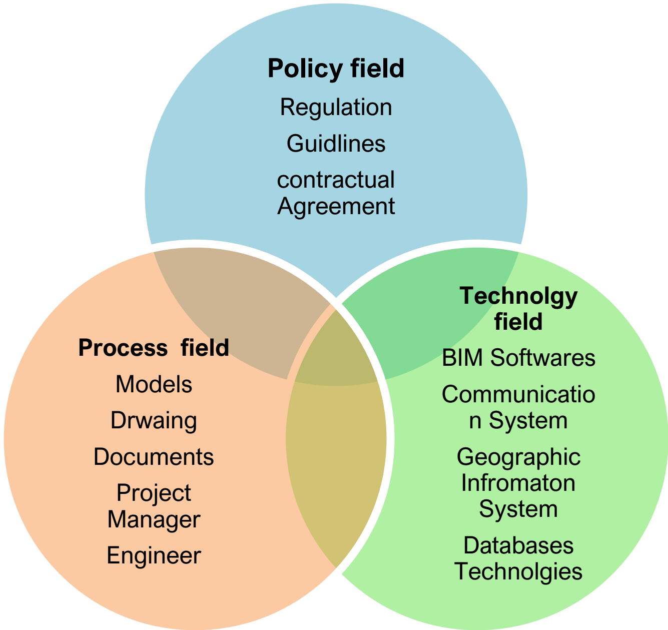


Figure 3-2: BIM field (adapted from Succar, 2009)

3.5.1 Policy Field

Kasim (2015) has conducted an examination of the possibility of facilitating the automatic checking of the BIM model against a set of regulations. The policies and regulations of the UK are considered as both drivers and enablers in this research.

3.5.1.1 Policy Makers and Regulations

A demand was made by the UK Construction Strategy (Cabinet Office, 2011) that construction projects should use Level 2 BIM maturity by 2016. This resulted in the establishment of organisations and groups, such as BIM2050 Group, BIM Task Group, Avanti, building SMART with the aim of responding to this demand. Existing organisations also changed their focus for that reason (Sinclair, 2012; RIBA, 2013a; Building Research Establishment Ltd., 2016). For instance, the BRE (Building Research Establishment) established arrangements aimed to make BIM certification available. Also, the RIBA owned Building Specification (NBS) has published research linked to BIM adoption in the UK.

The following standards have been used by the UK government to define Level 2 BIM maturity (NBS, 2015; NBS, 2016, BS EN ISO 19650-1, 2018):

1. PAS 11922: 2013 - Specification for information management for the capital/delivery phase of construction projects using building information modelling (BSI, 2014a).

2. PAS 11923:2014 - Specification for information management for the operational phase of assets using building information modelling (BSI, 2014a).

3. BS 11924-4:2014 - Collaborative production of information. Part 4: Fulfilling employer’s information exchange requirements using COBie (Construction Operations Building Information Exchange) – Code of practice (BSI, 2014b).

4. Construction Industry Council (CIC) Building Information Model (BIM) Protocol: This institutes precise liabilities, obligations, and restrictions on how the building information models can be used and embraced by clients to dictate specific working practices. It can be integrated into contracts and appointments by a model enabling amendment (CIC, 2013).

5. GSL (Government Soft Landings) - Created with the aim of championing more desirable outcomes for the build assets in the UK at the design and construction stages. It is supported by BIM with the aim of making sure that there is an achievement of value in an assert’s operational life cycle (BIM Task Group, 2013).

6. Digital Plan of Work (DPoW) - BIM Toolkit: This NBS developed toolkit seeks to assist in the definition of roles and responsibilities with regards to the preparation of information together with a verification 84 tool for identifying objects which are classified correctly and to endorse that the model contains all the required data (RIBA, 2013a, RIBA, 2013b).

7. Classification – Uniclass 2015. A system of classification which can be employed for the organisation of information across all phases of the design and construction process (RIBA Enterprises Ltd and NBS, 2016)

8. PAS 1192-5:2015: This is a requirement for building information which is security inclined, smart management of assets, and digital build environments. It provides guidelines on how to secure physical assets, a property of an

intellectual nature, the information linked to the asset, the process, the people, and the technology (BSI, 2015a).

9. BS 8536:2015: Facilities Management (FM) briefing for design and construction. This covers the infrastructure of buildings, guidance regarding the required environmental, social, and economic outcomes and also the processes that will be followed to achieve these outcomes (BSI, 2015b).

10. BS 8541: Assortment of principles for library items (architectural, engineering, and construction) (BSI, 2014c).

11. BS EN ISO 19650-1, 2018: in this, is used to generate a federated information model from a mixture of manual and processes of automated information management. This information model contents all information containers which the task teams have delivered them in relation to an asset or a project.

Through the process model, the type of the standard used will identify and approved for all parties which lead to facilitate the work. The responsibility for providing guidance on best practice on construction production information sits with the Construction Project Information Committee (CPIC). The CPIC was established by representatives coming from major UK industry institutions. This was done with the aim of ensuring that there was an agreed point of departure because the difference in interpretations of the term has been negatively impacting adoption. Still, a generally simple generic scheme, outlined by the RIBA Plan of Work 2013, is adopted by the UK AEC/O industry. Clearly, by the National BIM reports (NBS, 2015; NBS, 2016) provide confirmation of the adoption of the RIBA Plan of Work as a predominant standard for how the design process should be managed (71% and 40% respectively).

3.5.1.2 Contractual Agreements

In collaborative processes of BIM liability and ownership are considered as significant concerns in it (Barnes and Davies, 2014). The protocols and standards roles are information management, and the complex relationships between social and technical resources that represent the current organisational environment in terms of interrelationships, complexity, collaboration (Jernigan, 2008).

Several legal documents develop in the UK for BIM collaboration such as the “CIC BIM Protocol”, “CIC Best Practice Guide for Professional Indemnity Insurance when using BIM”, and “CIC Outline Scope of Service for the Role of Information Management” (CIC, 2013). According to Al-shammari (2016) evaluation, the CIC protocol is considered too difficult to control it “too process-driven” because of the amount of work that is necessary to fill the protocol appendices. However, this process can be simplified by following an automated approach to identify the project scope. Furthermore, deficiencies have been identified in CIOB's "Complex Projects Contact" by Gibbs et al. (2015) which focuses on the virtual model instead of the collaborative working process. Moreover, the contract neglects the rest of the project team members and focus on the relationships between the client and the contractor instead. Re-examination is needed for the contractual arrangements to accommodate BIM collaboration (Kumaraswamy et al., 2005).

Despite the existing valuable guidelines for implementing BIM as discussed in the publications above, there is a lack of clear roles of the participants in the collaborative process, still bespoke and ill-defined. Therefore, it essential to be defined and acknowledged. Thus, they can be used in the formal contractual agreements, so the services can be compensated to the responsible parties

3.5.2 Technology Field

In this section, the technological enablers of BIM and GIS-enabled collaboration are defined. The key issues that will be discussed will include software proficiencies and interoperability between applications together with collaboration platforms which make it possible for design deliverable exchange. The kinds of software applications have been distinguished by Lévy (2011) based on their functionalities: architectural design, structural analysis, MEP, BPA and assessment, coordination, and management of construction. Nonetheless, all the software pieces named above are BIM because at the centre of BIM is the management of information and it is based on the philosophy of integration.

The employment of different software types is in alignment with the idea that a project's evaluation process should not be perceived as something linear, but one that follows a cyclic pattern (Ding, 2008). Nonetheless, changing integration technology and changing workflows is a change in the management process. If the expectations for the next process are clearly defined, it will facilitate a situation for the whole team to work in tandem with the aim of making changes to their business in an effective and efficient manner (Jernigan, 2008). Future designers will have the capacity to have access to rich opulent sets of real-time facilities data and the systems they will use are rule-based in order to do away with most repetitive tasks. The norm will be systems that connect the business making process to decision-making. A unique chance for forecasting how a real structure will perform is permitted by prevailing technological options. However, the practical application of BIM will mean that traditional methods of design will have to be rethought. (Garber, 2009)

3.5.3 Process Field

It has been recognised that above all, BIM is a process that is likely to become more popular in the UK construction industry for the foreseeable future (Barnes and Davies, 2014). The main design decision arising at the initial stages will have to be found on the right information (Thomson, El-Haram and Hardcastle, 2009). Hence, this section will discuss the features of the design processes in the railway. These features incorporate people, the roles they play and their responsibilities, together with the implements that include the exchanges of information, and their components. It has been shown that effective collaboration does not solely lead to the application of information technology solutions; people and organisational issues also must be resolved (Bouchlaghem, 2012). There is an argument about the possibility of unifying the repeatable processes in order to simplify the process of the design. Therefore, automating repeatable processes is vital for collaborative design (Vreede and Briggs, 2005). This is important in a world that is moving from a hierarchical (command and control) to the direction of a distributed (collaborate and share) model (Jernigan, 2008). Communication is a major issue, particularly in performance-based design (Bakens, Foliente and Jasuja, 2005) as a result of the level of specialisation and complexity.

People and process elements are the most important through the collaboration process. It is generally agreed that an effective application of collaborative systems relies more 80% on dealing with people and process elements, and less 20% on resolving technological elements (Wilkinson, 2005). Resisting to the use of technology has two main areas (i) the collaborative working principle, and (ii) the adoption of the technology itself. To collaborate effectively, a combination must occur among processes, people, and technologies. However, the most challenging to get right is people. Hence, some have argued that evolving technology faster than people have (Jernigan, 2008). So, it is required to retool the social cultures in the world of building to take advantage of and utilise the current workforce. However, integrated technology should not be perceived to mean that architects now have to get rid of all the proven experiences and tools they have used in the past (Jernigan, 2008). It remains important that people should be able to share more in order to transfer from "*creative isolation*" to meaningful collaboration which is aided by the new technology. To achieve this, individual working patterns that exist have to change (Wilkinson, 2005).

Yudelson (2008) has suggested the use of the 4 Es to overcome fragmentation: *Engage Everyone Early with Every issue*. Collaborative design is accompanied by a significant expansion of the project team, together with interdependences the tasks and deliverables of team members. A system of managing the workflow with the ability to track information and provide updates automatically can help in the timely engagement of the appropriate stakeholders, right across the design process. The fact that a rules-based system can codify the knowledge concerning any subject (Jernigan, 2008). Through providing a definition of how these bits of knowledge are intermingled, most fact-based assessments which drive planning can be automated.

3.6 Geographic Information Systems (GIS)

3.6.1 Introduction

GIS is computer-based systems depends on geography, mapping, and remote sensing technology. It can capture, store, check, integrate, manipulate, analyse, and display information and data which are spatially referenced to the Earth and they can digitise and visualise abstract information (Fazal 2008; Wang, Pan and Luo, 2019). GIS is a database system with both the specific capabilities of spatial reference data, as well as a set of operations to work with data (Fazal 2008). While FHWA (2014) introduces it as a technology used to conduct an analysis of spatial and build maps. Aligning this system with Information Technology (IT) systems causes working barriers across organisational boundaries. Using new technology to share data, allows collaboration with other organisations to publish GIS data.

Similarly, Cromley and McLafferty (2012), define it as a system consisting of hardware, software, people, organisation and institutional ranking used to collect, store, analyse, and disseminate information around the earth.

Although there are several definitions of GIS available, however, they reached a similar outcome. Therefore, GIS is defined for this research as *A technology that used to share, store, analyse or a process used to improve collaboration to publish geospatial information or data*.

3.6.2 Applications of GIS

There are huge numbers of academic publications dedicated to GIS its benefits. Due to GIS capabilities to processing spatial data, it can be used in a wide range of applications, for example, for land surveys, cadastral management, environmental management in addition to its applications in regional planning, disaster monitoring, agriculture, and infrastructure maintenance (Wang, Pan and Luo, 2019; Zhang et al., 2009).

Gradually, GIS technology, analytical techniques, and data structures being integrated into a wide range of operations of management and decision-making (Fazal 2008). For a better understanding of GIS applications, it is necessary to characterise them logically to examine approaches and needs in terms of similarities and differences. This understanding is critical to deal with GIS procurement and its management (Fazal, 2008).

1- Functional classification: This classification deal with data characterisation such as themes, accuracy needed models for data.
2- Decision support tool: it is a great goal for GIS. It is a basis for GIS definition.
3- Planning in different trends: planning and design of urban, housing, planning for conserving architecture and for landscape.
4- Applying for street networks: such as scheduling and routing of vehicle: location, site selection and disaster planning.
5- Natural resource-based application: analyse the influence of managing an environment the natural resources.
6- Analysis of a field of vision: modelling of Hazardous for example and planning a path of migration.
7- Facilities management.

The advantages of GIS are enormous and there are many studies published in peer-reviewed journals examining the opportunities that can be gained from GIS (Fazal, 2008; Wang, Pan and Luo, 2019). Furthermore, its integration in the real world from simple representations of maps to produce powerful tools of analysis. From these, Masser and Campbell (1991) argued that GIS technology provides the integration of data between organisations, and alliance simulation within an organisation. In addition, the typical benefits of GIS identified by Sveinsson (2012) are saving costs, improving the availability of data and enhancing the relationships within the organisation. In terms of saving cost from different aspects, personality, facilities, acquisitions on data and maintenance all these can be reached from sharing data by organisations in an independent manner. Enhancing the relationships among organisations comes from sharing data which is significant for communication within organisations. It is assumed that sharing information and communication lead to rising the opportunity to develop new approaches to support the targets of business (Sveinsson, 2012).

On the other hand, Esri (2012) identifies several benefits of GIS similar to a study by Sveinsson (2012): high efficiency which leads to cost-saving, better decision making, enhanced communication and collaboration. Furthermore, lead to a better method to record geographic information and geographical managing (FHWA, 2014).

Despite the various benefits of GIS and the rapid increase in uptake, there is a lack of sharing data among organisations either due to poor coordination (Warnecke et al., 2000). This problem is not just due to technical limitations, but rather it springs from poor human acceptance for new trends. The focus of GIS is on geolocation and using real-world information and existing data or policies (Berlo and Laat, 2011).

3.7 Similarity and Differences between BIM and GIS

There are many differences between BIM and GIS despite the main functionality of both being to represent the real world digitally (Figure 3-3). They are considered as solutions to tackle various problems in different domains. For example, BIM is used to optimise models for new well-defined objects, while GIS is used to re-build existing objects when the availability of information is sparse and incomplete (Zhang et al., 2009).

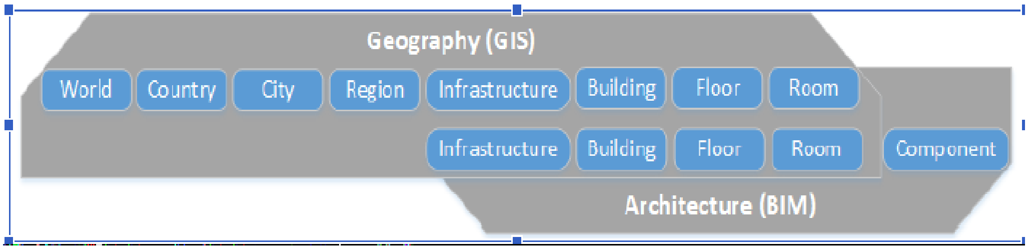


Figure 3-3: Relationship between BIM and GIS (HONG and PARK, 2014)

Furthermore, there are several conflicts between BIM and GIS because of the differences between their “worlds”. For instance, BIM represents indoor environments, in other words, it visualises the micro-level in the real world, whereas, GIS represents outdoor environments, i.e., at a macro level of the real world (Wang, Pan and Luo, 2019). Consequently, GIS depends on geographic coordinate systems and projections of the world map, whilst BIM coordinates depend on modelling objects not relative to a specific place on the earth (Zhang et al., 2009; Hijazi, 2011; Fosu et al., 2015). The nature of BIM is 3D (notwithstanding nD BIM) and focused on buildings and their features, but the range of the GIS is wider as it deals with whole cities and urban areas in mostly 2D. Moreover, the common standard of BIM is IFC, while CityGML is the controlling standard of the GIS. These incompatibilities are summarised in Table 3-1 below:

Table 3-1: Incompatibilities between BIM and GIS (Bureau, 2012)

Criteria	GIS	BIM
Modelling Environment	Mainly focus on the outdoor environment. Outdoor activity may need to be positioned in GIS.	Focused mainly on the indoor environment. Outdoors applications are limited to the outside of buildings. 3D modelling of site utilities and terrain modelling are also available in BIM.
Reference System	Geospatial data is always georeferenced. Objects are defined in a physical world with global coordinate systems or map projections.	BIM objects have their own local coordinate system, for example at the left comer of the building
Details of Drafting	GIS builds upon existing information and objects. It covers a large area with less detail and in smaller scales.	Drafting capabilities of BIM are utilised to develop large scales with a higher level of details.
Application Area	GIS is focused on urban and city areas.	BIM is rooted in the building and its attributes.
3D Modelling	GIS capabilities are limited to simple 2D shapes; Experimentation with 3D in GIS is in an early stage.	BIM is unique in its ability to work in a full 3D environment. BIM has a rich set of spatial features and attributes.

The type of information that each BIM (e.g IFC) and GIS (e.g CityGML) provide are different with different details. This difference leads to interoperability problems during exchanging data between them (Fosu et al., 2015).

3.8 Integrating BIM with GIS

Much research has been reported in each of BIM and GIS separately and each technology has its strengths and weaknesses. Merging them (BIM and GIS) offers powerful synergies and opportunities that can be used through a project lifecycle, especially in complex projects such as railway projects. Integrating BIM with GIS is not a novel idea (Fosu et al., 2015). Alshawi and Ingirige (2003) defined integration as the sharing of and collaboration over similar interoperable data/information of the project. By integration, ambiguity and construction errors and processes of Annotation Model (AM) may be reduced because integration enables changing and sharing data up to a more timely and accurately documented manner (Ajam, Alshawi and Mezher, 2010). Over the years, continuous attempts have been made to integrate BIM and GIS for different purposes (despite the incompatibilities between the technologies, specifically their respective formats) which can provide a project with an inclusive and highly detailed picture in terms of information from building information models and related geographical data (Fosu et al., 2015). By integrating BIM and GIS, the unnecessary effort can be avoided in redundant modelling. In this way, more detailed data in BIM can feed more general data in GIS, and GIS data can provide the context usually missing in BIM data (Ohori et al., 2018).

Recently, an integration approach is suggested by Karan and Irizarry (2015) through a semantic web format in order to query integrated models. Hagedorn et al. (2009) represented topological relationships amongst micro-entities like rooms and corridors according to a conceptual double graph. While, Nagel, Stadler and Kolbe (2009) proposed a transition approach using CityGML from a KML (Keyhole Markup Language: file format used for displaying geographic data in earth browser such as google earth (Hijazi, 2011) graphics model to BIM.

Following that, several methods were used to achieve a complete integration of BIM with GIS. Various authors invented methods and developed new tools by using available standards to merge the aspects for each area. As a result, extensions were created that may offer a needed functionality to be added to one or other platforms such as the extension of Geo BIM (Berlo and Laat, 2011), or the extension of urban information modelling for facility management (Mignard and Nicolle, 2014); also, the proposed new architectures such as BG-

ETL software architecture by Kang and Hong (2015) for supporting the integration.
In order to integrate BIM into GIS, a data model is suggested by Amirebrahimi et al. (2015). For the same purpose, an IFC-based tool has been created by (Hjelseth and Thiis, 2008).

El-Mekawy and Östman (2010); Mohamed, Ostman and Shahzad (2011) proposed an approach called Unified Building Model (UBM) which was a unique style giving the opportunity to users to combine the features and abilities for both BIM and GIS fully into one central mode.
IFC standards are used to convert data for both BIM and GIS as suggested by Shen and Yuan (2010), while a prototype is implemented to achieve interoperability between existing software platforms (Hwang, Hong and Choi, 2013).
Others proposed different, pure, and conceptual frameworks. For example, Wu, Yang and Fan (2014) developed a framework for the virtual assessment for the facility energy. Chen et al. (2014) proposed supporting information framework. Finally, Isikdag and Zlatanova (2009) put a framework to translate from BIM to GIS automatically.

3.9 Applications for Integrated BIM and GIS

Integrating BIM with GIS offers huge advantages which tiding information to the geographic location made an all-new way of working with our environment very easy (Salford-workshop, 2016). Laat and Berlo, (2011) argued that despite the users of BIM and GIS meet in many complex projects, however, both worlds using their own technology and ways of working as an attempt to solve planning questions. Targeted application areas of integrated BIM and GIS clearly include urban planning and landscaping; architectural design; activities of tourist and leisure; 3D cadastre; simulating of environment; mobile telecommunications; managing of disaster; security of homeland; vehicle and pedestrian navigation; training simulators; and mobile robotics (Kolbe, König and Nagel, 2011). The following are some examples of lifecycle phases where integrating BIM and GIS can be used (Table 3-2):

Table 3-2: Examples of phases that integrating BIM and GIS can be used

Project stage	Application
Planning and Design	Select the site and manage the fire response. (Isikdag, Underwood and Aouad, 2008)
	Easiest collaboration between planning. (Niu, Pan and Zhao, 2015)
	- Effective traffic planning. (Wang, Hou, Chong, Liu, et al., 2014). - Plan and make a decision of low- disturbance bridge construction bridge. (Sebastian, Böhms and Helm, 2013). - Identify the optimal number and location of tower cranes (Irizarry and Karan, 2012). - 4D topology and use novel IFC in planning a path for 3D indoor spaces respectively. (Su et al., 2012 and Lin et al., 2013). - Indoor geovisual analytics. (Wu and Zhang, 2016)
Construction	- Area for collaboration. (Tobiáš, 2015). - Speed up the work. (Shiu and Sar, 2014). - Managing construction supply chain, green design, construction and sustainable consequences. (Irizarry, Karan and Jalaei, 2013; Alexiadi and Potsioy, 2012).
Operation and Facility management	- Facility management, facility analysing, visualising and assess damage in buildings such as a flood. (Karan and Irizarry, 2014; Hijazi, 2011; Amirebrahimi et al., 2015) - Emphasise the materials delivered by enabling tracking the status of the supply chain. (Irizarry, Karan and Jalaei, 2013). - Flood damage assessment. (Amirebrahimi et al., 2015). - Evaluate the performance of construction. (Elbeltagi and Dawood, 2011). - Managing the processes of maintenance and repair of facility management. (Karan and Irizarry 2014) - Detect and map the information for pipe networks. (Liu and Issa, 2012) - Manage the maintenance using a UML (unified modelling language) in Taiwan railway. (Shr and Liu, 2016)

3.9.1 Planning and Design

BIM and GIS have a wide range of applications in different stages of projects; infrastructure and construction. For example, Isikdag, Underwood and Aouad (2008) used BIM/GIS to select the site and manage fire response, while Niu, Pan and Zhao (2015) used them to assist collaboration between planning for urban-level energy and design for building-level energy.

In addition, integrated BIM and GIS have been used for effective traffic planning by optimising and evaluating the site layout as demonstrated by (Wang, Hou, Chong and Liu, 2014). Similarly, Sebastian, Böhms and Helm (2013) investigated interoperability of BIM and GIS to plan and make a decision of low-disturbance construction, especially in bridge projects in the city. In the same way, in construction, there is some research used BIM and GIS in planning such as SU et al. (2012) and Lin et al. (2013) as 4D topology and use novel IFC in planning path for 3D indoor spaces respectively.

An argument is stated by Shiu and Sar (2014) that using technology tools such as BIM and GIS infrastructure can provide up to date and accurate information for design, construction and maintenance work. El-Mekawy and Östman (2010) stated that there is a need for sharing and exchanging data between objects of the building industry and (represented in IFC) and geospatial object (represented in CityGML). In other words, it is necessary to integrate IFC and CityGML as a needed step to obtain a comprehensive 3D model at a various detailed level (El-Mekawy and Östman, 2010). For this purpose, they developed a framework and extended the discussion to address the requirements.

3.9.2 Construction

There is no doubt that BIM and GIS have their role in the construction phase whatever the type of projects infrastructure or building. to illustrate that Tobiáš (2015) examined which area can benefit from integrating BIM and GIS. Whilst, Shiu and Sar (2014) developed GIS from 2D to 3D and used a BIM platform to speed up the work for different project stages. Furthermore, managing construction supply chain, green design, construction and sustainable consequences are another aspect that utilises BIM and GIS in their research (Irizarry, Karan and Jalaei, 2013; Alexiadi and Potsioy, 2012). Moreover, the utility of BIM and GIS has been applied to identify the optimal number and location of tower cranes (Irizarry and Karan, 2012). Also, in order to facilitate progress monitoring of repetitive construction Elbeltagi and Dawood (2011) developed a visualisation system from BIM and GIS to evaluate the performance of construction.

According to research conducted by Wang, Pan and Luo (2019), they examined BIM and GIS applications for the metro construction project. They revealed that GIS considered as effective tools to analyse a spatial function. Combining these with tools provided by BIM like coordinate, simulate, and optimise may generate a strong tool to construction industry compilation with metro projects.

3.9.3 Operation and Facility Management

In the operation phase, many studies are conducted for facility management, facility analysis, visualising and integrating BIM and GIS to assess damage in buildings such as flood damage (Karan and Irizarry, 2014; Hijazi, 2011; Amirebrahimi et al., 2015). For example, Irizarry, Karan and Jalaei (2013) developed a system for integrating BIM and GIS to emphasise the materials delivered by enabling tracking the status of the supply chain and providing warning signals. Furthermore, Integrating BIM with GIS enables it to provide the required information for flood damage assessment, while it is difficult to achieve that if there are used separately (Amirebrahimi et al., 2015). Shr and Liu (2016) developed a system to manage the maintenance using a UML (unified modelling language) in Taiwan Railway.

Isikdag, Underwood and Aouad (2008) point out that there are factors which prevent to compute the transforming information through building model to the geospatial environment (semantic information and spatial relationships). One of these factors is the lack of object-oriented data structures leading to a lack of ability of standard CAD to transfer semantic information and spatial relationships, while BIM has this ability. Another major factor is the difference in storing, handling and treating the object geometries between geospatial information models and building models.

Continuously, there are several researchers addressing different areas by using integrated BIM and GIS such as facility management, utility visualisation, analysis, assessed damage and natural disasters. For example, in the benefits of the visualisation field (Hijazi et al., 2009; Hijazi et al., 2011; Liu and Issa, 2012). In facility management (Kang, Park and Hong, 2016; Marzouk and Abdel Aty, 2012; Kivits and Furneaux, 2013). As well as, (Wu, Yang and Fan 2014; Saran et al. 2015; Hjelseth and Thiis 2008) applying integrated BIM and GIS in climate adaption and analysing energy.

On the other hand, the most important area that required using the integration of BIM and GIS is facilitating to provide a collaboration environment. Through collaboration, large problems can be tackled, and huge benefits can be gained. The collaboration includes facilitating sharing knowledge, risks, skills and reducing cost (Prahalad and Hamel, 1990).

From the literature review, it can be concluded that BIM and GIS are crucial technologies to provide collaborative environments effectively. Although there are many pieces of research in using these technologies in different stages of construction, there is rare of research in using them in the design stages of railway projects.

3.10 Summary

In this chapter, the focus was on the technologies that have the potential to achieve effective collaboration. The literature suggested that BIM and GIS are the future of collaborative building design. There is confusion about what they are and how they should be utilised and implemented. Even though using BIM 3D capable to produce visualisations is increasingly becoming adopted, its true (nD) potential is not yet exploited to manage information (NBS, 2015; NBS, 2016). Furthermore, BIM is presenting the indoor scale more than outdoor scale while GIS focuses on the outdoor scale. The combination is especially beneficial for railway projects which needed both.

To sum up, from the literature review it is obvious that railway projects need collaboration in order to achieve effective delivery of railway projects. For example, saving time, realising return on investment through saving cost, better quality, reducing carbon emissions, increase productivity and availability of information throughout the project lifecycle. In addition, collaboration can be supported by integrating BIM with GIS, which would add to several types of research using this integration for different purposes. However, despite the importance of collaboration and even with using BIM and GIS in railway projects, there is a lack of research focusing on using the *integration* of BIM with GIS to improve collaboration. Thus, this study will focus on this area because, according to the literature, collaboration may play a very crucial role in railway projects and the benefits of solving the existing problems and provide huge opportunities to share information effectively.

Chapter 4 : Research Methodology

4.1 Introduction

From the previous chapter after identifying the research problem, the need for proper methods is required to address them. This chapter presents a background of research methodology in general. Then presents the research methodology adopted and the rationale of this research. The summary of chapter presented at the end of the chapter to start with the data analysis in next chapters.

4.2 Research Design

Research design can be defined as a framework of data collection and analysis, whilst, the technique that is used for gathering data is called a *research method*. The research methodology is defined according to Fellows and Liu (2003) as "the principles and procedures of the logical thought process which are applied to a specific investigation". Research is a systematic procedure for finding a solution (Tan, 2004). It can be used to explore or generate a description of a phenomenon. Research can take many forms; it could be qualitative or quantitative, exploratory, descriptive, interpretive, casual, and pure or applied (Tan, 2004)

There are many research methods available to be used in research studies (Fellows and Liu, 2003). In the built environment, “nested” and “research onion methods” are the two most famous frameworks that are available for the research methodology (Kagioglou et al., 2000; Saunders, Lewis and Thronhill, 2012). Although both frameworks have similar steps for conducting research, the Research Onion Method has more detailed information (Omotayo and Kulatunga, 2015). Therefore, this method is adopted in this research project. These are illustrated in Figure 4-1 and Figure 4-2 below:

Figure 4-1: The nested model (Kagioglou et al., 2000)

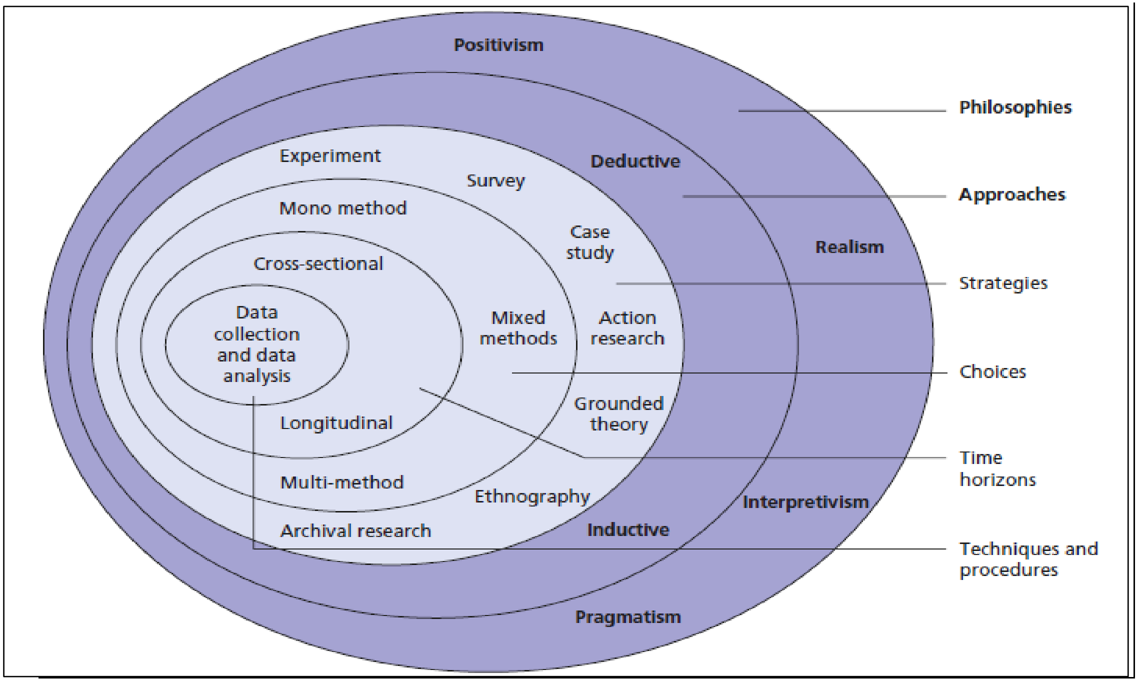


Figure 4-2: The Research Onion (Saunders, Lewis and Thornhill, 2016)

4.3 Research Philosophy

Research approach, strategy, and data collection methods are essential parts that guide the researcher to address the research questions. One of the main problems, any researcher needs to deal with, is the acknowledgement of research paradigm because this affects the research methodology which in turn will influence the suitable approaches for answering research questions (Sobh and Perry, 2006). Furthermore, according to Guba and Lincoln (1994), “questions of methods are secondary to questions of paradigm”. Therefore, there is a need to examine research decisions before choosing the research methodology.

Research paradigms are generally basic, general beliefs and global views that guide the researcher to choose the appropriate research methods. Hence, Guba and Lincoln (1994) have defined the paradigm as a set of basic beliefs seen from a wider global perspective in which an individual (researcher) can see the nature of the world. In short, the general set of adopted criteria or assumptions in which the researchers may work is called a paradigm.

Extensive research has been conducted to standardise the basic beliefs of paradigm into three important questions in which any paradigm can be effectively investigated. These are ontological questions, epistemological questions and methodological questions as illustrated in Table 4-1 (Iofrida et al., 2014). It begins with ontological assumptions about reality, then investigating this reality (epistemological assumption), followed by methodological assumptions that lead in adopting the research methods. (Morgan, 2007).

Table 4-1: Characteristics of different worldviews with regards to their ontological, epistemological and methodological properties (adopted from Iofrida et al., 2014)

Items	**Positivism-oriented**		**Interpretivism-oriented**	
	Positivism	Post-positivism	Interpretivism	Constructivism
Ontology: What is a reality?	Naive realism. Objective reality.	Critical realism.	Subject and object are dependent.	
Epistemology: How do you know?	Dualism researcher-research. Replicable findings are "true". Reality can be explained.	Dualism is not possible. Replicated findings are "probably" true. Impossible to fully explain reality.	Knowledge is interpreted. Reality can be understood.	Knowledge is constructed. Reality can be constructed.
Methodologies: How do you find it out?	Experimental, deductive. Mainly quantitative. Relationship cause-effect. Statistical analysis.	Experimental. Mainly quantitative methods, manipulative. Scientific Community plays an important role in validation. Statistical analysis. Probability sampling.	Interpretation. Mainly qualitative methods. Purposive and multipurpose sampling.	Mainly qualitative methods. Purposive and multipurpose sampling. Stakeholders involvement.

4.3.1 Ontology

The part of philosophy that deals with the nature of facts are called metaphysics, of which ontology is part (Willis, 2007). Hence, ontology deals with reality and its constitutions (Sobh and Perry, 2006; Scotland, 2012). Objectivism and constructionism are two ontological terms that deal with social entities and factors. If social entities are constructed from social actions, this is *constructionism*. However, if reversed, it is objectivism, which is an ontological status that means that social phenomena face us as external facts that far from our reach or influence (Bryman, 2012). Therefore, although reality affects individuals, it's distinct from human understanding.

In research, it is believed that the principles and procedures (a social phenomenon in this case) are not ideal solutions for the research problem. A summary of possible ontology approaches is presented in Table 4-2.

Table 4-2: Summary of the ontology approach

Ontology Approaches	**Definition**
The objectivism aspect	Social phenomenon out of individuals reach in a certain social context
The constructionism aspect	Accomplished social factors related to a social phenomenon
The critical realism aspect	Improve the current situation by viewing reality differently

This research acknowledges that achieving effective collaboration is dependent upon nature works. However, the best collaborative design process is based upon individual perspectives (how individuals perceive phenomena). For example, the success or failure to achieve effective collaboration. Therefore, the description of the interviews' experiences (provided during data collection) was provided.

4.3.2 Epistemology

Epistemology deals with what can be known about reality and how we can extract it. It assesses what could be regarded as acceptable knowledge in certain fields bearing in mind the argument whether the principle and procedures of the social world should be the same as natural sciences (Bryman, 2012). Thus, for any researcher on certain topics, there is always an epistemological purpose behind the research, irrespective of an individual's perspective.

The positivist and interpretive approaches are the two main ways to represent an epistemological concept (Bryman, 2012). The positivist approach is the one that supports the natural sciences approach to research (Bryman, 2012), which relies on neutrality and impartiality or objectivity by examining certain theories and hypothesis (Holloway and Wheeler, 2010). Hence, in this regard, researchers tend to believe that statistical analysis, simulation, or numerical measurement is preferable to obtain results or gain understanding in research.

So essentially, researchers tend to formulate a hypothesis and test it (Holloway and Wheeler, 2010). Table 4-3 summarise the epistemological concepts.

Table 4-3: Summary of the Epistemological concepts

Epistemological concepts	Definition
The positivist approach	support natural science way of research
The Interpretivist approach	believes in human recognition by focusing on their experiences and understanding
The pragmatist approach	knowledge is gained from interaction and communication between different groups of individuals along with their surrounding environment in which both creates a reality

This research follows the Interpretivist combined with a positivist approach. The focus of this research is the research problem itself, and to achieve that, the researcher followed the approach (qualitative and quantitative), which is believed to serve the needs of the research at each occasion. Questionnaire and in-depth interviewing methods align with Interpretivist theory-building and positivist research that emphasises experiences and understanding meaning rather than measurement (Healy and Perry, 2000).

4.3.3 Methodology

A research methodology is a guide or action plan that analyse a research method (Scotland, 2012). For a researcher to see if his/her beliefs can become reality (Sobh and Perry, 2006), there needs to be a well-adapted strategy or plan called research methodology and it is mostly guided by the researcher's ontological and epistemological concerns (Guba and Lincoln, 1994). Thus, adopting ontological and epistemological positions is necessary before doing any research (Scotland, 2012).

Most time to do research, the researchers distinguished between quantitative and qualitative methods as a classification of different methods of social research based on quantification presence and absence (Bryman, 2012). However, with respect to the epistemological questions of these research methods, they are different. For instance, the qualitative method is linked to positivism; the quantitative method is linked to interpretivism while the mixed method is associated with a pragmatist world view.

A- Quantitative Research

The basis of quantitative research is numerical data, which analyses the generated statistical information systematically (Deshpande, 1983). It depends on developing and using measured or mathematical models, theories and /or hypotheses related to phenomena. It provides authentic methodology and research with effective results (Gast and Ledford, 2014).

B- Qualitative Research

Qualitative Research is considered as a robust tool that can be effectively used in determining probable descriptions to subjects that need to be studied. Moreover, it is utilised in cases where no experimental results or data are available. Qualitative Research collects its data realistically either from organisations or directly from people (Graham, 2000, p.10). Analysing the collected data, such as questionnaires needs to be achieved by preparing forms of extracts and excerpts. Finally, this information is structured into groups and themes. (Johnson et al., 2007)

C- Mixed Methods/ Triangulation Research

Many definitions exist in mixed-method research, but they are emerging and evolving as the field matures (Creswell, Plano Clark and Hanson, 2010). In 2007, Johnson et al., (2007) provided a composite definition of mixed-method research as “a type of research in which a researcher or a team of researcher combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for breadth and depth of understanding and corroboration”. This perceived to be necessary to follow in this research in order to provide a depth understanding of collaboration and how BIM and GIS can be used as a tool to improve it.

For research to be considered as mixed-method research, Creswell and Plano Clark (2011) have recently defined six core characteristics and components as criteria for any mixed-method study. These include collecting and analysing both quantitative and qualitative data; integrating and mixing concurrently the two forms of data, or collect one type of data based on the other sequentially; prioritising one or both forms of data; using these procedures in a single study or in multiple stages of a study; using theoretical or philosophical views to frame these procedures; and finally determining a specific research design to combine the procedures to direct the plan for conducting the study. For this research, the third type was used (to collect one type of data based on the other sequentially) to achieve the research questions. The design of the questionnaire was upon the literature review and the first round of the interview design was based on the questionnaire findings. Finally, the second round of the interview was depending on the findings of the first round the interview.

4.4 The Rationale of the Philosophical Position used in this Research

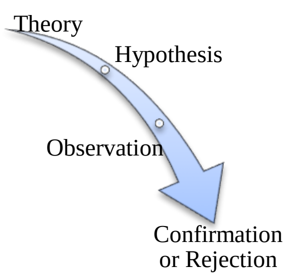
This research investigated the current practice of BIM and GIS in the design stage of railway projects. Furthermore, investigate BIM and GIS practices. For example, the experience of BIM and GIS, the most platforms used by them, the most stage required BIM and GIS, and the benefits and challenges of BIM and GIS and their integration. This to generate an idea about the current practice of BIM and GIS and identify the key challenges of implementing them. As such, the aim of this research is to prove the reality nature of BIM, GIS and collaboration, also their meaningful relationship and outcomes for action (BIM and GIS-enabled collaboration). The philosophical position of this research has been provided from the verification of the theory from epistemological positivism that resulted from the theoretical generation of that relationship built on ontological constructivism combined with interpretivism. It can be referred to this relationship as a triangulation of combined paradigms, whereby, adopted a mixed combination of positivist, constructivist and interpretivism philosophy.

This research explored collaboration issues and examines the current practice of BIM and GIS for collaboration. By this process phenomena of BIM, GIS and collaboration can be constructed, and through gathering information from industry experts, their meanings leading the research towards constructivist ontology. However, data related to the extent of BIM and GIS current usage and the effect of the potential use of them to improve collaboration of reality should be collected and analysed quantitatively (Leedy and Ormrod, 2010; Fellows and Liu, 2008). By this, a potential positivist epistemology route provided to the research. The exploration of the relationship between BIM, GIS and collaboration, the research represented individuals' perspective based on their own experiences. Therefore, this guided the research towards interpretivist epistemology in terms of constructing meanings from participants engaged within the research (qualitative research used open-ended questions to obtain shared views from participants).

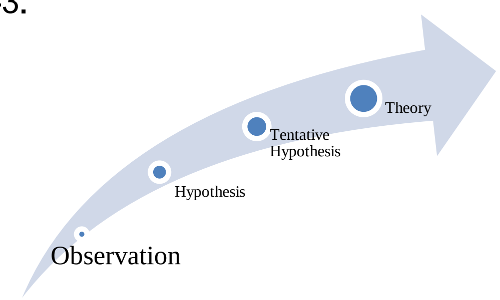
Previous research studies have explored the knowledge areas of BIM and GIS for collaboration individually, areas of BIM and GIS for collaboration in the design stage for railway projects have not been investigated yet. When through undertaking a literature review, the needs of the study and how to conduct it has been found out. Thus, the position of the research placed within the realism of constructivist ontology. However, further investigations have been conducted and developed by studying the human community which provided them with an opportunity to contribute with their own beliefs and experiences. This enabled to use an open-ended question for data collection for interviews. This drove the research towards the interpretivist epistemology position.

4.5 Research Approaches

Inductive and deductive approaches are the two types of research approaches. They are the two approaches to research stemming from different ways of reasoning research as shown in Figure 4-3.



Deductive process (adapted from Skinner, 2010, Zanni, 2016)



Inductive process (adapted from Skinner, 2010, Zanni, 2016)

Figure 4-3: Research Approaches Types

The deductive approach is based on a hypothesis (developing a theory) which may be accepted or rejected, depending on the collected data, and is a quantitative research key base (Alshehri, 2011).

An inductive approach is usually based on qualitative data. It is theory-based which depend on extracting inferences that could be generalised from the obtained findings from data (Bryman, 2008).

Both approaches were considered in this study as this study assumed from a theoretical perspective that collaboration is crucial for the railway projects and integrating BIM and GIS are the key to effective collaboration among participants.

4.6 Research Strategies

During identifying a suitable methodology for research work, it is essential to establish a strategy for data collection and analysis (Fellows and Liu, 2003). Strategies of research are the third layer of the Research Onion which consists of different methods: experiment, survey, case study, action research, ground theory, ethnography, and archival research. Survey method was adopted in this research to investigate the current status of BIM and GIS in railway projects. Although the survey method is could involve both deductive and inductive research approaches; the survey method used in this research is linked to deductive one. It is mostly used when answers to questions with 'what', 'who', 'where', 'how much' and 'how many' are needed. Hence, for instance, it is used in business and management research topics as these are mainly descriptive research. Moreover, questionnaires are popular nowadays as it is easy to use, effective in data collection and allows easy comparison of results for a sizable population (Fellows and Liu, 2003)

Consequently, the survey (questionnaire) approach was followed in this study because it is the easiest way to obtain the required information about the readiness of people to share information without any concern about the confidentiality of the shared data.

4.7 Data Collection and Data Analysis

4.7.1 Survey Questionnaire

By using a questionnaire, different responses could gather for a group of participants that could serve the main goal of the research. It comprises open-ended and close-ended questions. The questionnaire should be user-friendly, well-structured questions and with minimum human guidance. If compared with interviews, the questionnaire, which adapted in this research, has three distinct advantages it is cheap, for instance, many online websites offer free managed questionnaire. Secondly, it requires only minimum administration. Finally, participants may respond freely without being influenced by an interviewer. However, there are some drawbacks such as minimised length with a focus on limited issues. In addition, participants usually tend to write less which limit the usefulness of open-ended questions. Moreover, it is also vulnerable to data loss, non-identifiable persons along with low response rates (Bryman, 2008). The questionnaire needs to be designed and piloted before distributing it.

A questionnaire has been used in this research because it is the most proper method to serve the third objective (To assess the current practice of integrating BIM and GIS in railway projects). This aim required to know the stats of BIM and GIS. This is because through questionnaire more responses can be obtained easily than interviews. Furthermore, to avoid bias while choosing the sample. Moreover, the distributions of the questionnaire and analyse it easier than other types.

1- Questionnaire Design

The design of the questionnaire relies on different factors. These are the delivery method (to be collected or to be returned to the researcher) and the amount of contact availability with the respondents. As seen in Figure 4-4, there are two main types of the questionnaire:- self- completed (survey) in which the questionnaire can be answered using the Internet (the one used in this research) and interviewer completed, either by phone or face-to-face whereby the questionnaire usually distributed by hand and collected after completion. The latter method also called as structured interviews where it differs from semi-structured and in-depth interviewed (Saunders, Lewis and Thornhill, 2016).

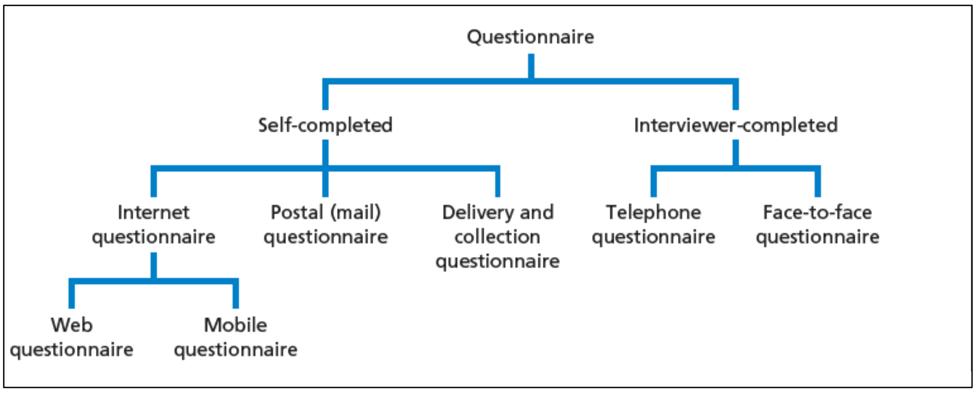


Figure 4-4: Types of the questionnaire (Saunders, Lewis and Thornhill, 2016)

The choice of questionnaire depends on various factors related to the research question(s) and research objectives, particularly (Saunders, Lewis and Thornhill, 2016):

1- Respondents' characteristics who wish to collect data from them.
2- The importance of the respondent sample.
3- The importance of the answers of the respondents.
4- The required sample size for analysis, taking the likely the rate of the response into account.
5- Question types needed to collect the data.
6- A number of questions needed for collecting data.

In this research, an electronic survey was conducted using BOS (Bristol Online Survey) since it is offering a variety of question types such as matrix, multiple-choice and other options in an easy way. The reasons for choosing electronic questionnaire include easy to design and create types of question required to serve the research objectives, easy to be distributed wildly as it is online and tend not to take a long time, as well as help to get the exact response needed according to the questions which often closed-end questions are rather than open-ended questions. Moreover, easy to analyse the respondent's answers, especially with the BOS web survey as it offers tools to analyse of the answers and calculate the number of responses. However, there are some drawbacks of the online survey. For example, because it is often closed-ended questions, the respondents will not be able to show their opinion, but this can be avoided by adding a few opened-end questions to allow respondents to give their views.

The other disadvantages include missing data, as sometimes the respondents miss some questions to answer. This can be avoided by putting a mark that the question is required to be answered.

Overall, each type of questionnaire has its advantages and disadvantages, which means that the researcher should be aware of which type will be useful and proper to achieve the required objective(s). In addition, the way to reduce or avoid the drawbacks of the chosen type of questionnaire.

2- Pilot Study

For this study, as a first stage, devolving a pilot questionnaire was conducted and sent to various participants who have experience in questionnaire design as well as in our research subject. A pilot study is a preparatory study that has been undertaken, on a small scale, before the main research to follow the latest development in the field and/or to improve the research design. It includes many aspects such as examining the writing style of the questions, checking coherency, deciding the questionnaire length with the required time to complete, and re-clarify unclear questions; also provide an opportunity to check the data collection technique that may be used in the main research (Naoum, 2007).

The questionnaire was then revised based on the received comments and criticisms in order to improve the questionnaire. Some advice and comments were regarding the length of the questionnaire while, other comments showed that it is obvious, easy to understand, and straightforward. After considering the comments from piloting the questionnaire, the revised version was distributed to the participants (see sections 4.12/phase 2).

4.7.2 Interview

There are many features that can be benefited from doing an interview for certain research. These are a verbal and non-verbal sense of the participants along with speech and hearing channels (Cohen, Manion and Morrison, 2011). Generally, interviews represent a communication circle between two or more people about common-interest topics to discuss opinions from their points of view (Cohen, Manion and Morrison, 2011).

There are four main types of interviews according to Cohen, Manion and Morrison (2011): structured, non-structured, indirect and focus interviews. In structured interviews, there is generally limited freedom the researcher can make as the questions, wording choices, and its sequence is given beforehand. In contrast, unstructured interviews have more adaptability with the question sequence and its content. Cohen, Manion and Morrison (2011) claimed that focused interviews were developed based on the need for control to the nondirective interview. In focus interviews, participants are usually come together in one place to speak about certain topics.

As for the nature of the interviews, they are from different types due to the methods of communications between the participants and the researcher. Among these examples are Skype, face-to-face and email (for follow-up questions only). These choices are mainly based on the convenient nature of the participants and the nature of restrictions concerning costs and time of travel (Baker and Edwards, 2012). As a fact, there is a disagreement among researchers about the most useful type of interview where some prefer face-to-face interviews with telephone interviews for their advantages, while others encourage them for participants who prioritise the method of anonymity (Sturges and Hanrahan, 2004). Yet, phone interviews are considered as to be more widespread among qualitative researches (Knox and Burkard, 2009) and are strongly found to be more operative in the process of maximising response rates (Tausig and Freeman, 1988). Likewise, it is found that telephone interviews and face-to-face interviews are equal in sharing the depth of response (Sturges and Hanrahan, 2004).

In this study, two rounds of semi-structured interviews were conducted following the questionnaire findings (see section 4.12- phase 3). A semi-structured interview was selected since it provides freedom for the interviewees to add their comments and make the interview as discussion and enable the researcher to ask any related question according to the interviewee's answers.

4.8 Appropriate Sampling Technique and the Sample

4.8.1 Unit of Analysis

Since information is mainly collected from the unit of analysis, hence it is vital to carefully select a clear unit of analysis, based on individual or group, this related to the research questions (Yin, 2003). Failure Lacking to obtain make a clear unit of analysis could result in ecological fallacy and the reduction is (De Vaus, 1991).

The purpose of this research project was to identify the critical components of a BIM and GIS-enabled collaborative process to achieve project objectives in the most possible economical way in terms of time, cost, and effort. The questionnaire approach aimed to access the current status of BIM and GIS. This was then followed by two rounds of in-depth semi-structured interviews to explore and investigate the collaboration issues and suggestions to tackle them based on experts' interpretations.

The unit of analysis, for both the questionnaires and interviews, was selected using involved with the sampling technique selection for the questionnaires and interviews through chronological and purposeful sampling methods, i.e. quantitative to qualitative, or vice versa (Tashakkori and Teddlie, 2008). Therefore, the unit of analysis of this research is individual depending on the sampling technique.

4.8.2 Simple Selection

1- <u>Questionnaire Sampling</u>

As discussed in section 4.6, the questionnaire and interviews were used for collecting quantitative and qualitative data, respectively. Collecting the concerned data from the entire population for the research is difficult and impractical (Conway, 1967). Hence, survey sampling should take priority consideration in the data collection process. Sampling can be defined as a part that can be easily managed from the chosen population (individuals' sample) for making conclusions concern to all populations drawn from a sample study (Conway, 1967). On one hand, draw a representative sample from the population is the aim of the quantitative sampling, which the studying results can be generalised back to the population (Marshall, 1996). On the other hand, in qualitative studies, the samples are much smaller than those utilised in quantitative studies (Crouch and McKenzie, 2006; Mason, 2010). This is because of the aim of the qualitative approach which enhanced understanding the complex human issues is more important than results generalisation (Crouch and McKenzie, 2006; Yin, 2013).

This research required respondents who have knowledge and experience related to any of, BIM, GIS and in railway design. Thus, the experienced specialised related to these technologies were selected as the sample for the research to access the current status of BIM and GIS in the railway design stage. Engineers, managers, BIM and GIS associated were targeted because they have rich experience in BIM and GIS and leading decision-making process across strategic, design and communication levels (Osmani, Glass and Price, 2006). The sampling method was adopted for this research was a non-probabilistic, a purposive sampling approach based on the experiences of participants. This constitutes Expert Sampling (Klein, Calderwood and Macgregor, 1989), whereby a sample of persons with known or demonstrable experience and expertise in the area is selected. The sample size for non-probability sampling techniques depends on the research questions and objective (Saunders, Lewis and Thornhill, 2016).

The important thing is trying to avoid biases by identifying roles and combining different perspectives into the research. Thus, purposeful sampling is implemented in both qualitative types of research. The questionnaire participants were chosen upon their backgrounds and specialisations in different companies. For example, from participants in related workshops, conferences and industry events. In addition, social media platforms (LinkedIn, Twitter and Facebook) were used. Furthermore, from an event held at University College London in London on 13 January 2017 (introduction to integrating 3D GIS with BIM) a hard copy of the questionnaire was distributed.

2- <u>Interview Sampling</u>

The sample of the interview followed the same approach followed for the questionnaire (A non-probabilistic, purposive sampling approach). The interviews have been conducted with specialists in one of BIM, GIS, and railway or all/some of them. For the first round of the interview, the questionnaire respondents were asked whether they were willing to participate in a follow-up interview. The selection of interview participants was based on three factors: the respondent interest to be involved in an interview; their experience in BIM, GIS and railway and the use of them for collaboration. While the others have been chosen from the attendances of webinars, workshops or by a common contact. Fifteen out of fifty people contacted responded (a response rate of 30%). The length of each interview varied and took approximately 1-2 hours. The interview questions were based on the results of the literature review and subsequent questionnaire data. The second round of the interview consisted of 10 out of 15 participants to develop the process model. It was upon the findings from the first round of the interview.

4.9 Techniques of Data Analysis

Statistical analysis more often present, compare, seek to, measure connections and relationships between variables along with making interactions and valid explanations between those variables (Naoum 2007; Fellows and Liu, 2008; Creswell, 2009; Leedy and Ormrod 2010). Statistical techniques are used to investigate or analyse data and therefore it is being chosen depending on the data nature along with its normal allocation. Thus, there are "parametric" and "nonparametric" statistics when classifying inferential statistics (Fellows and Liu 2008) as follows:

4.9.1 Parametric Statistics

There are two main conditions that parametric statistics are based upon. First, the data can be rationalised on a ratio scale and second the data accept normal distribution (for instance, the distribution is linear). These two assumptions based on data that are extracted from the population. "t" test analysis along with the analysis of Variance (ANOVA) and Regression Analysis are examples of parametric statistics. (Leedy and Ormrod, 2010). "t" test is mainly implemented to find whether a considerable difference exists between two means or values while Analysis of Variance (ANOVA) in turn determine for differences between three or more means or values by checking the variance (σ^2) between, within and across groups. Ultimately, Regression Analysis is used for prediction by finding how one or more independent -variables permits the value of the dependent-variable effectively (Naoum, 2007).

Regression Analysis in this research used as an explanatory to determine the relationship between variables and their impacts on collaboration. It shows the understanding of how much the change in the dependent variable will occur when the independent variables are changed. This technique is mainly used to predict the variability of the dependent variable depending on its covariance with all the independent variables (Kothari, 2004).

4.9.2 Non-Parametric Statistics

In contrast to parametric statistics, the two factors that Non-parametric statistics are based upon: first, the data is systematic in nature instead of interval or ratio; second, the data are highly inclined. Chi-square test, Mann-Whitney U test, Kruskal-Wallis Wilcoxon Signed Rank tests are examples of nonparametric statistics (Naoum 2007) and will be investigated below.

- Kruskal-Wallis Test

In this test, two or more groups can be compared when the data are ordinal. Bryman (2012) noted that this test is the non-parametric equivalent of ANOVA. This test was used in this research to compare the data in terms of experiences years in BIM and GIS and their impacts on integrating them.

- Wilcoxon Signed-Rank Test

The Wilcoxon Signed-Rank Test presumes that the samples taken randomly from a population with an equal frequency distribution. Thus, it is a non-parametric equivalent of a 1-sample t-test. In detail, in this test, there is always the same number of data values above and below the median hence there is no normality. During the procedure, a test statistic W_{STAT} being compared to an expected value. W_{STAT} can be obtained statistically by adding the ranked differences of the deviation of each variable from a hypothesised median above the hypothesised value. This test was followed to rank the significance of implementing BIM and GIS in different stages.

4.10 Methods Adopted in this Research

For this study, to achieve the research objectives more effectively, a mixed-method approach was adopted since it is often rare to find individuals who are experts in both BIM and GIS. Furthermore, the research questions require a combination of both qualitative and quantitative methods (mixed method) to ensure the best understanding of the research problems (Table 4-4).

Table 4-4: Summarised the methods adopted according to research aim and objectives

Objectives	Methods	Outcomes
to identify specific requirements for collaborative working in the railway sector review the current practice of BIM and GIS in railway design	Literature review on Collaboration, Railway, BIM, and GIS	An underpinning understanding of Collaboration, Railway, BIM, and GIS were correctly set to identify the research gap.
To examine the use of the state of the art in BIM and GIS to identify the gaps in knowledge for collaborative design	Literature review	To determine the factors that drive collaboration. To determine the awareness of BIM and GIS process and technology benefits
To assess the current status of integrating BIM and GIS in railway projects.	A combination of both qualitative and quantitative methods (mixed method).	• Identified current status of using BIM and GIS in the design stage. • Determine the specific issues in collaboration. • Demonstrated the process of using BIM and GIS in the design stage. • Identified the challenges of using integrating BIM and GIS for collaboration in the design stage. • Revealed suggestions for proper using of integrating IM and GIS to improve collaboration in the design stage in railway projects. • Revealed the potential opportunities that using integrating BIM and GIS may offer to improve collaboration.
To develop a 'BIM-GIS' process model for effective collaboration for the design stage of railway projects	quantitative methods (conducting in-depth interviews)	-Developing a process model to assist and guide participants in effective collaboration. - to identify the process model components. -Integrated Definition (IDEF) technique was used (see section 4.10) to develop a process model for enabled-collaboration using BIM and GIS.
To validate the proposed process through engagement with participants and to develop guidelines for implementation of this process model	Focus group and in-depth interview	Assessed the workability of the process model

4.11 Structured Diagramming Techniques and Justification of using IDEF Technique

The structured diagrams and their uses in four different areas are very important as argued by (Martin and McClure, 1985). First, they pinpoint the necessity of "overviewing systems analysis"; an analysis that takes place after having an overall drawn model of an organisation, a hierarchal decomposition of processes and flowing of modelled data and processes. Second, they arrange a group of programs that show separate modules of the architectural system in a step known as "program architecture". Martin and McClure (1985) go on to offer some insights in logic within the designed program module referring to their third area "program detail". Finally, they clarify "data structure" as the drawn file representations and database models. Upon the above-mentioned descriptions, IDEF0 and IDEF3 models were developed as they belong to "overview system analysis" description and they are the most suitable modelling languages to examine organisational processes.

On the other hand, qualitative and quantities methods have a vital role to play with structure diagramming techniques (Forbus, 1984). Defining approaches to modelling analysis, Pryke (2012) drew three different frameworks which initiate the first definition known as tasks' dependency, an example of which is critical path analysis. CPA employs PERT (Program Evaluation Review Technique) networks dividing the project into a group of needed activities to complete the project. In contrast, Pryke (2012) has advocated the use of SNA (Social Network Analysis) for construction management to raise the issue of formality and informality between stakeholders either of the management or of communications. Despite the fact that SNA highlights the person or the things to be done rather than putting the way of doing things into account.

Many researchers have sought to clarify the benefits and drawbacks of various structured diagramming techniques (Cooper, 2005; Hassan, 1996; Kagioglou, Cooper and Aouad, 1999; Pryke, 2012; Steele, 2000; Walker, 2007). Table 4-5 represents a summary and critique of the reviewed method. The main reason for choosing the IDEF (IDEF0 and IDEF3) methods is their high descriptive power, making them suitable for detailed processes that include the way things should be done. Furthermore, because this research attempt to develop a process model, the IDEF techniques are the best way to serve the research aim (section 4.11).

Table 4-5: Review of structured diagramming techniques (Zanni, 2017)

Technique	***Features***	***Strengths***	***Weakness***
Flowchart	Logical sequencing of actions, decisions, and attached information	Simple, flexible	No sub-layers, no specific method for implementation available.
Gantt chart	Matrix representation of the flow of activities in relation to time	Easy overview, simple	Dependencies not indicated sufficiently, no input/outputs
Petri Nets (PN)	System network, that comprises of transitions, places, tokens, and arcs	Well defined syntax, the flexible, non-deterministic algorithm	Time-consuming to create, no information transfer mechanisms, no hierarchy
Higher-Order Software (HOS) chart	Functional decomposition based on binary tree structures	The mathematically based tool, good for professional systems analyst (data flow modelling)	Complex, not user-friendly, prescriptive
Data Flow Diagram (DFD)	Data flow, that includes activities, information store, and source (or sink)	Top-down analysis, hierarchical, descriptive	No task dependencies, no iterative loops, no mechanisms
Hierarchical Input, Process Output (HIPO)	Set of diagrams that show input boxes, output boxes, and functions	Show the flow of data, more suitable for small-scale systems	Shows "*what*" but not "*how*", difficult to draw
Business Process Modelling Notation (BPMN)	The flow of events, activities, and gateways	Includes pools and lanes for participants, and artefacts (data object, group, annotation)	No hierarchical representation, no clear dependency between process models
Social Network Analysis (SNA)	Social structures modelled as a network utilising graph theory	Links between actors and information exchanges	No hierarchy, no tasks' representation, no activity flow
Program Evaluation and Review Technique (PERT)	Nodes represent events and arrows indicate the sequence of tasks (critical path)	Explicitly defines and makes visible dependencies, parallel or concurrent tasks considered	No resources, no completion time, no decision-making points, sequential without iterations
Entity Relationship Diagram (ERD)	Description of objects as entities within a system and their relationships	Internal consistency, easy to create software, identify objects	Complex model, no process or information flow, static
Role interaction diagram (OMG UML)	Flows of activities and roles' interactions, sequential system behaviour	Intuitive to understand, clear notation principles	Not comprehensive, no inputs/outputs
IDEF0	The flow of activities, inputs, outputs, controls, and mechanisms – Structured Analysis and Design Technique (SADT)	Clear representation, a good amount of information, permits iterative loops	Sequential waterfall diagrams, not a clear distinction between roles and tools, no parallel activities
IDEF3	The flow of activities, objects, and decisions (process flow view and object state transition view)	Dynamic and comprehensive, flexible allows parallel activities and iterations include multiple decision scenarios	Many sub-diagrams, a lot of data needed to be constructed, time-consuming and complex to create

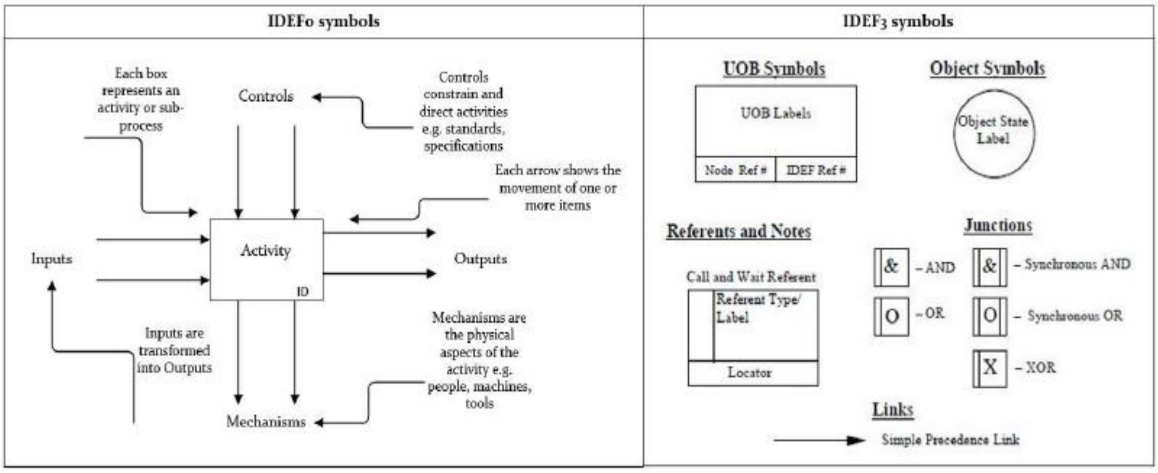
4.12 Integrated DEFinition (IDEF) Methods (IDEF0 and IDEF3)

IDEF0 produces a "function model", a structured representation of the functions, activities, or the modelled system's and the subject area's processes (Lee and Barrett, 2003; National Institute of Standards and Technology, 1993). For this research, part of the IDEF's definition is how it has been approved to form the collaboration workflows' structure and sequencing. Because of its clarity of modelling activities and information flows, IDEF0 is a good tool for use in research.

There is a difference between IDEF0 and IDEF3, as the later improve the former's drawbacks. As it is commonly known, IDEF0 is unable either to promote the information process flows or to seize the concurrent processes (Mayer and DeWITTE, 1999). It has not also considered time while processing. On the other hand, IDEF3 succeeded in dealing with IDEF0's problem via having descriptions about the activities' sequencing, determining critical decision points or milestones of the process differently (Mayer et al., 1995). IDEF3 has been improved, especially to model situation or process as a kind of organizing and ordering sequence of events and activities (Mayer, Painter and DeWitte, 1992). The main purpose of IDEF3 of conveying the domain expert's knowledge about the method of a particular system or organisations working is to afford a structured method. Putting into account these reasons, IDEF3 Process Description Capture Method succeeds to keep its simplicity as well as its high descriptive power (Dorador and Young, 2000).

Table 4-6 exposes the used symbols to reveal the process description schematics. The boxes reflect the process as they took place in real life, referring to them as UOB or (Units of Behaviour) (KBSI, 1993). These boxes are connected to each other by arrows pointing to priority among actions. Constraints are shown through junctions that facilitate the process branching. Junctions, also, have another role to play, which is providing choices among various parallel and alternative sub-processes. Synchrony, asynchrony start, and the end of the process are logical decisions that referred to the use of AND (&), OR (O) and EXCLUSIVE-OR (X) respectively. Circles are the symbols of objects; where they show the different status, connected by arrows; i.e, whose entry, transition, state, and exit conditions are displayed by UOB's referents (Mayer et al., 1995)

Table 4-6: Symbols used for process description schematics (Knowledge Based Systems Inc. (KBSI), 1993; Mayer et al., 1995)



4.13 Research Design and Techniques

At first, the current section presents consecutive description concerning the decisions happening during the process of research and describes in-depth the nature of the data generation process and the procedures of analysis. It should be noted that a mixed approach has been adopted based on semi-structured interviews and a well-organized questionnaire (King, 1994). To identify the collaborative environment's elements and develop the process model adopted in Chapter 6, content analysis (Elo and Kyngäs, 2008) was effectively used. Besides, to map the component related interdependencies based on the findings resulting from the experts' interview results, the modelling techniques (IDEF0 and IDEF3) have been used (see Chapter 6). A combination of quantitative and qualitative methods was applied to analyse the data (Schutt, 2018).

The *"iterative theory-building process"* (Drongelen, 2001) was separated as shown in Figure 4-5 into three main distinct stages. The main stages are exploratory (Stage 1), data collection and analysis (Stage 2), and validation (Stage 3). These stages classified into five phases. Phase 1 in stage 1, phase 2 to phase 4 in stage 2, and phase 5 in stage 3.

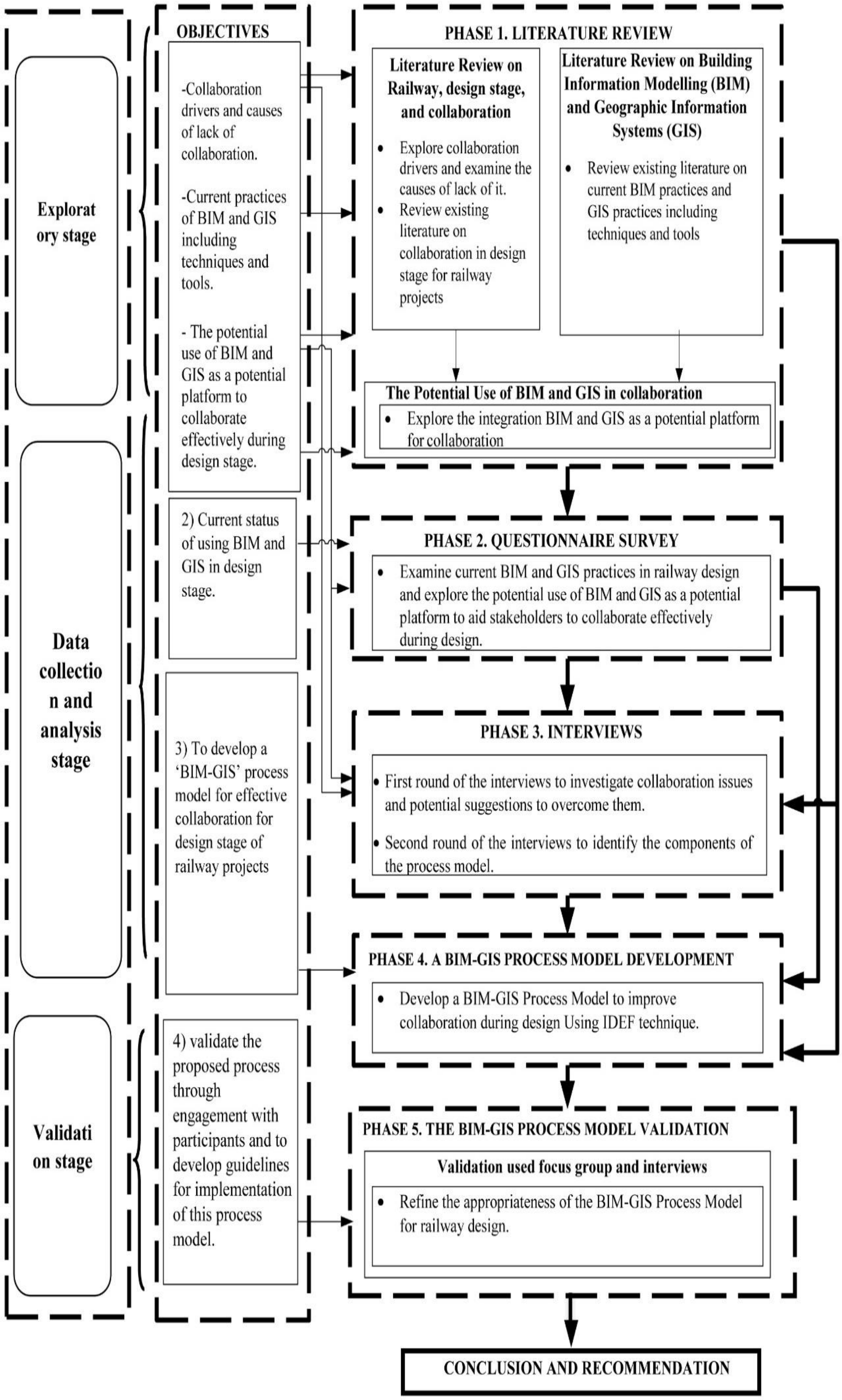


Figure 4-5: Overview of the research design

The following sub-Sections presents the description of collecting, analysing, and interpreting data through the whole research process.

Stage 1: Exploratory Stage

The first stage of the research was exploratory, which consists of a literature review, conducted to create a background of collaboration, BIM and GIS and to investigate the current practice of integrating BIM with GIS processes. The main outcome of this stage was revealing the BIM-GIS's feasibility that helps in enabling cooperation and explaining the insight of the researcher concerning the whole areas of the problem (Saunders, Lewis and Thornhill, 2009). Consequently, the study's first step lies in conducting the primary research as it is deemed a vital step in designing an operative procedure of data collection, for it assists on identifying limitations before beginning the key body of the data collection procedure (Axinn and Pearce, 2006). Besides, the methods applied in this phase contained a wide-ranging literature review study in order to gain a sound insight and understanding of the research problem. This positively led to getting a sound appreciation of the problem, recognise research gaps and create its required main questions.

Phase 1: Literature Review and Content Analysis

The current research process's first step was an inductive one. Chapters 2 and 3 consisted of the related literature review that enabled the researcher to attain a sound, deeper and more detailed insight concerning the concept and term of collaboration, it's managing plus the state and form of the art methods for its application using new emergent technologies, namely: BIM and GIS. Additionally, it does assist in developing an initial theoretical framework later amended and adopted based on the research findings (Andrade, 2009; Jabareen, 2009). In order to address both high-level aspects and low-level aspects of the design process (Zerjav, Hartmann and Achammer, 2013), a high level IDEF0 process model, and its decomposition was developed based on the developed Collaborative Plan of Work (CPW) from the findings based on a combination between RIBA Plan of Work 2013 and GRIP Stage.

As a fact, the inductive content analysis was strongly adopted in the process of defining and quantifying a certain phenomenon in order to attain the primary model of the research process for the constituents of the railway design process (Elo and Kyngäs, 2008). This is deemed to be completely suitable for unstructured data such as the findings resulting from a literature review (Krippendorff, 2012). Also, it is supposed that when the related data are categorized into the same groups, phrases and words will share mainly the same meanings (Cavanagh, 1997). This feature is adequate to create a fully systematic process for BIM and GIS to enable collaboration. The inductive content analysis comprises several steps such as open coding, abstracting and creating categories (Elo and Kyngäs, 2008). As for open coding, it means that the required headings and notes are mainly written in the text while reading it. Having this open coding achieved, the categorise lists are collected under headings that are categorised under the term “belonging” (Burnard, 1991; Elo and Kyngäs, 2008). Thus, the process of creating the research topic’s general description is fully accomplished through abstraction (Burnard, 1991; Robson, 2002). As a result, it is clearly seen that the content characteristic words are effectively used name each category. Subcategories with parallel events and incidents are gathered together as categories, and then, these categories are gathered as main categories (Elo and Kyngäs, 2008; Robson, 2002).

Stage 2: Data Collection

This stage divided into three phases in order to achieve the research objectives. These phases sequentially start with a quantitative method, namely a questionnaire (online survey). Followed by a qualitative method which consists of two rounds of in-depth interviews with experts. The final phase in this stage is called a BIM-GIS process model development.

Phase 2: The Questionnaire

In the next step, a quantitative method is used which consists of a questionnaire (online survey) and a hard copy of it. The questionnaire is designed by utilising BOS (Bristol Online Survey) (section 4.6.1/1). The questionnaire divided into five main sections following the funnel approach (Oppenheim, 2000). In approach, the questionnaire starts with very broad questions and narrow down to the scope of the questions reaching the end when a focus on very specific points. At this phase, close end and some open-end questions were implemented where in order to maintain the spontaneity and expressiveness they were not followed by any type of choice (Oppenheim, 2000). The questionnaire instruments can be found in Appendix B.

A pilot study was conducted after designing the questionnaire to validate the questions and make sure that the questions are understandable, and the time is taken to answer them (details in sections 4.6.1). Following the comments and recommendations, the survey was got from the pilot survey and sent to experts with more than 500 questionnaires sent to them through a link created by BOS using emails. A total of 114 responses out of 500 were received with a 22% response rate, which is considered good, particularly with the lack of experts in both BIM and GIS at the same time. In addition, experts who have experience in these fields are very busy and the time for them is very important and costly. Thus, obtaining a reply from them was challenging.

The purpose of the questionnaire was to assess the current status of using BIM and GIS in railway projects. Furthermore, the questionnaire investigated the areas where both BIM and GIS are used together with the main challenges that faced the respondents to get the most benefits out of BIM and GIS. Therefore, an idea has been created about BIM and GIS in terms of usage, benefits, software used, challenges and recommendations to tackle these challenges.

Phase 3: Interviews

Phase 3.1: First Round of the Interviews

The first round (15 interviews) an inductive way, that were designed to identify the collaboration issues that faced the participants during the design stage of railway projects. In addition, to investigate the BIM and GIS role to assist design participants to overcome these issues. The interviews were conducted with experts in BIM, GIS and Railway. The sample of the interview followed the same approach followed for the questionnaire (A non-probabilistic, purposive sampling approach) (section 4.7.2/2). Some of the questionnaire participants took part in the follow-up interview, while the others have been chosen from the attendances of webinars, workshops or by a common contact. Fifteen out of 50 people contacted responded in addition to five people, but they were with no experience of BIM or GIS so they uncountable (a response rate of 30) (section 4.7.2/2).

Most of the interviews were conducted through Skype conference (twelves interviews), and in-person (three interviews). The interviews were recorded, after participant's permission is taken, read and agree with the informed consent form, utilising Olympic Recorder device and iPhone smartphone recorder (face-to-face interview). After that, the interviews were transcribed using Microsoft Media Player (audio), and Microsoft Word (text). These methods were the most efficient as it is saving time and cost. The interviewees' details are presented in Table 4-7. The researcher; after the end of each interview and based on the provided answers; engaged in an unstructured dialogue. This dialogue presented the opportunity to consider new emerging themes that need to be included in the next steps.

Appendix (C) shows the interview instrument in the first round, which consisting of three sections. The first section focuses on collaboration issues that may be faced by designers in the design stage. The second sections focused on the views of the participants on the potential of BIM and GIS to effectively deal with these issues and suggestions to overcome them. Finally, the last section collects background information regarding the participants and their companies.

Thematic and content analysis (Elo and Kyngäs, 2008) was performed to analyse the interview data, which thematic analysis is looking through the data to identify common issues and summarise all the views under the main themes (Aronson, 1995; Braun and Clarke, 2006). Below the description of the key stages in the thematic analysis (Aronson, 1995; Bendassolli, 2013; Braun and Clarke, 2006):

- Text transcribing and annotating. Through transcribing and reading, initial ideas arise, and initial observations are illustrated.

- Creating a coding scheme constructed on the previous stages' preliminary observations. The data's same line(s) may be coded in numerous different methods, starting from very initial codes to categories that echo more broader analytic themes.

- Exploring new themes to make them as abstract as possible. Transcript excerpts are mainly used as examples during the process of analysis.

- Reviewing and refining related and explored themes.

- The repeated process of collecting, coding and analysing the searched information is still continued throughout the second sets of data collection.

Table 4-7: Interviews details

Interview code (1st round)	Interview code (2nd round)	Years of experience	Position	1st round of interview	2nd round of interview
I-1	__	11	Head of BIM at a constructor	*	
I-2	__	5	Civil Engineer working for a small consultant	*	
I-3	__	+15	Manager at a General contractor	*	
I-4	II-1	+5	BIM Consultant a Railway company	*	*
I-5	II-2	+30	Head of BIM at railway company	*	*
I-6	II-3	15	BIM and GIS Manager at railway company	*	*
I-7	II-4	6	BIM Director/ Head of GIS at railway company	*	*
I-8	__	20	Engineering Information Manager at railway company	*	
I-9	__	18	Engineer at a general contractor	*	
I-10	II-5	7	BIM Engineer at railway company	*	*
I-11	II-6	4	Architect at Architecture and Construction Management	*	*
I-12	II-7	8	Senior Quality Control Engineer at a construction company	*	*
I-13	II-8	23	Assistant Professor of Railway Engineering	*	*
I-14	II-9	12	BIM specialist, senior civil /highway/infrastructure design engineer, Autodesk Certified Instructor	*	*
I-15	II-10	+12	Creative Director/Project Manager	*	*

Phase 3.2: Second Round of the Interviews

The second round of interviews was inductive, conducting semi-structured in-depth interviews with 10 out of 15 the interviewees who participated in the first round of the interviewees

The same process and analysis are followed in the second round of the interviews as the first round which all the interviews performed utilising Skype, and Olympic device recorder is used to record the interviews after taking the interviewee's permission.

For both rounds of the interviews, when the main open-ended questions were asked to follow a semi-structured approach, opportunities for the in-depth discussion is provided. Cues and prompts are provided by the interviewer in case insufficient responses was provided to clarify their (interviewees) answers. Next, the related questions are deeply examined to avoid the following areas (Knox and Burkard, 2009; Rowley, 2012): (i) the leading process of the unclear expectations and suppositions; (ii) merge two questions into one; (iii) utilise the method of answers "yes/no"; (vi) being too ambiguous or too general; and (v) being in any uneasy and invasive sense. Additionally, the process of forming the required questions was gradually done during analysing one interview after the other, leading to the fact that ineffective questions were dropped, while new ones were strongly picked and selected due to certain new themes (Dicicco-bloom and Crabtree, 2006). More importantly, the process of unplanned follow-up questions was also applied, relying on the interviewee's answer, to attain the participant's adequate responses (Turner, 2010).

Also, there was a protocol highly required to conduct the interviews that involved the following components (McNamara, 2009; Turner, 2010): (i) selection of zero-distraction environment; (ii) the explanation of the objective of the interview; (iii) the addressing of both privacy and anonymity; (iv) making sure if the interviewees have questions regarding any issue (pre and post the interview); (v) getting the permission of recording the interview and once attained (the recording is done via (iPhone smartphone); (vi) keeping the notes while the participants answering the questions because these notes will enhance the next questions; (vii) frequent verifying the recorder for getting high performance and function (viii) so as to ensure sympathy and understanding, the researcher reaffirmed the most substantial ideas made by the interviewees, and other nods such as *"uh huhs"* that stimulated the responses; (ix) acknowledging the efforts of the participants at the end and asking them whether desiring to know more concerning the results of the research outcome if willing to answer more new questions in the future interviews; and (x) lastly, inviting the participants of nominating other colleagues or helpers to enable the researcher achieve the criteria of the research (snowball sampling method) (Baker and Edwards, 2012; Ritchie et al., 2013).

Phase 4: BIM-GIS Process Model Development

In this phase, the process model was developed upon the outcome of the analysis, the second round of the interviews in addition to the literature to obtain reliable results. The developed process model presented using IDEF technique.

Stage 3: Validation Using Focus Group and Interviews

The validation process consists of focus group and qualitative methods were conducted with experts in a railway company to assess and validate the underlying process model (chapter 8). The basis of chosen the focus group was the experts in BIM and GIS for railway were very rare (as found it from the questionnaire) and the experts in a big company of railway agree to participate. This made the purpose of validation achieved as this company already followed a CDE and in this way significant feedback obtained, and any possible mistake is avoided. The focus group is a data collection technique, it is defined as "group comprised of individuals with certain characteristics who focus discussions on a given issue or topic" (Anderson, 1999 cited from Fellows and Liu, 2015, p.241) According to (Denscombe, 2007, p.115), "focus group consists of a small group of people, usually between six and nine in number, who are brought together by a trained moderator (the researcher) to explore attitudes and perceptions, feelings and ideas about a topic".

Industrial user-friendly consists of commercial Common Data Environment called Viewpoint (formerly 4Projects) to convert the IDEF process model to workflows in the Viewpoint which was used as a platform to implement the process model (detailed in chapter 8). An Olympic device recorder is utilising to record the conservation and discussion.

4.14 Summary

In this chapter, the adopted methodology for this PhD research project has been discussed. It has reviewed the explanation of methodology following research onion in terms of theoretical concepts, the design of the research, methods and strategies including case studies. Furthermore, presented the implemented methods and techniques, for data collection, have included a questionnaire, semi-structured (mixed methods). Structured diagramming techniques (IDEF0 and IDEF3) have been utilised to map the collaborative process. After that based on the chosen methodology, data will be collected and analysed have been demonstrated, split into three main stages and five minor phases. The explicit has been made for the sequential and simultaneous processes of data collection and analysis.

The following Chapters (5-7) will present the analyses of the research findings, which fulfil the aim and objectives of this research (presented in Chapter 1), by applying the methodological approach discussed in this Chapter. Table 4-8 reveals a summary of the research design of this research.

Table 4-8: Summary of research design

Philosophy	The interpretivist approach combined with positivist
Research approach	Inductive and deductive
Research strategy	survey (questionnaire) approach
Data collection methods	Questionnaire and two rounds of Semi-structured interviews
Data analysis methods	Content analysis, thematic analysis Iterative theory-building process comprised of three phases (exploratory, main, and validation stage).

Chapter 5 : Discussion of the Results and Data Analysis

5.1 Introduction

This chapter presents the analysing process of the data collected in this research (presenting in chapter 4). First, start with the analysis of the questionnaire, then the summary of the key findings from it. Furthermore, this chapter presents the analysis of the first round of the interview to identify the collaboration issues and suggestions to overcome them. Finally, key findings from the interviews have been summarised which led to the next round of the interviews discussed in the next chapter (chapter 6).

5.2 Questionnaire Analysis

To analyse the questionnaire results, a descriptive analysis was conducted. Tests such as Wilcoxon Signed Ranks and Kruskal-Wallis Test were performed using SPSS software. The aim of using these tests was to determine the statistical significance of implementing BIM and GIS in different stages of railway projects. Another reason for using these tests was to test the significance of the variables on each other (section 5.1.4). This would achieve the third objective: to assess the current practice of using BIM and GIS in railway projects, as demonstrated in the next sections. As illustrated in section 4.6.1, the total number obtained from the distributed survey was 114 out of 500 respondents from both the online survey and the hard copy.

According to the aim of the questionnaire which to describe satiation, SPSS was the most proper software can be used to apply descriptive statistics and hypothesis testing to the questionnaire data. Furthermore, SPSS is friendly, easy to use and code-based which there is no need for programming such as MATLAB.

Most questions used the Likert scale, acknowledging the arguments for and against their Likert scales and how to analyse their Likert data (Carifio and Perla, 2008). The application of parametric statistical methods to Likert data has been defended by researchers (Norman, 2010). For the questionnaire used here, the 5-point scale was adopted; studies (Dawes, 2008) have shown that the differences in data characteristics are not significant between 5-, 7- and 10-point Likert scales.

The questionnaire consists of five sections, as shown in Appendix B. These sections range from general to specific questions, of open-ended questions that allow the respondents to create a full picture. The last section was about personal information to enable the researcher to contact the respondents if any further information was needed. The information was also useful for the researcher to send the respondents the outcome of the research. The next sections illustrate the questionnaire analysis in detail.

5.2.1 General Information

This first section includes general information about the respondents. This information provided a basis for the perceptions reported later in the questionnaire. This section consists of six questions about the participants in terms of role, years of experience, type of sector they work in it, the size of their company, procurement method they used, and place of work.

Regarding the role or professions, Figure 5-1 reveals that more than 51% of the respondent’s experience range between 1 and 5; followed by 14% with experience of 6 to 10 years. Around 6% of the respondents with more than 15 years of experiences. The profession in the “*Other”* category has the highest ratio of 29%. This is because BIM and GIS have plenty of uses, which BIM is likely to be started recently to be implemented in projects, even though it has existed since the 1970s (Smith, 2014). This results in different roles using them. The professions that had been chosen by respondents in “Other” consists of the Consultant in BIM or GIS; BIM Specialist; GIS Specialist; BIM Manager; GIS Manager; Information Manager; and BIM and GIS experts and Academic. The second-highest percentage of the responses came to be professions working in civil engineering and architecture: 22% (25), and 19% (21), respectively. The Quantity Surveyor category had the lowest percentage: 1.8%, but with 2-5 experience.

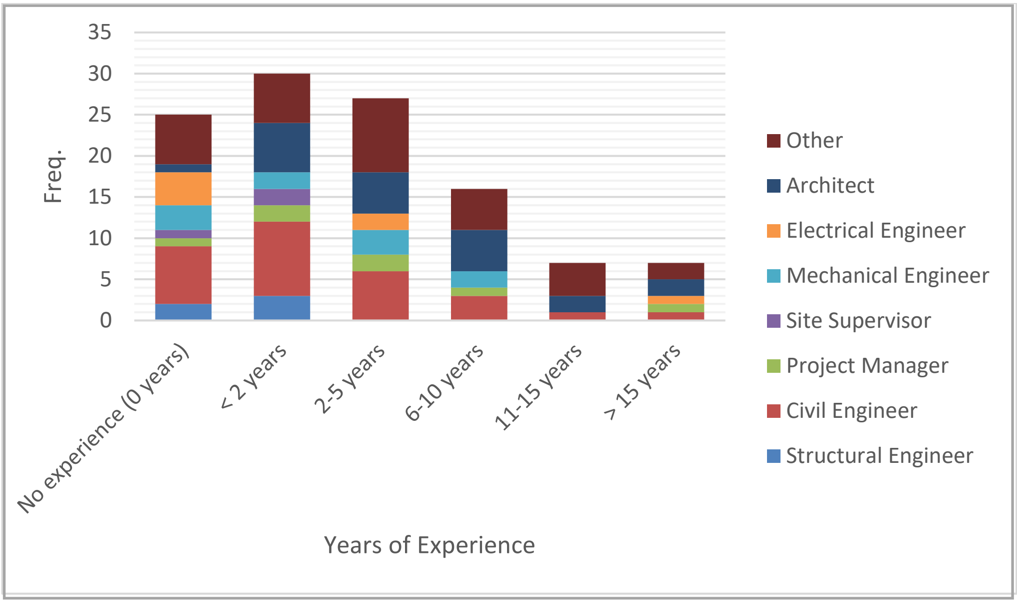


Figure 5-1: Profession for different BIM experience

It is illustrated in Figure 5-2 that there is an obvious difference in years of experience with BIM and GIS. Respondents have more experience in BIM than they do with GIS. This is despite the fact that BIM is more recent than GIS. The reason behind this scenario may be that BIM became mandatory in several countries (Bradley et al., 2016). The researcher believes that BIM demonstrates the importance of GIS by bringing GIS opportunities and using them in BIM and conversely. In other words, integrating BIM with GIS. There are almost 38% of participants with no experience in GIS and this is less by about 16% when compared to participants with no experience in BIM. There are just 8% with more than 15 years of experience in GIS the rest (more than 50%) with experience ranging between less than 2 to 10 years' experience.

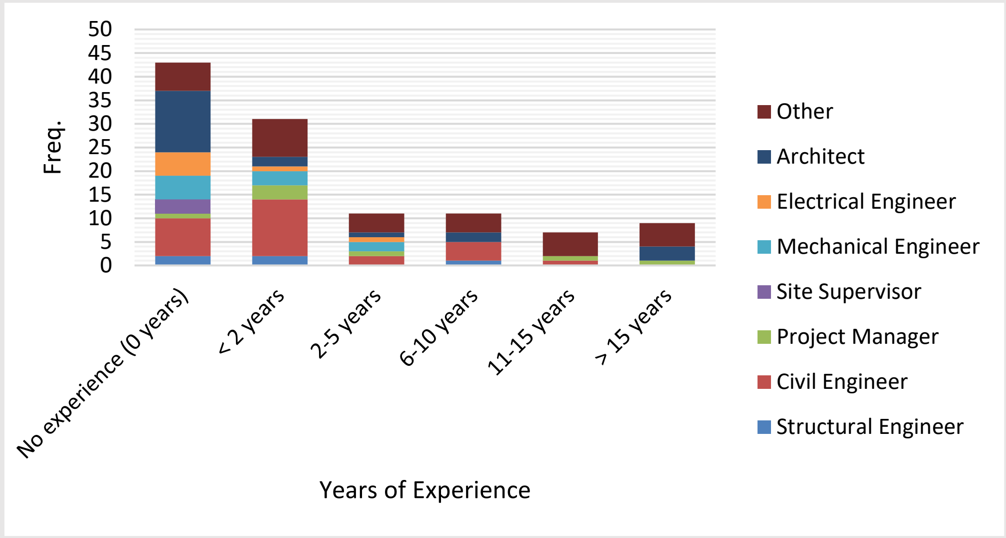


Figure 5-2: Profession for different GIS experience

Figure 5-3 demonstrates that most respondents are from different profession and they are working in a large company with 250 or more employees and nearly half of them belong to the public sector. Whilst, most private sectors are medium and small companies and just 6 of the respondents are not working. Furthermore, both private and public sector used various methods of procurement. The most common procurement methods used by the respondents were the traditional method and Design-Build (Figure 5-4). This could be because implementing new ways using BIM and GIS is challenging due to lack of proper training, lack of awareness regarding BIM and GIS and lack of encouraging stakeholders to change their own ways. Therefore, to facilitate adopting new technologies, a process to guide the stakeholders may make the process of change easier.

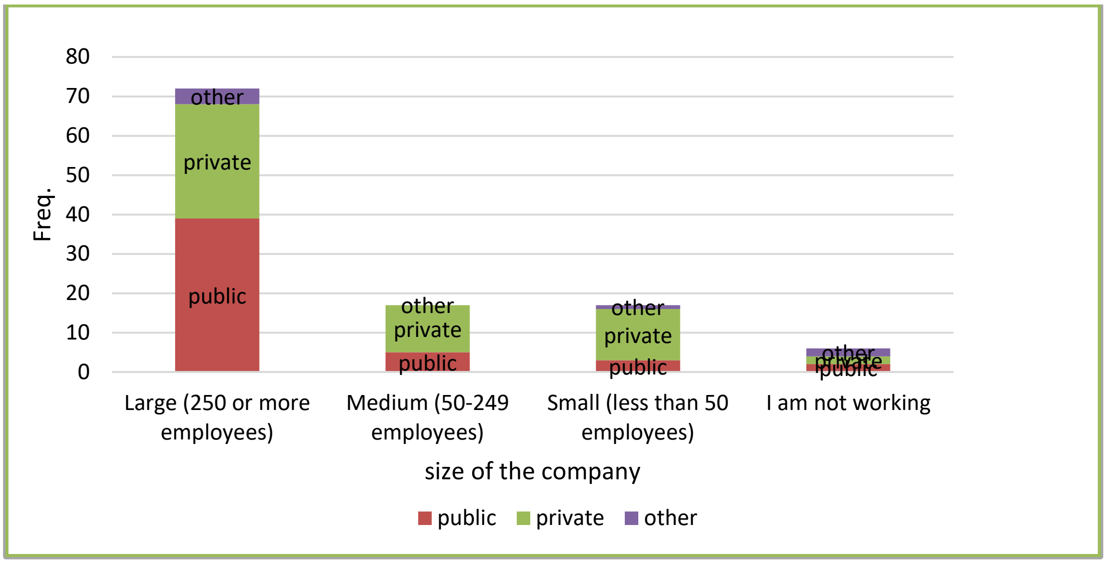


Figure 5-3: Size of Respondents Company for a different sector of their work

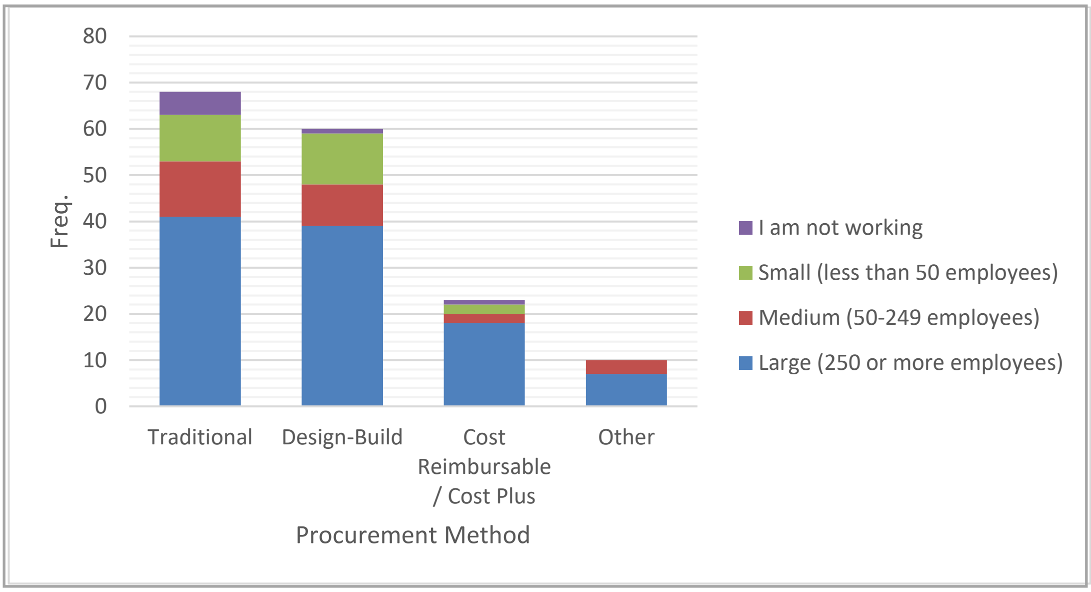


Figure 5-4: Sector of work for different procurement methods used

From this section, the results can be summarised that BIM and GIS experts, Civil Engineer and Architect are the professions most involved in this survey using BIM and GIS. In addition, the respondents have experience in BIM more than GIS. Furthermore, more than half of the respondents are working in the public sector using traditional and design-build as procurement methods more than in medium and small companies.

5.2.2 Applications of BIM and GIS in Projects in General

The purpose of this section is to demonstrate the people acceptance and awareness regarding BIM and GIS. Accepting of new technologies facilitates the process of change toward new ways and technologies and using them properly.

5.2.2.1 BIM and GIS Training

As it was mentioned before in section 5.1.1, the respondents have experience in BIM more than GIS. It is also interesting to note that those who have experience in both BIM and GIS are self-taught, even in the public sector, as shown in Figure 5-5 and Figure 5-6 respectively. They demonstrate that there is a lack of training provided by the companies which cause inappropriate implementing of BIM and GIS. As a result, this reduces the capability of these two technologies and a lack of fully benefiting from them.

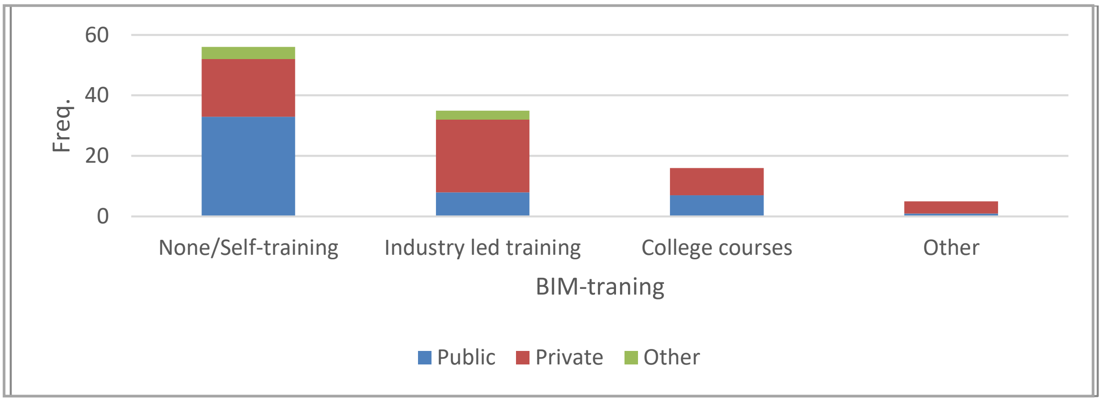


Figure 5-5: Sector of work for different BIM training

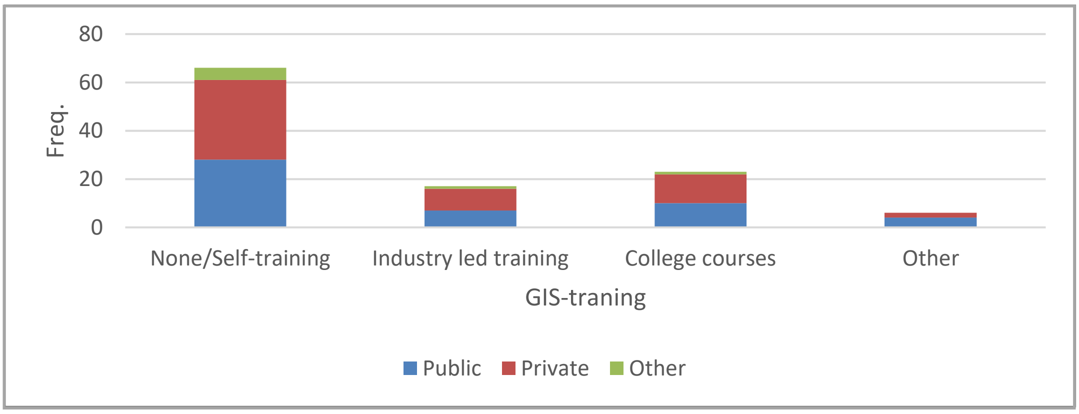


Figure 5-6: Sector of work for different GIS training

5.2.2.2 Satisfaction of the Respondents

The responses showed satisfaction with collaboration among the project teams. Although the percentage of the respondents' answers either satisfied or neutral is the same, overall, the satisfied respondents are the most because neutral responses not accounted as the respondents are neither satisfied nor dissatisfied. Therefore, the number of respondents satisfied will be higher than dissatisfied (Figure 5-7). This gives a good indication that people are willing to collaborate and are aware of the collaboration benefits that can be offered.

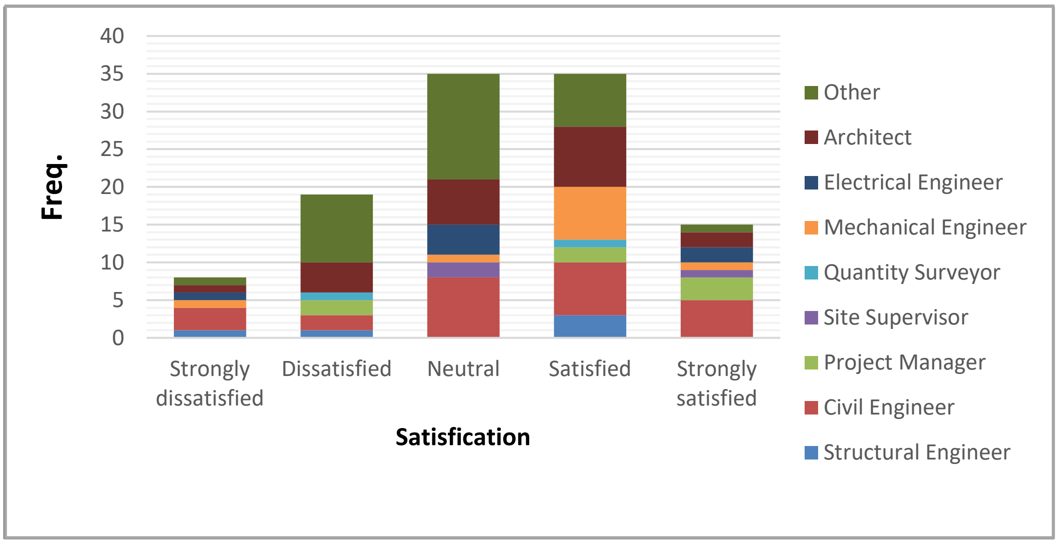


Figure 5-7: Satisfaction for different professions

In general, as revealed in Figure 5-8, the responses showed their agreement with all statements, while the most statement that gets the highest average score was (1.35) was implemented BIM and GIS properly results in better impacts in terms of time, cost, quality and environmental impacts. This is a good sign to the idea of developing a guideline will reduce the challenging to change. Especially, the findings reveal the average score of the statement "implementing BIM and GIS make work easier" was (1.25) for BIM and GIS (1.07) respectively.

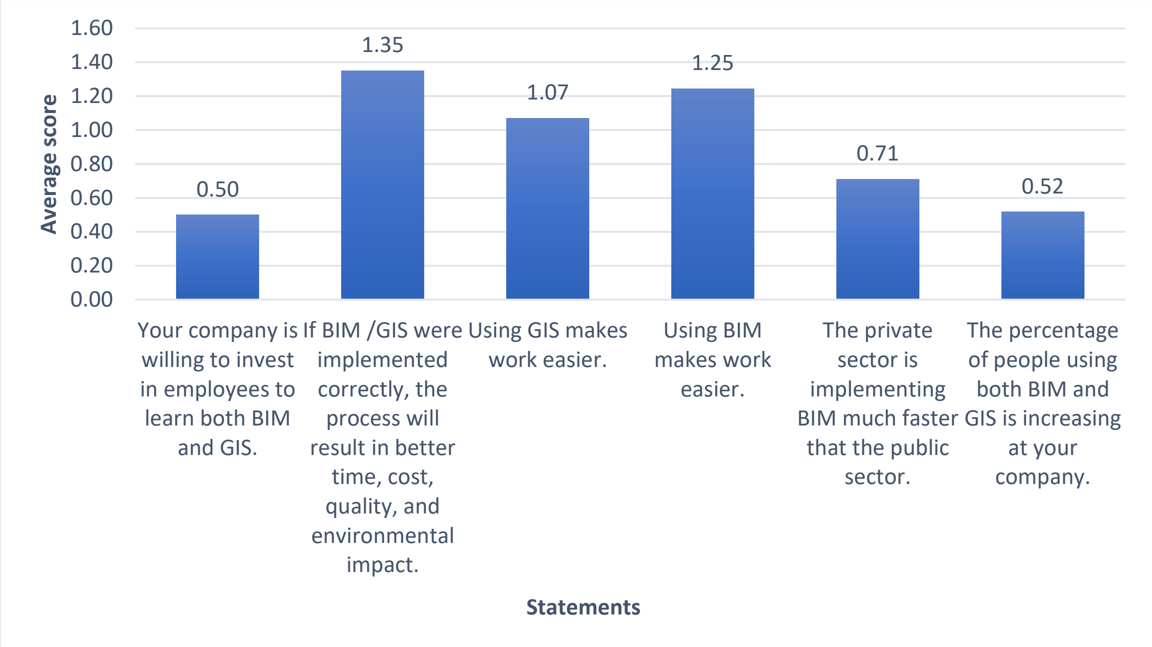


Figure 5-8: Respondents agreement regarding BIM and GIS statements

5.2.3 Applications of BIM and GIS in Railway Projects

This section aims to provide a review of the BIM and GIS current status and their practices in railway specifically. For example, to identify the experience of BIM and GIS in railway specifically. This questionnaire is an investigation to assess the participants experience in BIM and GIS in general in order to identify the issues that reduce the use of BIM and GIS in the railway projects. Furthermore, identify the benefits and challenges of applying BIM and GIS in railway projects, how important using them is, and the types of software used for BIM and GIS. Accordingly, a clearly built vision of the BIM and GIS in railway projects.

It is critical to know the respondents' experience in railway have no effect on the results of responses that make them more accurate in terms of the relevant questions to BIM and GIS in railway as shown in section 5.1.4. Figure 5-9 shows that the ratio of experienced respondents with no experience is higher compared with those participants of experience. That is probably due to the fewer number of railway projects than building projects, which consequently infers that the number of people participating in rail project works will be less than those engaged in building. Additionally, the years of experience varied from less than 2 years to more than 15 years. However, regarding the respondents' experience in GIS, they reached nearly 67 persons with no experience. This is quite surprising since GIS is very critical for the railway (El-bakry and Awad, 2010). For example, to identify the optimum station or determine the shortest distance between the given two stations (El-bakry and Awad, 2010).

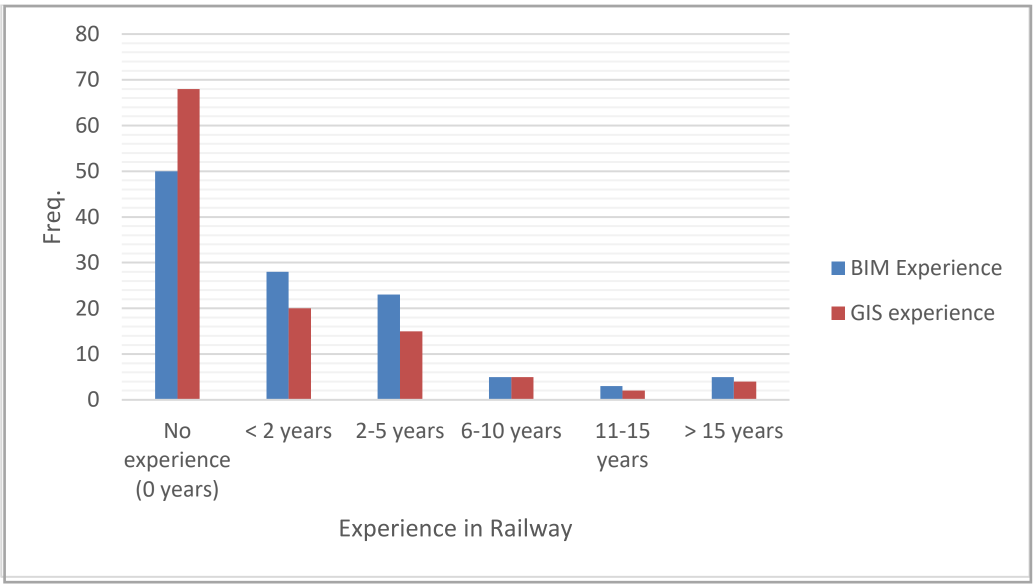


Figure 5-9: Experience in BIM and GIS in Railway

Findings indicate that the experience in both BIM and GIS is very low in railway projects, even with the significance of these two technologies being applied in railway projects as mentioned in section 5.1.2.2 that these technologies make work notably easier if appropriately implemented. Therefore, attention and more investigations are needed to illustrate the reasons and challenges of lack of experience of BIM and GIS and how to overcome it. Furthermore, it will be crucial to demonstrate the benefits and challenges of these technologies to create a related overview.

The significant issues need to be addressed is the proper use of each BIM and GIS in the proper position in order to achieve the maximum exploitation of the BIM and GIS abilities and the opportunities that they have to offer. By referring to the results shown in this survey that implementing BIM and GIS correctly had led to a better impact in terms of time, cost, quality and environment. Figure 5-10 and Figure 5-11 indicate that BIM is extremely beneficial for design and construction more than other stages, in contrast to GIS which responses reveal that it is extremely beneficial for planning and pre-respondents' experience with BIM in railway is less and about 49 respondents reported no experience with it. Yet, this percentage is larger when it is planning while less benefit from design (Table 5-1 descriptive analysis using SPSS). Nevertheless, overall, the highest portion of the respondents tends to agree that BIM and GIS are beneficial for design, planning and construction. This goes incompatibility with the companies that applying BIM and GIS, which Figure 5-12 and Figure 5-13 show BIM being used for design stage the most indifferent size of the companies. Whilst, these companies using GIS for the plan, operational and maintenance stage the most, followed by design as Figure 5-13 and Table 5-2 demonstrated.

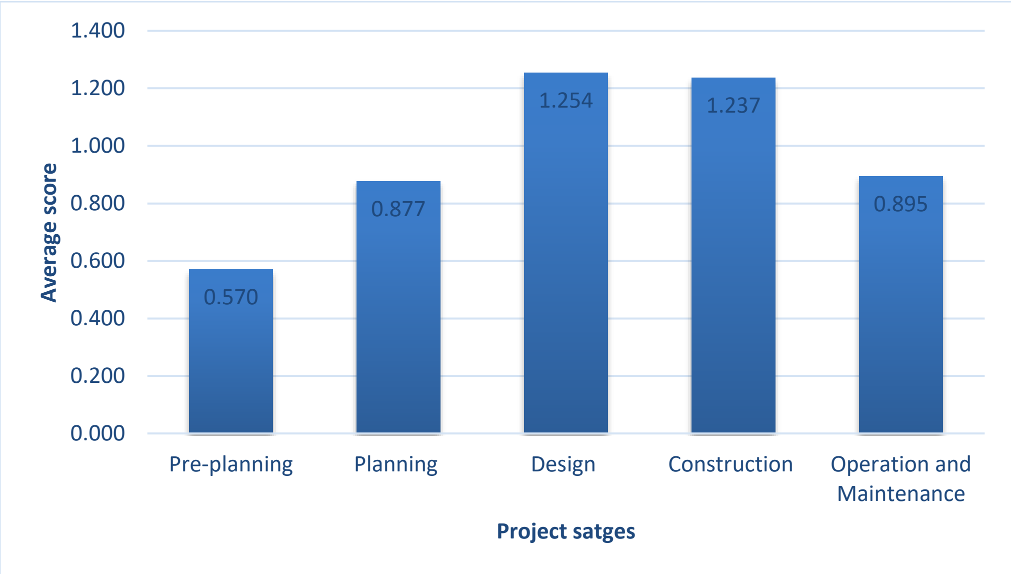


Figure 5-10: Benefits of BIM in most important railway stages

Table 5-1: Extent to which BIM is beneficial at various project stages

	Mean	Std. Deviation	**Beneficial degree BIM**	significantly rank
Pre- planning - BIM	3.6	1.373	**71.6%**	5
Planning - BIM	3.9	1.226	**77.9%**	4
Design- BIM	4.3	1.084	**85.5%**	1
Construction - BIM	4.3	1.129	**85.2%**	2
Operation and Maintenance - BIM	3.9	1.234	**78.2%**	3
Q3.5 BIM TOTAL	4.0	1.015	**79.7%**	

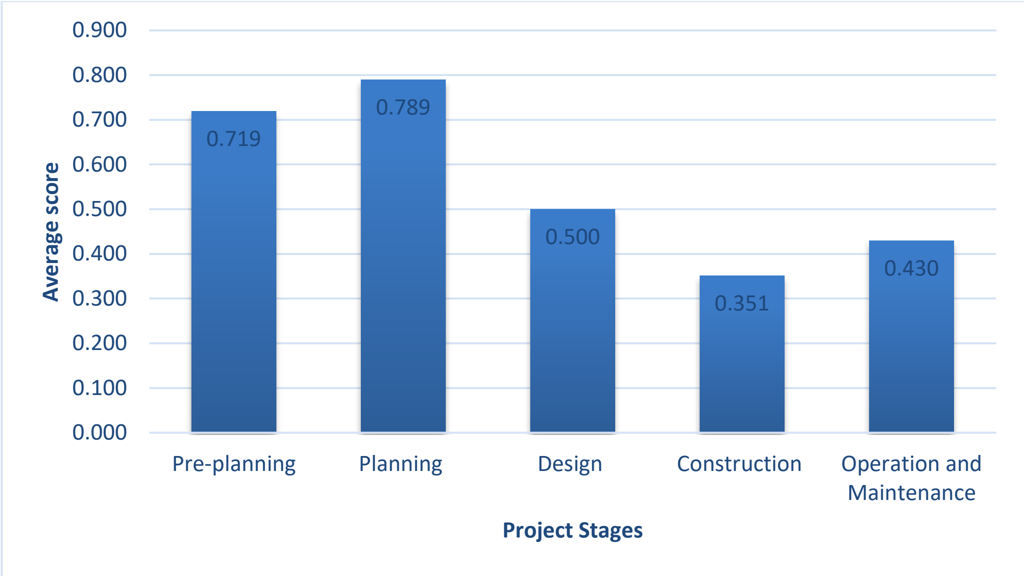


Figure 5-11: Benefits of GIS in most important railway stages

Table 5-2: Extent to which GIS is beneficial at various project stages

	Mean	Std. Deviation	**Beneficial degree GIS**	significantly rank
Pre- planning GIS	**3.7**	1.335	**74.6%**	2
Planning - GIS	**3.8**	1.307	**76.1%**	1
Design - GIS	**3.5**	1.301	**70.2%**	3
Construction- GIS	**3.4**	1.400	**67.1%**	5
Operation and Maintenance - GIS	**3.4**	1.432	**68.8%**	4
Q3.5 GIS TOTAL	**3.6**	1.128	**71.4%**	

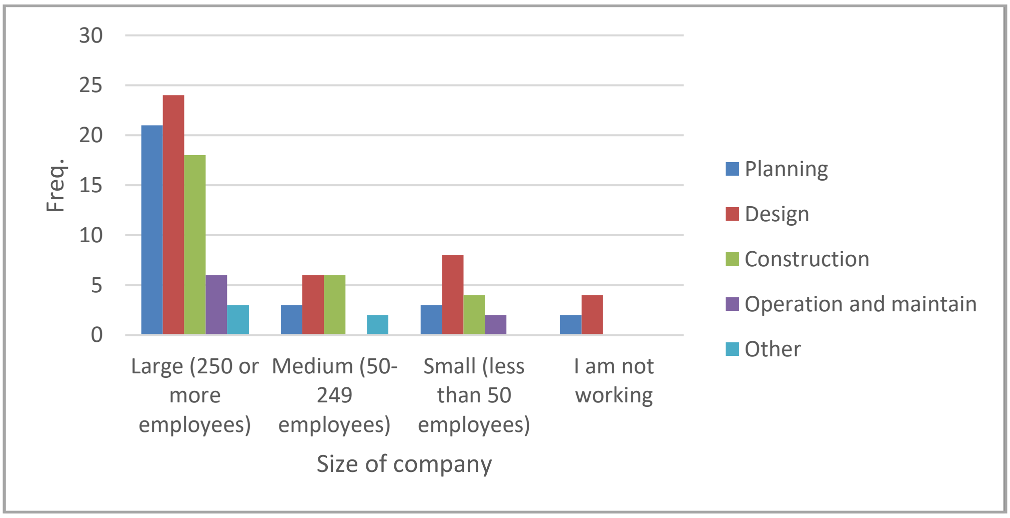


Figure 5-12: Size of the company for the most stage where BIM is used

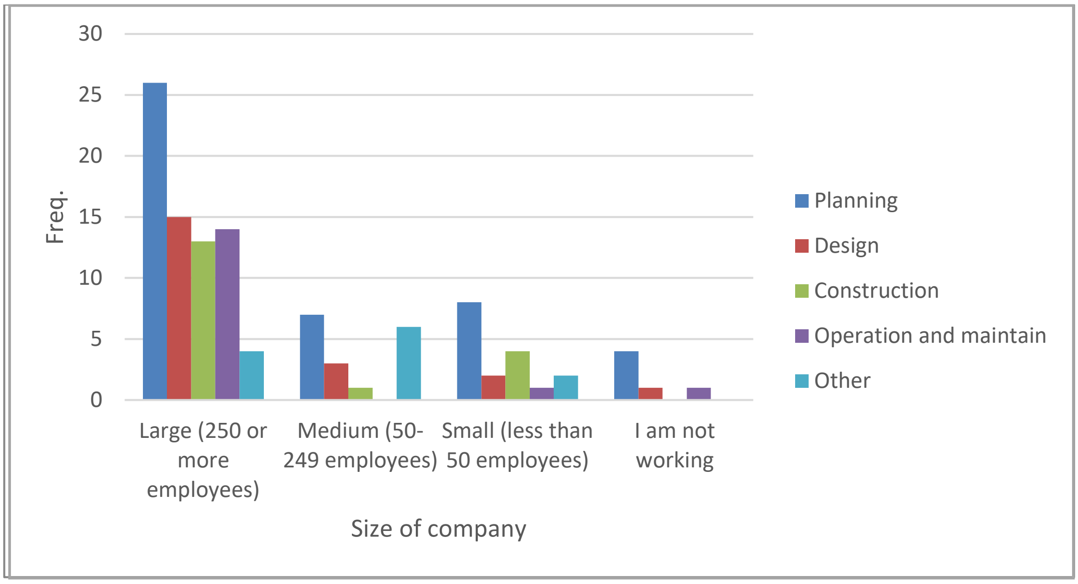


Figure 5-13: Size of the company for the most stage that GIS is used

It seems that BIM and GIS can be used in the whole project lifecycle. BIM and GIS complete each other and integrating them will offer a great value of any project in which they would be well used. (Fosu et al., 2015)
In addition, AutoCAD and Revit are of about equal usage; that small difference will not be statistically significant (Figure 5-14). For the option *"Other"*, respondents indicated the following tools: Archicad, Autodesk BIM 360, and mixed between Bentley, Revit and Navisworks.

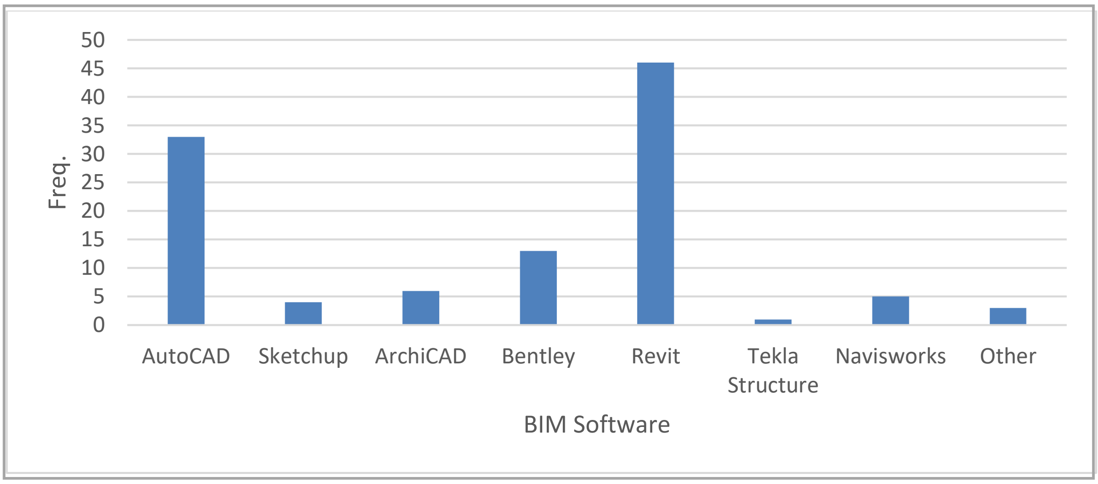


Figure 5-14: Software used for BIM

Figure 5-15 illustrates that the ArcGIS is by far the most software used in GIS.

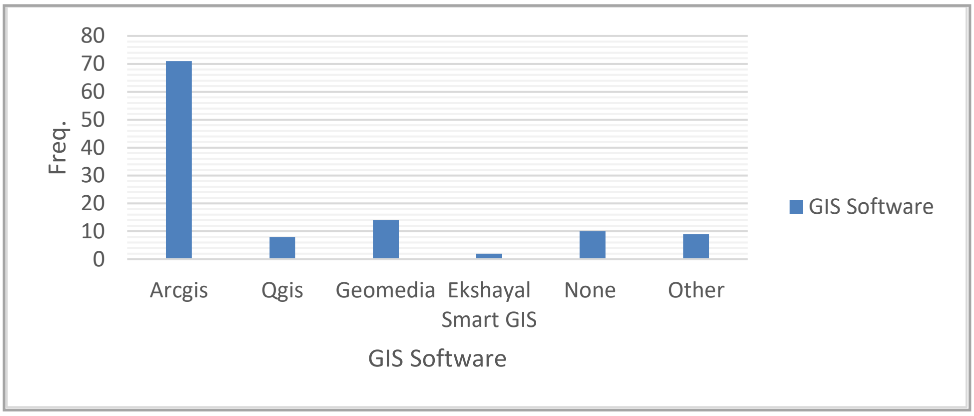


Figure 5-15: Benefits of BIM for different statements

BIM and GIS are perceived to have brought huge benefits to the projects. This can be seen in Figure 5-16 and Figure 5-17. Where the respondents were asked to indicate their agreement with the statement, “the benefits of BIM and GIS for the project in terms of improving design quality, reducing time, cost, avoiding redesign issues, increase collaboration among participants, clash detection, and better decision making”. The highest average score indicates to clash detection, followed by better decision making and improve design quality.

For *GIS*, on the other hand, the highest average score indicates to that GIS did provide those benefits to some extent such as better decision making, increase collaboration and improve design quality, which provides evidence that BIM and GIS might be beneficial for the above items.

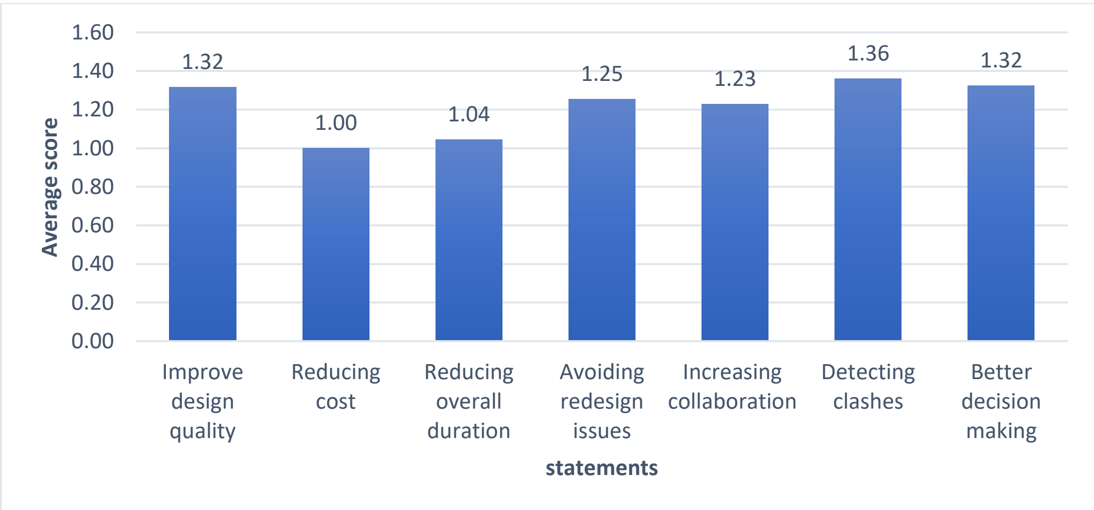


Figure 5-16: Benefits of BIM for different statements

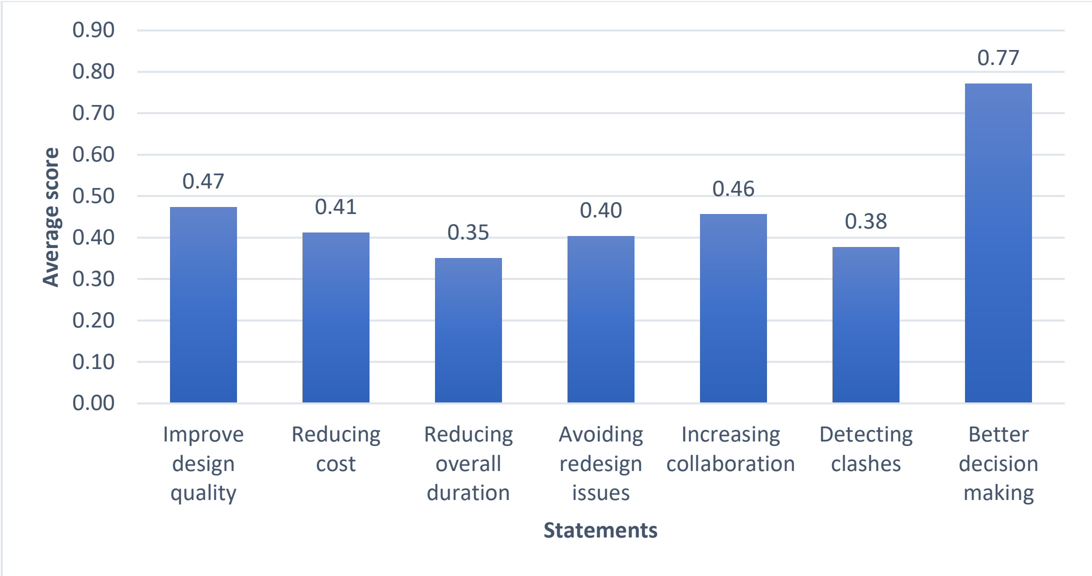


Figure 5-17: Benefits of GIS for different statements

According to the results in Table 5-3, BIM for clash detection was ranked top, followed by better decision making.

On the other hand, for GIS, decision making was the highest-ranking benefit, followed by data availability, while improving design quality came third for both BIM and GIS, as shown in Table 5-4 illustrated.

Table 5-3: Benefits of BIM

Statement	Mean	Std. Deviation	**Benefits of BIM (%)**	significantly rank
BIM Improves the design quality	**4.3**	1.037	**85.9%**	3
BIM Improves productivity of estimator in quantity take-off	**4.2**	1.050	**83.6%**	7
BIM reduces overall cost	**4.0**	1.131	**79.6%**	10
BIM reduces overall duration	**4.0**	1.070	**80.2%**	8
BIM helps to avoid redesign issues	**4.2**	1.016	**84.8%**	4
BIM supports collaboration	**4.2**	1.105	**84.5%**	6
BIM helps to detect clashes	**4.3**	1.053	**86.8%**	1
BI supports- project delivery	**4.0**	1.110	**79.1%**	11
BIM helps to reduce risks	**4.0**	1.040	**80.0%**	9
BIM improves data availability	**4.2**	1.024	**84.8%**	5
BIM supports better decision making	**4.3**	0.976	**86.1%**	2

Table 5-4: Benefits of GIS

Statement	Mean	Std. Deviation	Benefits of GIS (%)	significantly rank
GIS Improves the design quality	**3.5**	1.294	**69.8%**	3
GIS Improves productivity of estimator in quantity take-off	**3.2**	1.364	**64.8%**	11
GIS reduces overall cost	**3.4**	1.213	**68.4%**	8
GIS Reduces overall duration	**3.4**	1.237	**67.1%**	10
GIS helps to avoid redesign issues	**3.4**	1.286	**68.8%**	7
GIS supports collaboration	**3.5**	1.329	**69.5%**	5
GIS helps to detect clashes	**3.4**	1.303	**67.7%**	9
GIS supports- project delivery	**3.5**	1.237	**69.3%**	6
GIS helps to reduce risks	**3.5**	1.230	**69.6%**	4
GIS improves data availability	**3.7**	1.280	**74.6%**	2
GIS supports better decision making	**3.8**	1.299	**75.5%**	1

It can be said that "*information*" is a common theme among these factors. Getting the right information at the right time for the right person will lead to clash detection, effective decisions, and avoidance of reworking. Thus, BIM and GIS are not just general repositories of information, but tools which facilitate the routing of relevant information for specific purposes.

5.2.4 Integrating BIM and GIS in the Design Stage in Railway Projects

This section demonstrates the status of integrating BIM and GIS in railway projects specifically in the design stage and the opportunities that BIM and GIS (after integrating them) may offer in addition to the potential challenges to the integration process.

Findings showed that integration between BIM and GIS is a very recent phenomenon. Figure 5-18 shows that most companies integrated BIM with GIS for less than 2 years, and most of those respondents are from a large company. Furthermore, just 2 respondents reported integrating BIM with GIS for 11-15 years. It appears that integrating BIM and GIS in small companies are less than large companies.

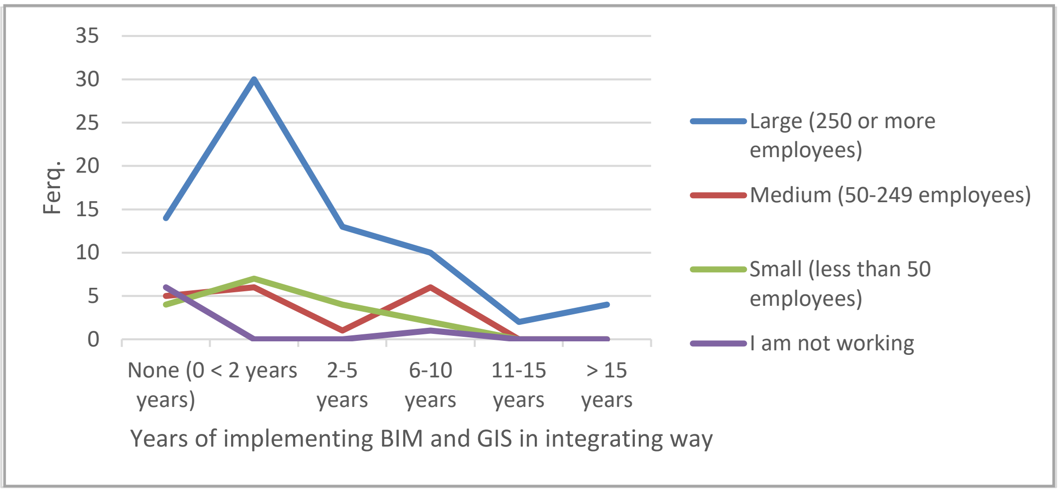


Figure 5-18: Size of the company for different years of implementing BIM/GIS in an integrating way

To find out the drivers for integrating BIM with GIS and the features that this integration may offer, this survey included questions to illustrate the importance and the challenges of this integration. Integrating BIM and GIS enables problem-solving in civil, building, and infrastructure sectors significantly (Liu et al., 2017). According to this survey, the respondents responded positively regarding the importance of integrating BIM and GIS. Figure 5-19 indicates that the largest proportion of the responses is going with that integration BIM with GIS is extremely important, especially for coordination, visualisation, decision making clash detection, and collaboration. It is important to pay attention to that coordination needs a high degree of collaboration.

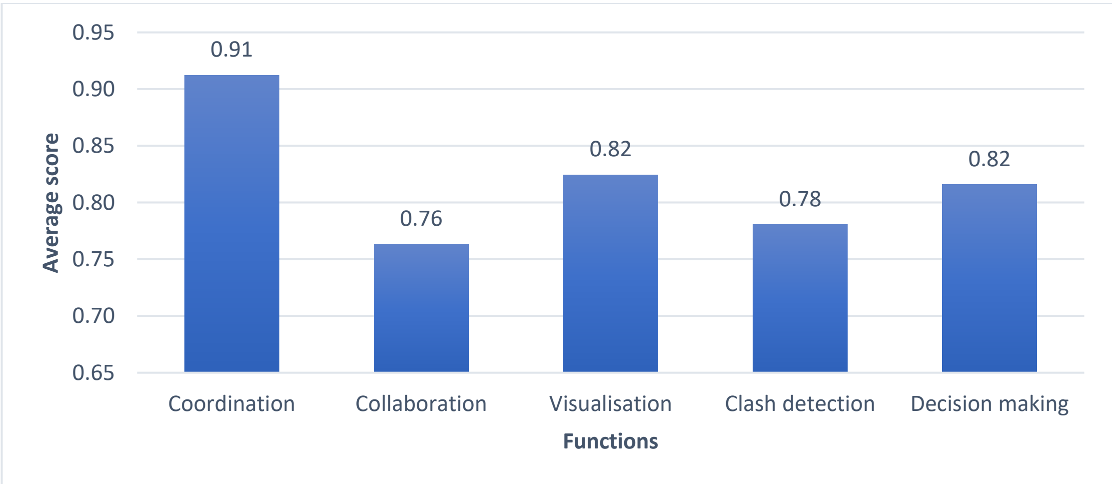


Figure 5-19: Respondents responses regarding the importance of integrating BIM and GIS

From testing the significance of years of experiences of BIM and GIS on implementing them using the Kruskal-Wallis Test, it was noticed that the years of experience did not have a huge impact on implementing BIM with GIS shown in Table 5-5. This table reveals that there is no significant difference in (q4.5, q4.6 and q4.7; in Appendix B), which the respondents' opinion was similar even with the difference of their profession or years of experience; this might be due to the fact that their usage process is the same, but they need the proper approach or framework to use it effectively.

Table 5-5: Difference of implementation BIM and GIS

Ranks				df =4	
Q4.1 Years of implementation BIM/GIS		N	Mean Rank	Chi-Square	P_value
Q4.5/ important of issues/barriers in integrating BIM/GIS	No experience	28	51.8	1.004	.909
	< 2 years	43	57.9		
	2-5 years	18	57.8		
	6-10 years	18	60.3		
	11+ years	5	52.6		
Q4.6/ integrating BIM/GIS in the design stage could enhance (Collaboration,…..etc)	No experience	28	49.4	6.124	.190
	< 2 years	43	60.5		
	2-5 years	18	65.7		
	6-10 years	18	45.6		
	11+ years	5	68.1		
Q4.7/ integrating BIM/GIS could enhance the interaction between the project's stakeholders	No experience	28	49.2	5.525	.238
	< 2 years	43	58.5		
	2-5 years	18	62.5		
	6-10 years	18	50.6		
	11+ years	5	79.6		

Integration of BIM and GIS is important for the whole project lifecycle from planning down to operations and maintenance (Liu et al., 2017). This integration is achieved due to the focus of BIM in the design process, while GIS is more about real-world modelling (Liu et al., 2017). According to Figure 5-20, most respondents agreed that in the design stage, integrating BIM and GIS can enhance the first-place collaboration followed by other factors.

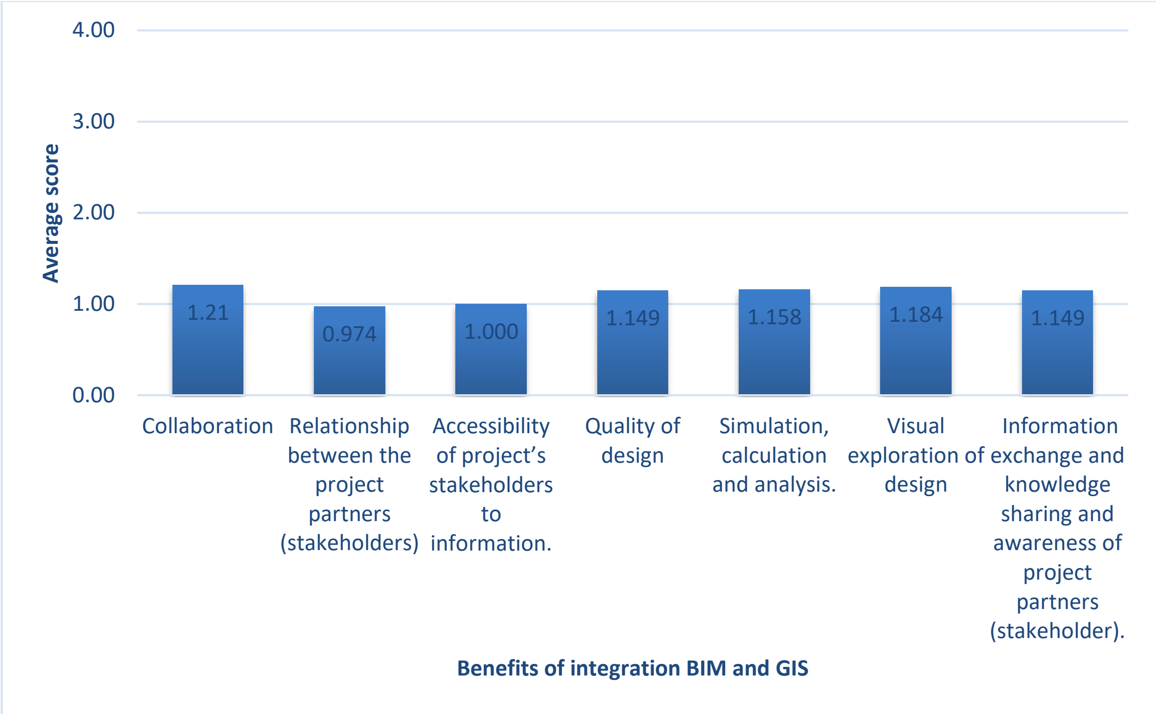


Figure 5-20: Respondents responses regarding integration BIM/GIS in design

To identify the relationship between variables and their impacts on collaboration, linear regression analysis (assumed) was used (see section 4.8). In order to identify the factors with the most significant effect on the dependent variable (improve collaboration), the Stepwise method was used; a method which allows removal of the factors of no significant effect on the model while keeps the variables which significantly affect the model. As Table 5-6 shows, the independent variables ("*X1= Understanding of roles within a team*", "*X2= Collaboration, information exchange and knowledge sharing and awareness of project partners (stakeholders)", and "X3= Ease and enjoy of working*") are the most factors affecting dependent variable ("*Y= Improving collaboration*").

Table 5-7, on the other hand, summarised the most challenges to collaborate and demonstrate the relation between the dependent variable ("*Y= Challenge to collaborate*") and the independent variables *("X1= access to needed data", "X2= Clash detection", "X3= Exchange information", and "X4= Reduced cost").*

Table 5-6: Regression analysis for factors benefits to collaboration

Coefficients[a]					
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.563	.251		2.248	.027
X1: Understanding of roles within a team.	.319	.081	.320	3.942	.000
X2: Information exchange and knowledge sharing and awareness of project partners (stakeholder).	.384	.071	.411	5.435	.000
X3: Ease and enjoy of working.	.198	.066	.215	2.998	.003
Dependent Variable Y: Improve Collaboration.					

Table 5-7: Regression analysis for the challenges to collaborate

Coefficients[a]					
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.055	.179		.306	.760
X1: Access to needed data.	.194	.058	.183	3.344	.001
X2: Clash detection.	.317	.073	.333	4.334	.000
X3: Exchange information.	.302	.071	.305	4.239	.000
X4: Reduced cost.	.208	.066	.209	3.161	.002
Dependent Variable Y: Improve Collaboration					

Although integrating BIM with GIS has several benefits of projects overall and for the design stage, in particular, there are many barriers to reduce the opportunities that this integration may offer. From these highlighted barriers in this survey, for example, collaboration, exchange information and resistance to change as shown in Figure 5-21. This is owing to awareness about BIM and GIS has been increased recently. Furthermore, mandatory BIM makes users more willing to learn. Moreover, after using BIM and GIS in the work of the project became easier and the advantages of BIM and GIS became remarkable.

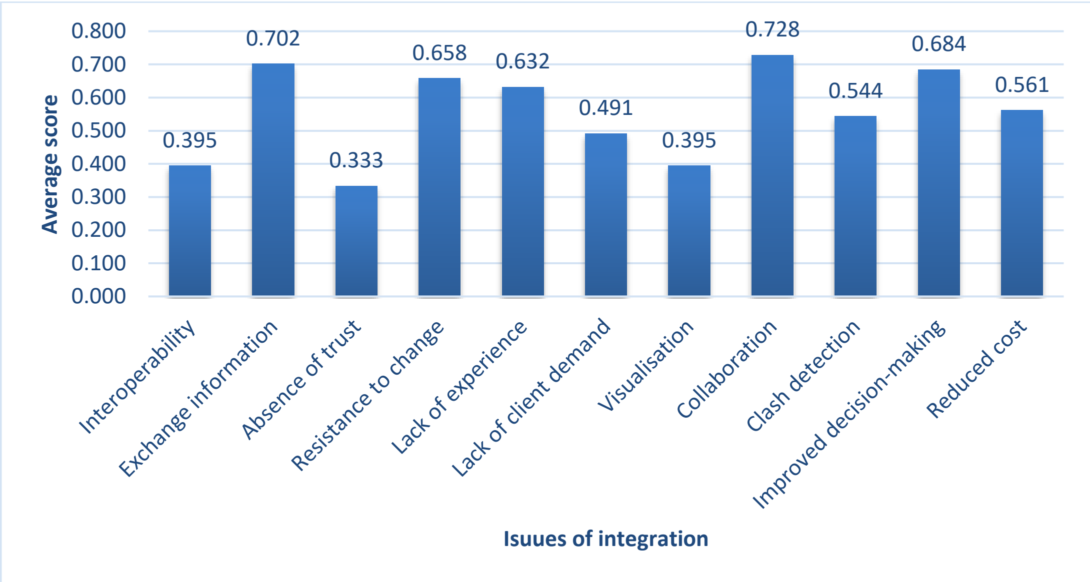


Figure 5-21: Barriers to integrating BIM/GIS in the design stage in railway projects

Figure 5-22 illustrates that the most important challenges started with “Improved decision-making” to fewer impact factors “Not suitable for the project”. The researcher believes that improving collaboration will lead to tackling other challenges such as exchanging information and decision making. The reasons for this belief are that collaboration enhancing to provide the right information at the right time for the right purposes. Thus, this research will attempt to develop a process model to enhance collaboration through integration BIM with GIS. Therefore, a follow up in-depth interviews conducted to investigate the collaboration issues and suggestions to produce a process to clarify the components of the suggested model to enhance collaboration.

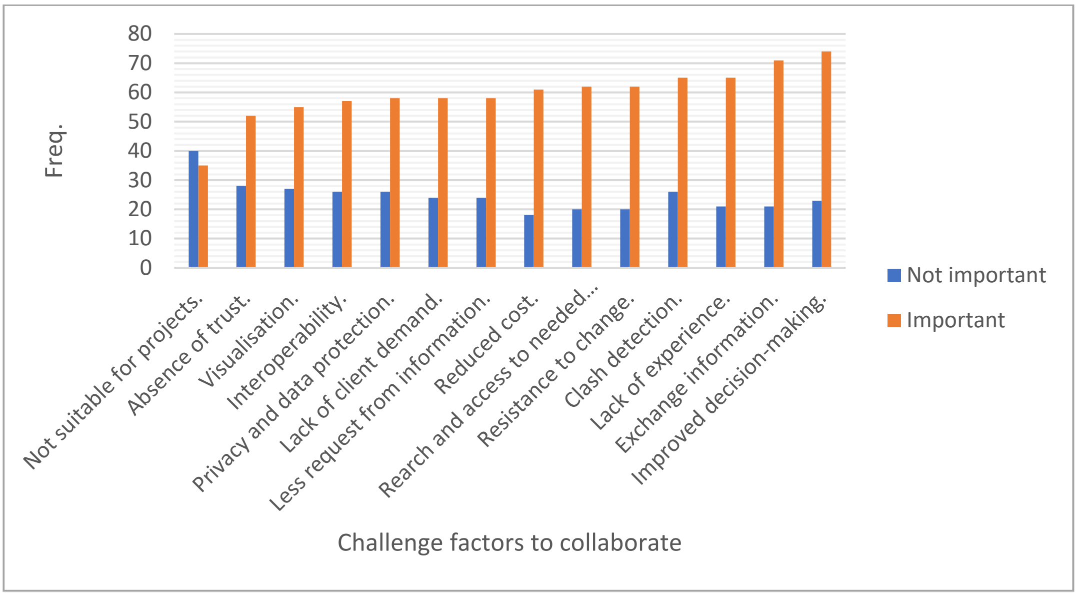


Figure 5-22: Challenges to collaborate

Finally, interaction among project stakeholders is a key factor for effective collaboration as the results appear in this survey and shown in Figure 5-23 below. Coordination obtained the highest average score (1.33) then communication and decision making got a similar average score. Finally, learning the lowest average score (1.21).

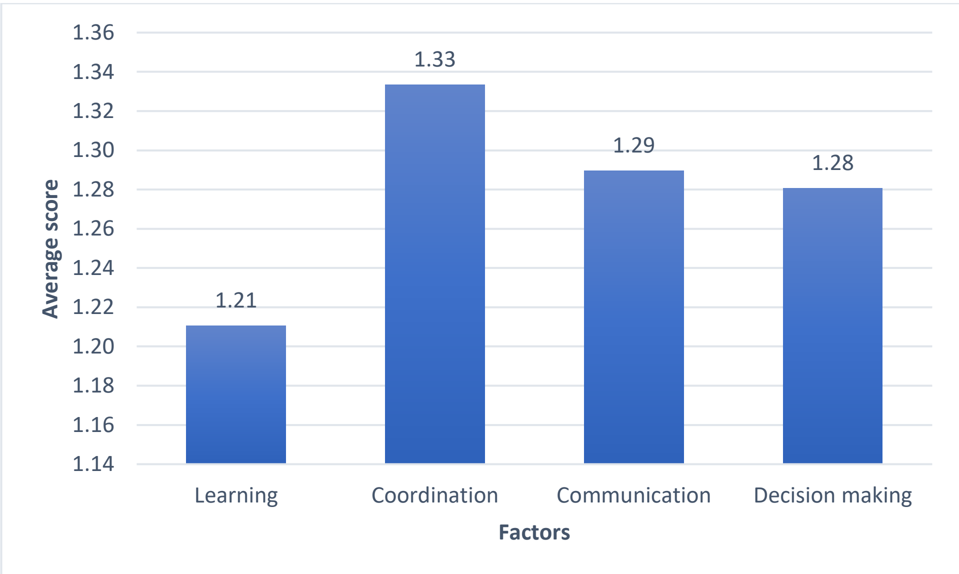


Figure 5-23: Respondents responses regarding integration BIM/GIS in enhancing the interaction between the project's stakeholders

5.3 Summary of Questionnaire Data Analysis

In summary, this survey yielded interesting results. Firstly, professionals are willing to learn new technologies (BIM and GIS) even if it is a self-learning process, not to mention how. Integrating BIM and GIS offers huge benefits and opportunities for the projects. Secondly, the stages in which BIM is most used are the design and construction stages while planning and pre-planning were the most stages that GIS is used for. Therefore, the integration of BIM and GIS will provide a comprehensive picture of the project. AutoCAD and Revit are the two most software used in BIM, whilst ArcGIS for GIS. Furthermore, integration enhances coordination, collaboration, visualisation, clash detection, and decision making. However, there are challenges faced this integration such as for example collaboration, exchange information and resistance to change. While the challenges to collaborate effectively were: access needed data, clash detection, information exchange, and reduced cost. Fortunately, these barriers can be reduced or tackled by developing a process model to improve collaboration which resulting solution for these barriers which effective collaboration is considered as a key success factor to get the right information at the right time for the right purposes. Effective collaboration will enable the stakeholders to share, manage, and take decision toward the same goal. As a result, all of the above barriers could be reduced or avoided. Thus, this research will focus on collaboration in the design stage through the integration of BIM and GIS. A follow-up round of interviews has been conducted for a better understating of collaboration issues, in addition, to suggestions for effective collaboration through a clear process. The summary of the questionnaire results and the areas which need more investigations (with the symbol (*)) are shown in Table 5-8 below:

Table 5-8: Summary of the questionnaire results

Results / Questionnaire questions	Output		Focus in subsequent interviews
	BIM	**GIS**	
Profession	BIM manger, civil engineering	GIS manager, civil engineering	
Year of experiences	2- 5 years	<2	
Size of the company	Large company, public sectors		
Procurement methods	Traditional	Traditional	
Satisfaction with collaboration	Satisfied		
Training	Self-training	Self-training	
Awareness of BIM and GIS	Increase	Increase	
Experience in railway	None - <2	None - <2	
Most stage BIM and GIS are used for	Design	Planning	√
Software/ platform used the most	AutoCAD, Revit	ArcGIS	
Benefits	Clash detection, better decision making, increase collaboration	Better decision making, improve data availability, improve design quality	√
Years of integrating BIM with GIS	None <2 years		
Importance of integration	Coordination, visualisation, decision making		
Barriers/challenges of collaboration	Access to data needed, clash detection, exchange information, and reduced cost		√
Benefits of collaboration	Understanding the role of the team, information exchange, knowledge sharing and awareness of project partners (stakeholder) and ease and enjoy of working.		

5.4 Interview Analysis

The following sections present the findings expected from the semi-structured interviews (the details of the interview discussed in Chapter 4, section 4.12). Two rounds of interviews were conducted. In the first round, 15 interviews were conducted to identify the collaboration issues that face professionals during the design stage of railway projects. In addition to investigating the role of BIM and GIS in assisting design participants to overcome these issues. This was followed by a second round where 10 of the interviewees from the first rounds were interviewed a second time to refine the suggestions and identify components of the process model. It can be defined as a set of constructs utilise to describe an event, object, or process (Svato and Prague, 2017). Needed information has been taken from the first round of interviews and was further used when necessary to develop the process model to avoid repetition and waste time such as the participants involved in the design stage, how BIM and GIS can be used to provide effective collaboration. The interviews were conducted with experts in BIM, GIS and Railway (section 4.12). The rationale of choosing the same interviewees for the 2nd round of interview, that the difficulty to find experts in BIM and GIS in railway projects specifically. Furthermore, the interviewees from 1st round agree to participate in further investigation. Moreover, they had an idea about the research, and they identify the collaboration issues and suggested solutions to overcome these issues.

The interview questions were based on the literature review and subsequent questionnaire data as shown in Figure 5-24.

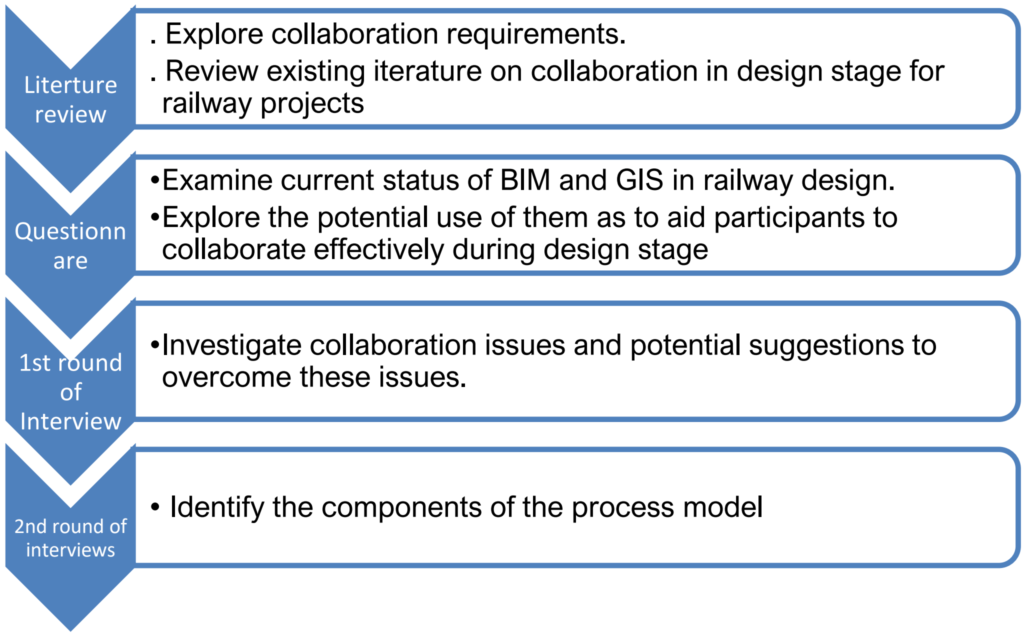


Figure 5-24: The research method for developing the process model

This chapter started with the analysis of the first round of interviews to clarify the collaboration issues. This is followed by the analysis of the second round which presents the components of the process model that constitute the process of BIM and GIS-enabled collaboration. To enhance the internal validity of the analysis, quotations from the transcripts have been woven into the narrative throughout.

5.5 Analysis of the First Round of Interviews

The interview instrument consists of three sections and is given in Appendix C. The first section focuses on collaboration issues that may be faced by designers at the design stage. The second section focused on the views of the participants on the potential of BIM and GIS to effectively deal with these issues and suggestions to overcome them. Finally, the last section collects background information regarding the participants and their companies.

5.5.1 Collaboration Issues

The main scope of this research is collaboration among stakeholders during the *whole* design stage of railway projects, from early design to the end of the design. A bespoke project process model is proposed, the Collaborative Plan of Work (CPW), developed by combining the RIBA Plan of Work and GRIP process model (section 5.4.3).

Almost all the interviewees (14 out of 15) emphasised the importance of collaboration and noted that it is about working together to achieve the same goal. For instance, according to interviewee I-7, BIM director:

> "*Collaboration for me is essentially everyone having the same goal and working together to achieve that, but that does not mean everyone is best friends but where people constructively challenge each other. It doesn't have to be friendly but tries to achieve the same thing".*

At the same time (I-5, Head of BIM) illustrated that through collaboration a single source of truth will be achieved and with a very high level of security by asking participants to use a specific format and share the information collaboratively *"if we just have one system that everybody uses we can have a very secure system,…… so that enables us to create that environment where people can now collaborate & work together, working upon the same standards".*

Collaboration facilitates to detect clashes which all the involved parties able to work on the same piece of work at the same time (interviewees I-3 General Contractor and I-9 contractor). Furthermore, through collaboration, the process of decision making will be effective and fast as all parties are involved to decide (interviewee I-4 BIM Consultant). Moreover, collaboration requires to unify the language which means all the participants should use the same file format and the same tools to exchange information without losing any information (interviewee I-5 Head of BIM and I-4 BIM Consultant).

In the end, all interviewees agreed that collaboration leads to a better outcome in terms of time, reducing the project cost by avoiding rework, and effective decision making.

Although, with the opportunities that collaboration provide, there are many significant challenges facing the process of effective collaboration. The most significant challenge is how to collaborate, what information needed, who is/are the right person to deliver this information, and when (interviewee I-4 BIM Consultant and I-12 Senior Quality Control Engineer). I-4 BIM consultant emphasised that it is essential to identify the information needed *"it is required to define the nature of the information needed for example, what are the needed information from GIS to import it to BIM model because GIS able to contain lots of information and it may not require during the project life".* The letter added, the aim of BIM and GIS need to be defined and how to transfer this information between BIM and GIS needed to be clarified. In addition to identifying the participants involving in the process of design to collaborate.

Similarly, I-5 Head of BIM highlighted to collaborate effectively, several things needed to be considered from the beginning of a project such as, identify the information needed by saying *" from the beginning of the project, you need to identify what information you need at any particular time, so you can make sure you get that information and doing something with it to make a decision at the end".* Therefore, getting the right information at the right time for the right purposes and the right person is the most significant challenge that stakeholders face. This is because there is a lack of clarifying this process in most standards (I-4 BIM Consultant). The letter argued the necessity of providing information requirements, which called (EIR) and BEP to identify the aim of the project which as a result provide the information needed (section 5.5.1/3/iii)

Interviewees (I-5 Head of BIM and I-4 BIM Consultant) indicated that collaboration needs to use the same language, however, people do not tend to do so as I-5 Head of BIM mentioned that:

> *"People are unfamiliar and not flexible or come along the CAD and to explain to them to try it. To collaborate they should use the same language. If people have a different language and refuse to use common language it will be difficult to collaborate. So, it is about People should accept to collaborate".*

The same view when I-8 Engineering Information Manager indicated that the most challenge to collaborate is a resistance to change, people tend to use their own package. In the same issue, I-5 Head of BIM suggested that people working in companies need to be encouraged to change their ways and use new technologies by providing them with a guide showing the collaboration process and make sure the availability of software to them to use in free.

The reasons for resistance to change to implement new technologies may return to issues that may occur while utilising them such as loss of data during exchange information or interoperability (I-5 Head of BIM, I-7 BIM director, I-6 BIM Manager, I-4 BIM Consultant). Also, I-1 BIM Manager mentioned that *"Collaboration between various stakeholders using different technologies is a challenge".* This aligns with the view of the Interviewees (I-6 BIM Manager) and (I-4 BIM

Consultant) when they emphasised that the interoperability is the most common challenges to achieve effective collaboration. Also, the same challenges have been identified from the analysis of questionnaire findings (section 5.1.4). However, a number of recent research focused on this issue and how to tackle it such as (Chang-Hee and Heegu, 2014, Karan et al., 2015). Therefore, the main issues of the collaboration are to get the right information at the right time for the right purpose, followed by resistance to change that need to be overcome.

In summary, collaboration is necessary to reduce and overcome the above challenges by defining the roles and responsibilities, deliverables and information needed (next sections from 5.5.1 to 5.5.3). However, there is still a shortage of clear framework or guideline showing clearly the process of collaboration, almost all the plan of work addresses the information with lack of managing the responsibilities (interviewee I-5 Head of BIM). Thus, this research is developing a process model (as discussed section 5.4.3) for effective collaboration of designing a railway showing the activities, the responsible participants (from the first set of the interviews) and the information needed, through using BIM and GIS. The two aforementioned technologies are the basis or key points to achieve effective collaboration which both associated with each other to provide the right information at the right time for the right purposes.

5.5.2 Suggestions for Effective Collaboration

Each project follows the different plan of work such as the RIBA Plan of Work (section 2.6.1) and GRIP (section 2.6.2). According to the interviews, the participants confirmed that they follow their own plan of work for the railway project. While some of them follow a specific plan of work such as the UK Government's Building Information Modelling mandate and RIBA plan of work. Although GRIP stages are a specific sort of plans of work which are very customised for the railway project, not all the companies adopt them (interviewee I-2 Civil Engineer). The reasons for that they emphasised that the focus of each plan differs. Also, each railway project has features and conditions which vary from others. The concern of the plans of work not just with deliverables; many of them are mainly concerned about providing details of the design activities that lead to deliverables, while some other plans indicate how the activities of the design link together with process diagrams (Churcher and Richards, 2011), the know-how in these processes still missing though.

From the interviewees' responses, several of the effective solutions have been suggested to collaborate effectively and to get the right information at the right time, which is the most challenging issue that had been faced by the design participants during the design stage. After having the interview responses read and compared, suggestions are combined under one comprehensive category to reach an effective solution. For instance, interviewees (I-3 General contractor and I-4 BIM Consultant) emphasised having a clear BEP (BIM Execution Plan) and the necessity to follow EIR (Employer Information Requirements). While the interviewee (I-2 Civil Engineer) suggested using modelling methods early which can feed into system definition and effective use of the GIS to aid in the integration of railway projects into the wider environment and the wider railway system. Having a clear and specific framework of the process model for the design stage of the railway will be really interesting and valuable (interviewees I-5 Head of BIM, I-1 Head of BIM, and I-6 BIM Manager). They added, this process should clarify the components is required for collaboration such as to define, design activities; participants and information needed but should follow an obvious plan of work which is a significant solution for effective collaboration (the components of the process model in section 5.5). It will additionally help to make the right decision at the right time.

On the other hand, the existent process model for effective collaboration very crucial to get the right information at the right time and making critical decisions in an effective manner. This could be achieved through clarifying the process model components in terms of activities, the roles and responsibilities, the information needed and critical decision points (I-4 BIM Consultant). Accordingly, saving plenty of time and cost and make effective decisions. From these, development process model depends on a plan of work to follow was developed. Furthermore, the process model required to include activities, participants, the information needed, and any components needed that facilitate to achieve effective collaboration. Therefore, a Collaborative Plan of Work was developed then the process model.

5.5.3 Developing a Collaborative Plan of Work (CWP)

It is important to develop a plan of work to be the basis of the process model to follow. All the participants were familiar with different plans of work and standards RIBA Plan of Work 2013, BS 1192:2007, PAS 11922: 2013 and CIC protocol. However, few of the participants mentioned they follow one of these plans of work. For example, interviewee I-5 follow the RIBA Plan of Work 2013, interviewee I-3 General Contractor follows BS 1192:2007 (Collaborative production of architectural, engineering and Construction information), and I-4 BIM Consultant follows PAS 11922: 2013 (Specification for information management for the capital/delivery phase of construction projects using building information modelling), but none of them follows CIC Building Information Model (BIM) Protocol. Furthermore, 2 out of 15 were familiar with GRIP (developed by NetworkRail). However, 12 out of 15 reported not following any specific standard plan of work and they create their own plan of work because they felt the lack of those plans adequately concerned about collaboration. They all agreed that establishing a plan of work for collaboration and railway based and not referring to any specific organisation will fill a gap that there is a lack of process to how to collaborate.

In the RIBA Plan of Work, collaboration is missing when it is trying to address poor coordination (chapter 2, section 2.6.1) While, GRIP is schemes of managing investment to reduce and alleviate the risks that related to project delivery (NetwokRail, 2015). Furthermore, the overall approach of the GRIP stages is driven by-product rather than process (NetwokRail, 2015). Nevertheless, GRIP has very specific features related to the railway to ensure the optimum option is chosen and is feasible such as the railway route. While, RIBA Plan of Work is a generic descriptive model of the design stage resulted from the organisational approaches for collaborative design (Mendler and Odell, 2000). Regarding that interviewees suggested a combination of RIBA with GRIP approach that may fulfil the collaboration requirements because these two plans complete each other if it is combined in one plan of work (interviewees I-4 BIM Consultant, I-5 Head of BIM, and I-6 BIM manager). Thus, a plan of work called Collaborative Plan of Work (CPW) Table 5-9 was developed by combining a RIBA plan of work and GRIP stages, focusing specifically on collaboration during the design phase of railway projects.

The CPW is focusing on the collaborative process and managing information among the project participants to facilitate the design process and making critical decisions. This because the objective of the project will be well-defined and the responsible participants for each task will be known. Moreover, the railway elements from GRIP will be defined within the descriptive process management from the RIBA.

Overall, to summarise the finding from the first round of the interviews, there are the main issues and suggestions to overcome them. The main challenging issues were to manage the information to get the right information for the right purposes followed by with resistance to change. However, the significant solutions to tackle these issues consist of several steps to reach an effective solution. Developing a process model, including project components, participants, tools used, the information needed will facilitate to collaborate effectively and making effective decisions. The concern about the process model should follow a clear plan of work. As a result, CPW will be developed, which is an interesting suggestion to develop the process model on it. To develop a process model, the second round of interviews has been conducted to identify the components of the process model, participants, role and responsibilities and decision points.

Table 5-9: Developed Plan of Work (CPW)

RIBA Plan of Work				GRIP Process				From research (CPW)			
Phase	*Stage*	*Tasks*	*Output*	*No.*	*Stage*	*Task*	*Output*	*No.*	*Stage*	*Task*	*Output*
Preparation	*0.Strategic Definition (Appraisal)*	*Identify the needs and objectives of the client, business case and potential constraints on development. Prepare feasibility studies and options assessment to assist the client to decide to proceed or not*	*Clients requirements and preferable feasibility option*	*1*	*Output Definition*	*Define Project Output*	*Identify the definitions of the needs and requirements*	*0*	*Strategic Definition*	*Define public needs, project objectives, business case, prepare a feasibility study. (managing project need)*	*Clients requirements, project objectives, feasibility study. (project needs)*
	1.Preparation and Brief	*Develop and confirm Initial Statement of requirements into the initial project brief*	*Preferable feasibility option and project objectives*	*2*	*Pre-Feasibility*	*Define the investment scope, identify the constraints on the network, confirmation regarding that the output can be delivered economically and aligned with network strategy*	*Identify solutions for the requirements*	*1*	*Project Brief*	*Identify network constraints, develop and confirm an initial statement of requirements into the initial project brief. (managing information and project outline)*	*BIM execution plan, designer responsibilities, specifications. (project outline)*
final Design	*2.Concept Design*	*Implement initial project brief and prepare concept design. the preparation of design concept includes proposals outline for structure and building services systems, specifications outline and plan of cost. procurements route review*	*Prepare Sustainability Strategy, Risk Assessments. Review and update the Project Execution Plan.*	*3*	*Option Selection*	*Address the constraints by developing options, assessing the options to select the optimum. Confirm that the output can be delivered economically*	*Determine the single option, stakeholder approval.*	*2*	*Option Selection development*	*Investigate to identify the options and develop it considering the economical delivered. Prepare concept design. (collaboration to make a decision)*	*Optimum layout of railway track, civil engineering structures and systems.*
	3.Developed Design	*Develop concept design and complete project brief*	*Concept Designs*	*4*	*Single Option Development*	*Developing the selected to single option Finalise business case and schedule implementing resources*	*Outline design*		*Develop concept*	*Preparing an outline of the concept design such as structures, civil, systems, and services plan of cost. (collaboration and using of technologies)*	*The final project brief, outline track, civil engineering structures and systems*
	4.Technical Design	*Prepare technical design, cost information, project strategy and specifications*	*Technical designs cost information, project strategy and specifications*	*5*	*Detailed Design*	*Produces a complete robust engineering design to provide a final estimation of cost, time, resources and risks.*	*Final design*		*Develop detailed design*	*Prepare an outline of the technical design of the track, civil, systems in detail. (collaboration and using of technologies)*	*Detailed design of the track, civil engineering structures and systems*
Construction	*5.Construction*	*Manufacturing and constructing accordance with the construction programme and design queries*	*Project ready for operation.*	*6*	*Construction, Test and commission*	*Deliver to the specification and testing to confirm the workability of the asset and system in accordance with their design.*	*The project built, tested and authorised into use.*	*3*	*Construction*	*Manufacturing and construct taking into consideration the construction programme and design queries.*	*The project built and ready for operation.*
Handover	*6. Handover and Close Out*	*Handover activities carried out*	*Conclude the building contract*	*7*	*Project Closeout*	*Settle the contractual accounts and put the warranties into their place. also, carry out the benefits assessments*	*Project and project support system formally closed*	*4*	*Handover and Project Close-Out*	*Settle the contractual accounts*	*The project formally closed, conclude the contracts*

5.6 Analysis of the Second Round of the Interviews

The purpose of this interview was to identify the components of the suggested process model (from the findings of the first round of interviews), roles, responsibilities, and critical decision points. The second round of interviews consists of three sections (the questions in Appendix D). The first one focused on the process of working in the design stage, which focuses on design activities and stakeholders involved in the design process; followed by the addresses of the uses of BIM and GIS in the design stage. In the third section, the focus was on the components of the suggested process model in the design stage and the possible participants in each one are recorded.

5.6.1 Components of the Process Model

This model presents the components of the collaborative process using BIM and GIS (Figure 5-25). Through using content analysis (Elo and Kyngäs, 2008) and thematic analysis (Braun and Clarke, 2006) of the interview transcripts as discussed in section 5.4 then followed by the second round of interviews, the components have been identified and defined to illustrate the opportunities and challenges for BIM and GIS-enabled collaboration. As interviewees (II-1 BIM Consultant, II-5 BIM Engineer, II-8 Assistant Professor of Railway Engineering, II-3 BIM Manager) indicated that the most important key points for effective collaboration are following a process model of the design stage activities assigned to defined parties with needed information. Furthermore, they added the output and when the decision should be taken. Interviewee II-2 Head of BIM indicated that the process model should include the related components to collaboration such as identify the activities, parties involved. On the other hand, interviewee II-3 BIM Manager added that take care when the BIM and GIS are used for each activity.

As a result, the process model can be classified to the main category is BIM and GIS-enabled collaboration. Then the process model consists of four generic categories "*Roles*", "*Tasks*", "*Deliverables*", and "*Decision Points*" as illustrated from the findings of the 1st round of the interview. These categories and sub-categories will be clarified in the coming sections. The roles and responsibilities of the project team towards collaborative design presented first.

Followed by presenting the tasks delegated to each role and their deliverables. Finally, at the end of this chapter, the summary of the main arguments reported in this chapter is presented.

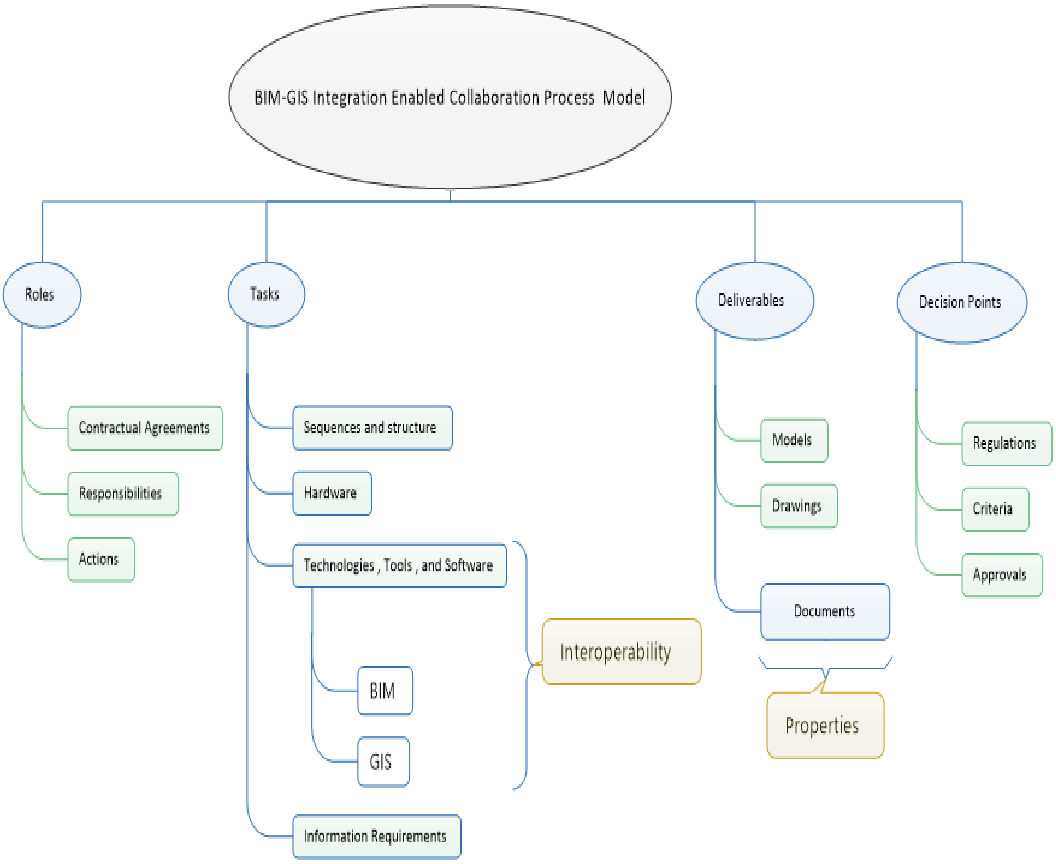


Figure 5-25: Components of the Model

1- Contractual Agreements

The interviewee II-9 BIM Specialist the importance of the contractual agreements saying:

> *"The contractual implication is great because you have to have it, if you have a contractual model abstracts the flow of information & there are plenty of those, are practically used the standard for contracts, requires a changing culture which means to be Collaboratory".*

While, interviewee II-1 BIM Consultant *stated, "the contractual agreements, in general, are different, but the main issue here is the copyright of this information, who has the discretion of them which may have a level of security*". The same interviewee added the contract should include the BEP, information requirements, as well as interviewee II-3 BIM Manager emphasised that the collaborative environment is very secure because through collaboration one source of truth be used by all the participants.

Associated legal aspects with BIM implementation includes three categories (Sackey, 2014): (i) risk and liability, (ii) information ownership, and (iii) security and confidentiality. Therefore, it becomes crucial to define the roles, responsibilities and deliverables of information for each project participant in a collaborative effort. This way, it will be easier to track managing the processes of the complex work and a large amount of information (Sebastian, 2010). The latest suggested collaborative contracts to apply IPD (Integrated Project Delivery), partnering, and principles of the alliance that based on open communication, trust and avoided of disputes.

2- Roles, Responsibilities, and Competencies

According to Sinclair (2013) argument, the importance of the procurement form, specialist, and subcontractors' roles became increased, adding that: *"their involvement must be clearly defined early on".* The roles of specialists and their responsibilities are essential due to the given of the multidisciplinary collaboration requirements of sustainable design (Zanni, 2016). To accommodate the uses of the BIM core, the new roles have been identified, such as sustainable design (Barnes and Davies, 2014). However, the roles of the BIM and GIS for effective collaboration for railway design need to be effectively defined and specialist roles for a range of experts are required (II-2 Head of BIM, II-3 BIM Manager) so that assigned tasks for each participant will be defined earlier. For example, BIM manager, BIM information manager, BIM coordinator, GIS information manager, GIS coordinator (from the answers of the first round of interviews (interviewees II-5 BIM Engineer, II-1 BIM Consultant, II-3 BIM Manager). The identifying and defining the required roles for effective collaboration will be presented in the following sub-sections.

- Definition of Collaborative Railway Design Roles

The establishment of the collaborative project team needs to be at RIBA Stages 0 "Strategic Definition" and 1 "Preparation and Brief" (Sharp, Finkelstein and

Galal, 1999, RIBA, 2013c, Sinclair, 2013) to be involved in the design process early for effective collaboration. Interviewees (II-3 BIM Manager, II-6 Architecture and construction Manager) provide a comprehensive account of the role's responsibilities under the question of a "participants that involved in design stage". Furthermore, the provided information has been crosschecked, and enriched, from the transcripts of the rest of the Interviewees. The interviewees emphasised that the roles and the responsibilities differ from project to another and depends on the type of the projects (new project or repair an old one). Because of the railway projects consider as megaprojects and it takes a long time and a huge amount of money to design, it is assigned to different companies of design, not just one. So, this means that the deal will be different among participants from different which make the collaboration is necessary to achieve the project objectives. Even though, the specialists for specific tasks are the same and need to be identified from the beginning.

According to the interviewee's opinions, the role and responsibilities differ from project to another. For example, interviewee (II-3 BIM Manager), revealed that the external stakeholders could be categorised into authorities (A), consultants/contractors (C), and operators (O). While the interviewee (II-2 Head of BIM) emphasised that involving maintainers at the early design process is crucial to collaborate effectively *"getting the future maintainers to give the designers their asset management requirements is one of the keys collaborate effectively*". Some companies categorise the stakeholders to BIM team, GIS team and project team such as Crossrail and HS2. As a result, in this research, the main roles and responsibilities of the design stage of the railway projects have identified as shown below. Through adopting a common language for job titles, descriptions, and responsibilities, clear objectives for the project management of railway route projects will be achieved. Thus, based on the interviewee responses from the first round and the second round of the interviews, the main parties involved in the design process can be summarised as follows:

- Authorities (A): Government public works authorities that grant the building permits; Government network authorities that own and operated the utility networks; Roads authorities that will provide the traffic study, define project limits and define the right of way; Collaboration organization that manages the collaboration with all interfacing projects/facilities.

- Consultants/contractors (C): The construction material suppliers/vendors; Contractors & subcontractors.
- Operators (O): Operator- municipality or city transport authority; Private sector companies.
- Client/Client Adviser: Approvals; commissioning; consultation with stakeholders; the possibility of shared facilities; security. Ensuring that the setup of the project is executed adequately in terms of risks, health, and safety of those who may affect.
- Architect/Lead Designer: Site investigation; shared facilities; security; responsible sourcing of materials; insulation; hard landscaping; modelling.
- Landscape Architect/Ecologist: Site investigation; ecological value protection; reuse of land; enhancing ecology; outdoor space; hard landscaping, and boundary protection.
- MEP (Mechanical, Electrical, and Plumbing services) Engineer: Site investigation; community energy supply; low and zero-carbon technologies; daylighting; internal and external lighting levels; lighting zones and controls; potential for natural ventilation; indoor air quality; thermal comfort; thermal zoning; reduction of CO_2 (carbon dioxide) emissions.
- Structural Engineer: Site investigation; re-use of building façade and structure; recycled aggregates.
- Civil Engineer: Site investigation; water management; irrigation systems; flood risk.
- Geotechnical Engineer: Site investigation; re-use of land; contaminated land.
- Hydrologist: Site investigation; check drainage patterns; contribution to location bridge assessment.

- Interface and network analysis engineer: Check the interfacing with other existing networks.
- Environmental Expert: Assess the environmental impact
- Tunnelling Engineer: Check, assess and design tunnel
- Railway Track Engineer: Check, assess and design railway track.
- Signalling Engineer: Check, assess and design signalling systems
- Cost Consultant, quantity survey: CapEx (Capital Expenditure); OpEx (Operational Expenditure); Lifecycle cost assessment.
- BIM team: responsible that all BIM data used for the project has been created according to appropriate standards that fit the purpose of the project. Consists of BIM manager, BIM coordinator, BIM data information manager, civil eng, MEP, systems and signalling engineer, and BIM systems analyst.
- BIM Manager/Coordinator: Develop BIM strategy; assist the team with software selection and interoperability; determine information exchanges; develop BEP; coordinate BIM models and information (4D, 5D); review model and detect clashes; report clashes; resolve areas of uncertainty in the model; general overview that the BEP is followed as planned.
- GIS team: responsible to manage and distribute intelligent mapping data. Consists of; GIS manager, GIS system analyst, GIS programmer.
- Projects team: other stakeholders who involved in the design process such as clients, project manager, maintainer, etc.

3- Tasks and Implementation Methods

This section discusses the tasks that the design stage of railway projects may consist of. According to the interviewee's experiences, the design stage of railway projects is various from a project to another. From the interview responses, despite the tacks of the design stage are changeable, they indicated main tasks that should be included in the design process of the railway projects. Some of the interviewee's opinion, such as interview (II-3 BIM Manager) pointed out that the design activities are executed differently saying:

"It d*epends on the nature of the project and design limitations. If you are renovating an existing metro line, then you might start by the systems, then stations. But if we assume a new project, then normally you start by railway track substructures (to check for any design constraints such as utility networks provisions and available right of way), then civil engineering structures to check constructability, and the superstructures then the systems/premises*".

Similarly, interviewee (II-5 BIM Engineer, II-1 BIM Consultant) alluded to the fact that there is no specific or tightening structure or process to follow in executing activities. Another interviewee (II-2 Head of BIM) stated:

"*At the initial design stage design, you start with very broad assumptions about alignment and structures. There are good interactive CAD /GIS systems that now let you design alignments taking into account terrain. Broad generalisations will be made about the track, structures and systems to enable an alignment to be created so that assessment on the land take, costs etc can be made. When you get into the detailed design phase, then the specific types of track, track bed, rail and substructure can be defined in more detail, together with all the structural details required to support them*".

Therefore, from their experiences and opinions, all the participants agreed that the tasks can be defined as basic information about the project in the first stage such as the EIR, BEP, project objectives, budget analysis, and feasibility study. This is reflected in the CPW. The stage after that is selecting the optimum route and locations, for example, the location of systems, civil engineering structure and rail track. Finally, the tasks related to the design of the railway components such as railway track, bridge, tunnels, stations, and signals systems. Therefore, the tasks differ for each project, nevertheless, there is no standard and clear framework clarifying the process or identifying the tasks. As a result, this research attempt to identify a process model, providing these tasks with the participants and the information needed.

i- Technologies, Tools, and Software Used

The selection of BIM and GIS software tools varies according to the project type. A variety of software packages are utilised by large organisations to combine the strengths of different tools. Railway as a straight project differed from the building which affects on the choosing of proper software. From the Phase 1 of data the collection (questionnaire), 60% of the responses used

ArcGIS for GIS software, while the different percentage for using BIM software such as 41% for Revit, 29% for AutoCAD and so on for Bentley, SketchUp, and Navisworks. The reasons for this different percentage compared with GIS that each software of BIM has a variety of usage, which makes using packages of them will combine the strengths of them. After BIM became mandatory by 2016, using of BIM widespread and used by most companies, however, according to the interviewees replies most developing countries did not use BIM effectively.

The finding suggests that depending on the project type and design stage a wide range of software tools are used. Interviewees (II-2 Head of BIM, II-3 BIM Manager, II-9 BIM Specialist) stated that they utilised Revit software, for buildings, while they preferred MicroStation software for infrastructure projects. Interview (II-2 Head of BIM) reported, *"We tend to use CAD for designing specific elements and use GIS to shows where all the utilities are locating" also added "we have our CAD model which is Bentley MicroStation".* For scheme design development (RIBA stages 1 and 2), SketchUp and Rhino were used rather because of their simplicity. (Zanni, 2016). Different software tools such as Navisworks and Solibri are used for coordination of different disciplines' model (architectural, structural, and mechanical services). Despite the Solibri is more advanced, Navisworks is used for coordination (Zanni, 2016).

GIS exists for ages; however, it became more usable when BIM start to appear. This is because the information from GIS can be imported to BIM and vice versa. Interviewees (II-3 BIM Manager, II-5 BIM Engineer) concluded that any information related to the project itself (indoor level) BIM is used while any information related to landscape (outdoor level) GIS is used with bearing in mind importing and exporting of information is possible when needed.

ii- Software Interoperability

An essential factor to achieve integration between BIM and GIS for effective collaboration is interoperability. The interoperability of data between BIM and GIS means to exchange information between them without losing any of the information (Zhu et al., 2018). The interviewees reported that the interoperability considered as one of the barriers of integrating BIM with GIS and in consequence for effective collaboration (II-1 BIM Consultant, II-10

Creative Director). Also, the same issue presented by the 1st out of the interview and the questionnaire (, section 5.4.1 and section 5.1.4). Even though, after the rapid development and increase using BIM and GIS, several types of research have been focusing on interoperability and ways to tackle this problem. To obtain a successful interoperable data, users should have full understanding for both BIM and GIS and their functionalities to use common data format to exchange information geometrically and semantically without losing any data (Karan, Irizarry and Haymaker, 2016, Zhu et al., 2018). Furthermore, interviewees (II-2 Head of BIM, II-3 BIM Manager) indicated that using a specific data format and encourage participants to use it to make the process of collaboration effective and easier because this specific format will be familiar with other systems. The interoperability can be overcome, especially after GIS can be used as a 3D as same as BIM and by using common data environment and specific data format which lead to transfer the information without missing any data.

iii- Utilisation of Common Data Environments (CDEs)

Utilising CDEs is crucial for effective collaboration. BS 1192:2007 (BSI, 2007) is a standout amongst the most noteworthy norms which bolster carefully empowered digital cooperative working in construction. The concept of the highest-level in BS1192 standard is the Common Data Environment (CDE). It represents any digital environment in a way enabling the project information to be uploaded to, shared, accessed and revised. The standard consists of four "areas" in the CDE 'Work in Progress", "Shared", "Public Documentation" and "Archive". Managing of moving the data among these four phases is the key to the process where here the processes of checking, approving and issuing are implemented.

Although Common Data Environment (CDE) is important for effective collaboration, there is a lack of using it in lots of companies. Eight out of tenth of the Interviewees emphasised that to achieve successful and effective collaboration, a CDE should be existing to use. No matter the difference in the name or the type of this CDE as long as it provides the role of CDE. Some of the projects are using different types of CDE such as Bentley indicated by the interviewee (II-2 Head of BIM) *"We use something called "eB" (is a content management system designed to organise project information into a simple, centralized location".* While some of the interviewees, they still have a lack of using CDE, but still common to use CDEs to exchange information (interviewees II-8 Assistant Professor of Railway Engineering, II-6 BIM Engineer). BIM Execution Plan (BEP) is a very effective solution to collaborate effectively as the interviewees (II-1 BIM Consultant and II-2 Head of BIM) suggested: *"in order to overcome the challenge of getting the right information at the right time, we should be very prescriptive and explain exactly what information is needed and when through using EIR, BEP, and etc."* (II-2 Head of BIM).

On the other hand, for companies that not used CED for collaboration. Interviewees (II-1 BIM Consultant, II-10 Creative Director) described that different type of ICT (Information Communication Technology) was used to collaborate synchronously, such as telephone conferencing, while at the same time manipulating the model. However, the main forms of communications remain during design development processes such as meetings, phone calls, and emails. Participants stated that a significant technological limitation is consuming time during preparing the model to share it with other disciplines and upload the BIM model and this led to cause big data problems which prevent to work on the cloud (II-3 BIM Manager). Instead, the interviewee (II-1 BIM Consultant) reported that a transferring cycle of each design discipline's model performs once a week. Therefore, it was concluded that the capabilities of networks' and internet connections may limit ICT use.

5.6.2 Deliverables and Information Requirements

The findings indicate the capabilities of BIM software and despite working on level 2 BIM, collaboration with other disciplines had not affected in an expected way in theory as reported by the interviewees. The interviewees illustrated that exchange information process with other stakeholders has been simplified using BIM and GIS software.

1- Correspondence between Project Team Members

Formal and informal communication are the two types of corresponding that have distinguished in the collaborative process implementation. Formal meetings occur at the end of each design stage and involving all the project team members (Zanni, 2016). As demonstrated by the interviewees the occurring period of these meetings depends on the size of the project. For example, the involving project team members and client approvals (is needed) to prepare progress reports. However, the exchanging of information and sharing the data happened regularly and sometimes required daily communication through emails, phones and face- to- face meetings to discuss any change may happen (interviewee II-3 BIM Manager, II-8 Assistant Professor of Railway Engineering). For the companies who used CDE they upload the model to the specific CDE and then they collaborate around any issue or to share any information that they have. This platform is very secure because all the stakeholders utilise a single source of truth instead of several sources, several formats, and data files (II-2 Head of BIM). Therefore, because of the bespoke nature of the project, it is difficult to prescribe the interactions between participants. To facilitate the collaboration process, it is important to identify critical decision points when it's defined during daily communication.

The interviewee (II-4 BIM Director) argued that collaboration is working together to achieve the same goal not necessary be a close friend *"collaboration is essentially everyone having the same goal and working together to achieve the same goal and challenge each other but everyone is getting that same goal".*

2- Data Exchange Format and File Types

Defining the contents and the format of BIM and GIS is crucial as discussed by several interviewees (II-2 Head of BIM, II-3 BIM Manager, and II-1 BIM Consultant), as well as avoiding duplication of elements by clarifying who is responsible for what. Interviewees (II-2 Head of BIM, and II-4 BIM Director/Head of GIS) indicated that to achieve effective collaboration they required for stakeholders to use a very specific file format and systems

> *"We make sure all our contractors are required to use our systems, as part of the contractual requirements that people use our systems and that make*

sure that we can get all of the right information in the right way" (interviewee II-2 Head of BIM).

The letter also illustrated that they emphasised on the user to use a specific file format. For example, the format used for infrastructure is (dgn) and for building (dwg) because of the infrastructure often long, liner and the (dgn) is better for that. Architects were particularly very familiar with a Rivet (dwg). (Interviewees II-2 Head of BIM, II-3 BIM Manager, II-5 BIM Engineer, II-4 BIM Director/Head of GIS).

The most important thing besides the identification of the file format is obligatory, making sure that stakeholders are going to use it which mean it is kind of forcing them to collaborate, the deliverables need to be defined in a more specific way, indicating the elements that should be included in the model, along with the way that they need to be built and the only problem that hinders the collaboration process is cultural "*persuading people to use new techniques and technologies, as they do not like change*" (interviewee II-2 Head of BIM). Miscommunication amongst the design team resulted in causing rework, and thus, delays in the project programme. Therefore, defining the stakeholders' role, deliverables, technologies, and formats before design start will enable the right information to be got at the right time.

3- Defined Design Deliverables

Knowing file types alone is not sufficient to achieve a seamless of the workflow of BIM and GIS that adequacy of collaborative design. Defining the deliverables in a more specific way is needed and indicate the elements that the model should include an addition to the construct it a required way. Lack of defining deliverables and BEP cause process problems and consequently miscommunications among participants, which cause reworking and as consequences, delay in the project program (interviewee II-1 BIM Consultant). Furthermore, the interviewees (II-1 BIM Consultant, and II-3 BIM Manager) stated that it is necessary to identify the deliverables and the information needed to be put in the model to avoid the big data problems and the model will be too heavy and impossible to run. Moreover, difficulty to reach the information needed and this will consume time, so following clear EIR and BEP is very important (interviewees II-1 BIM Consultant, and II-2 BIM Manager). Laos the same concern suggested in section 5.4.1.

On the other side, several interviewees reveal that to avoid duplication, interoperability and provide more secure systems it is crucial to work within one source of truth and following authorised standards and protocols. Therefore, obvious deliverables, file formats will be provided. Interviewee (II-2 Head of BIM) suggested that existing a process or a framework with well-defining the deliverables and clear responsibility/ies for each participant is great and interesting. However, there is a lack of a clear framework defining deliverables and participants assigned to each defining task of the project i.e clear process of collaboration.

5.6.3 Critical decision points and project programme

PAS1192:2-2013 (BSI, 2013) presents the decision points identified as a critical aspect of the BIM process. Two types of gates included in the phase-gate review of decision points: (i) hard-gates, which means freezing the design until the review is conducted, and (ii) soft-gates when the project activity can be conducted in parallel (interviewee II-3 BIM Manager). Hard gates (such as waiting for clients' approval) assist with a commitment to decisions collectively while implementation. Soft gates (such as evaluating the options of selecting the route) which allow the project to proceed at the same time of reviewing. To achieve collaborative objectives, implementing design strategies and evaluating them in order to reach a set of criteria. The time of taking decisions is crucial because of the commitments at the early stage of a process which will result in avoiding repetition of work that has already been done, which will be more costly (interviewee II-3 BIM Manager, and II-6 Architecture and Construction Manager). Therefore, to achieve that the right information should be delivered to the right people at the right time. Interviewee (II-3 BIM Manager) emphasised that lack of having a good collaboration and a clear process of collaboration will cause a repetition of work. This is aligned with the interviewee (II-1 BIM Consultant) argument that the project objectives should be well defined by the clients or through clear EIR to avoid unnecessarily or not needed information, which makes systems running heavily and consuming time to get the needed information, aside from the cost. Furthermore, full coordination and collaboration is an absolute necessity for all the parties in order to have a successful project using BIM (Park, 2004). Thus, to get the right information at the right time for the right purposes a clear and understandable process of collaboration should exist, so the role, responsibilities, and decision points will be obvious.

5.7 Summary of the Interviews' Analysis

In this chapter, the analysis of the interviews is presented. From the findings of the first round of the interviewers, collaboration issues and the suggestions are discussed. Then from the second round of the interviews, the components that constitute the BIM and GIS process model are defined. First, the role and responsibilities of the project team members have been presented. Then, the tasks and implementation methods have been discussed. Followed by examining the content and methods of the deliverables and exchange of information.

The analysis of the interview data reveals that there is a lack of clear process to collaborate in terms of showing project tasks, the roles and responsibilities and the information needed at the same time. This makes delivering the right information at the right time is challenging. More importantly, it has been shown that such a process is missing; even when it is required to improve collaboration. In the next chapter, a structured process model for effective collaboration will be presented in the early design stages of the railway projects based on the developed CPW from this research as illustrated in section 5.4.3.

Chapter 6 : Development of the Collaborative Process Model

6.1 Introduction

In the previous chapter, the components constituting the BIM and GIS-enabled collaboration was presented and the need for process model has been outlined. This chapter presents the development of the components into a coherent process model for BIM and GIS-enabled collaboration, CPW, as shown in Table 6-1. As described in chapter 4, interviews were used to develop the process model, using various types of IDEF (Integrated DEFinition) notation. The high-level decompositions are presented in section 6.2. followed by detailed decompositions. Finally, section 6.4 summarises the chapter.

Table 6-1: IDEF align with CPW

From research (CPW)				IDEF			
No.	Stage	Task	Output	Level 1- IDEF0	Level 2- IDEF3 and IDEF0	Level 3-IDEF3	Level 4-IDEF3
0	Strategic Definition	Define public needs, project objectives, business case, prepare a feasibility study. (managing project need)	Clients requirements, project objectives, feasibility study. (project needs)	High level 1- IDEF0	Undertake strategic definition- IDEF3	-Define project objectives. - Appoint Team Appointment. - Develop EIR. - Prepare Site Information	- Define Managerial Aspects. - Define Commercial Aspects - Define Technical Aspects
1	Project Brief	Identify network constraints, develop and confirm an initial statement of requirements into the initial project brief. (managing information and project outline)	BIM execution plan, designer responsibilities, specifications. (project outline)	High level 1- IDEF0	Prepare project brief- IDEF3	Develop BIM Execution Plan	Develop a Communication Strategy
2	Option Selection development	Investigate to identify the options and develop it considering the economical delivered. Prepare concept design. (collaboration to make decisions)	Optimum layout of railway track, civil engineering structures and systems.	High level 1- IDEF0	Prepare design stage- IDEF0	Develop Single Option	Develop Route Options
	Develop concept	Prepare an outline of the concept design such as structures, civil, systems, and services plan of cost. (collaboration and using of technologies)	The final project brief, outline track, civil engineering structures and systems			Develop Concept Design	Develop Railway Track Model
	Develop detailed design	Prepare an outline of the technical design of the track, civil, systems in detail. (collaboration and using of technologies)	Detailed design of the track, civil engineering structures and systems			—	—
3	Construction	Manufacturing and construct taking into consideration the construction programme and design queries.	Project built and ready for operation.	—	—	—	—
	Handover and project Close Out	Settle the contractual accounts	Project formally closed, conclude the contracts	—-	—	—	—

6.2 High-level IDEF0 process model [Stages 0 – 1 – 2]

Further to the literature review (Drongelen, 2001), and the interviews (section 4.12), IDEF0 was used to break down the design phase into three stages in the CWP with hard gates between them. However, the top level of the CPW utilised three-stage numbering as follows: 0 (strategic definition), 1 (Preparation and Brief), and 2 (Design stage) for a complete process model using both the IDEF0 (the UOB number starts with letter) and IDEF3 (the UOB starts with a number) notations. This is followed by the second IDEF0 model to show the design stage in detail: develop single options, develop concept design, and develop a detailed design. Iterations are used to optimise the design on the basis of feasibility.

Figure 6-2 and Figure 6-3 below shows the IDEF0 model which uses the ICOM (Inputs, Controls, Outputs, and Mechanisms) Mechanism notation (Knowledge Based Systems Inc. (KBSI, 1993). There is a standard meaning for each side of the function box in terms of the relationships of the box arrows, Figure 6-1. The inputs are the entering arrows from the left side of the box. The inputs are transformed or consumed through the function to produce outputs. Arrows that enter the box from the top are called controls. Controls are used to specify the required conditions for the function to obtain correct outputs. Outputs are the arrows that leave a box on the right side which is the data or objects produced by the function. Mechanisms are presented by the arrows pointing into the bottom side of the box. These are upward-pointing arrows which identify the means that support the function execution. Furthermore, the downward-pointing arrows are call-arrows which allow the sharing of details between the models or between portions of the same model.

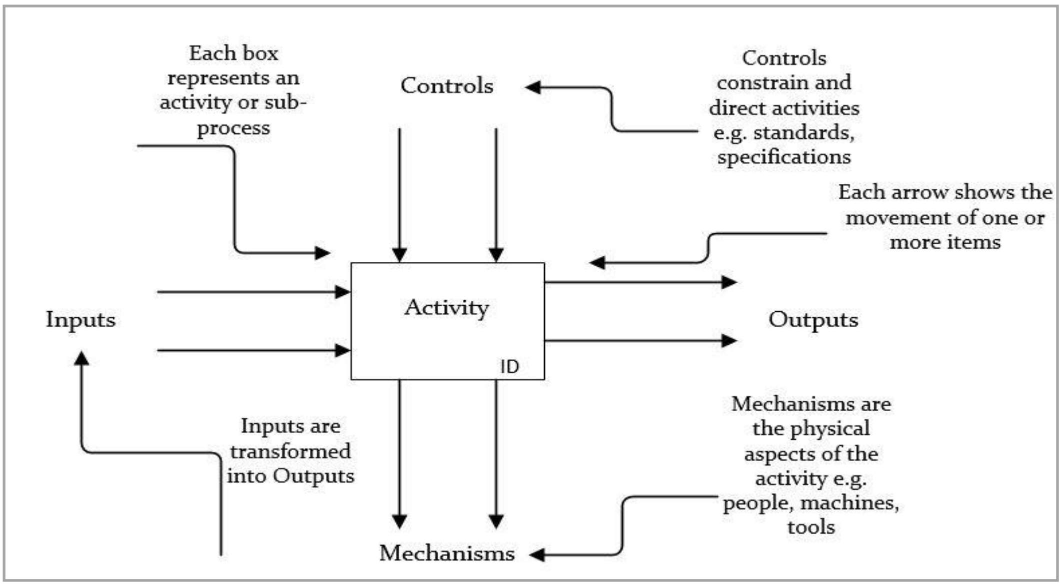


Figure 6-1: IDEF0 Symbols (KBSI, 1993)

The developed decompositions identify Model/BIM/GIS Uses (i.e. tools, processes, and tasks) and Model-based Deliverables (i.e. outputs), (Succar, Saleeb and Sher, 2016) of BIM and GIS-enabled collaboration.

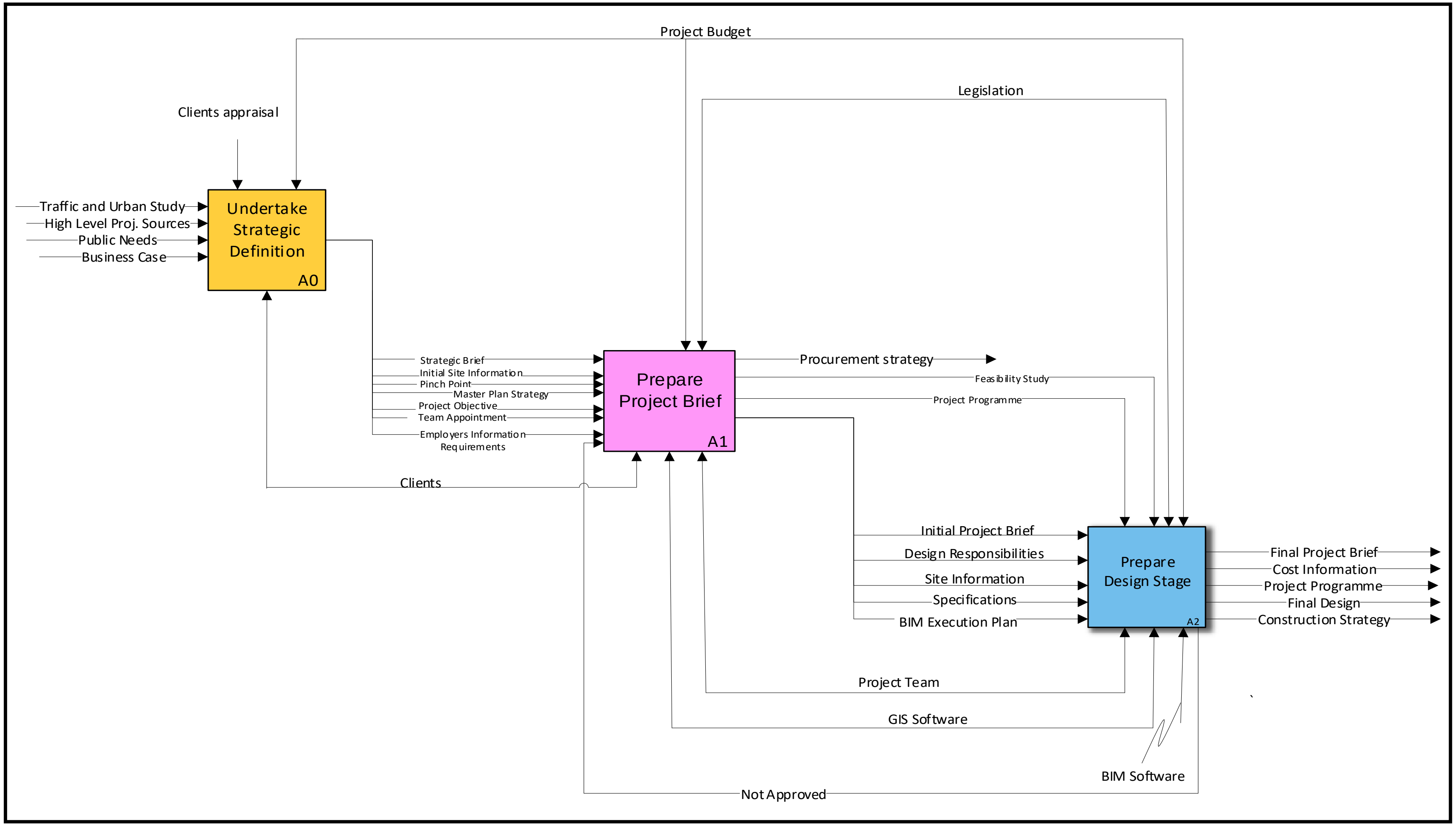


Figure 6-2: IDEF0 Decomposition Diagram for Stage [0-1-2]

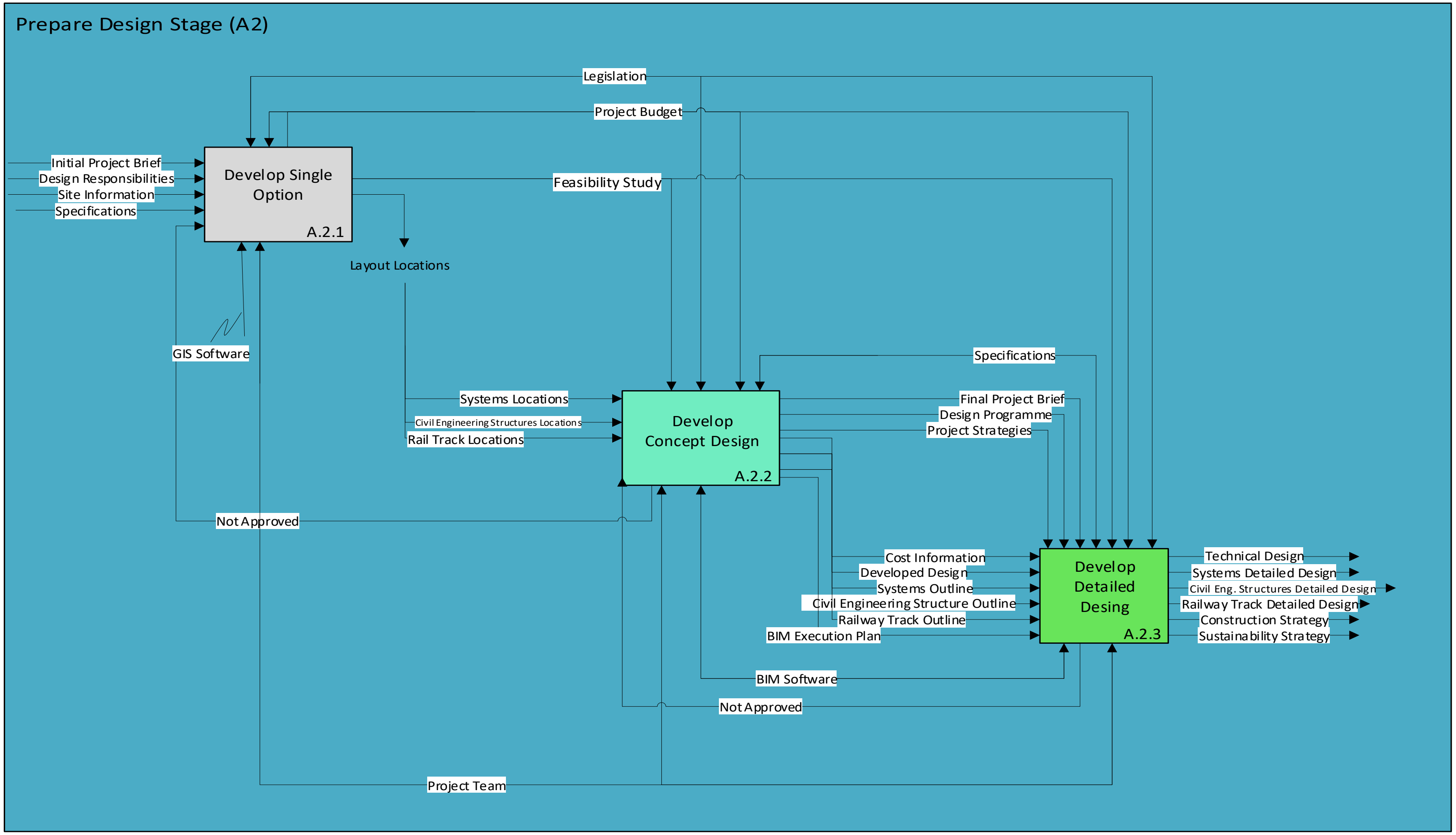


Figure 6-3: IDEF0 Decomposition Diagram for Stage [2]

The hierarchical relationships of the UOB (see section 4.11) of the IDEF diagrams of the stages (undertake strategic definition, prepare a project brief, and BIM execution plan) are shown in Figure 6-4 below:

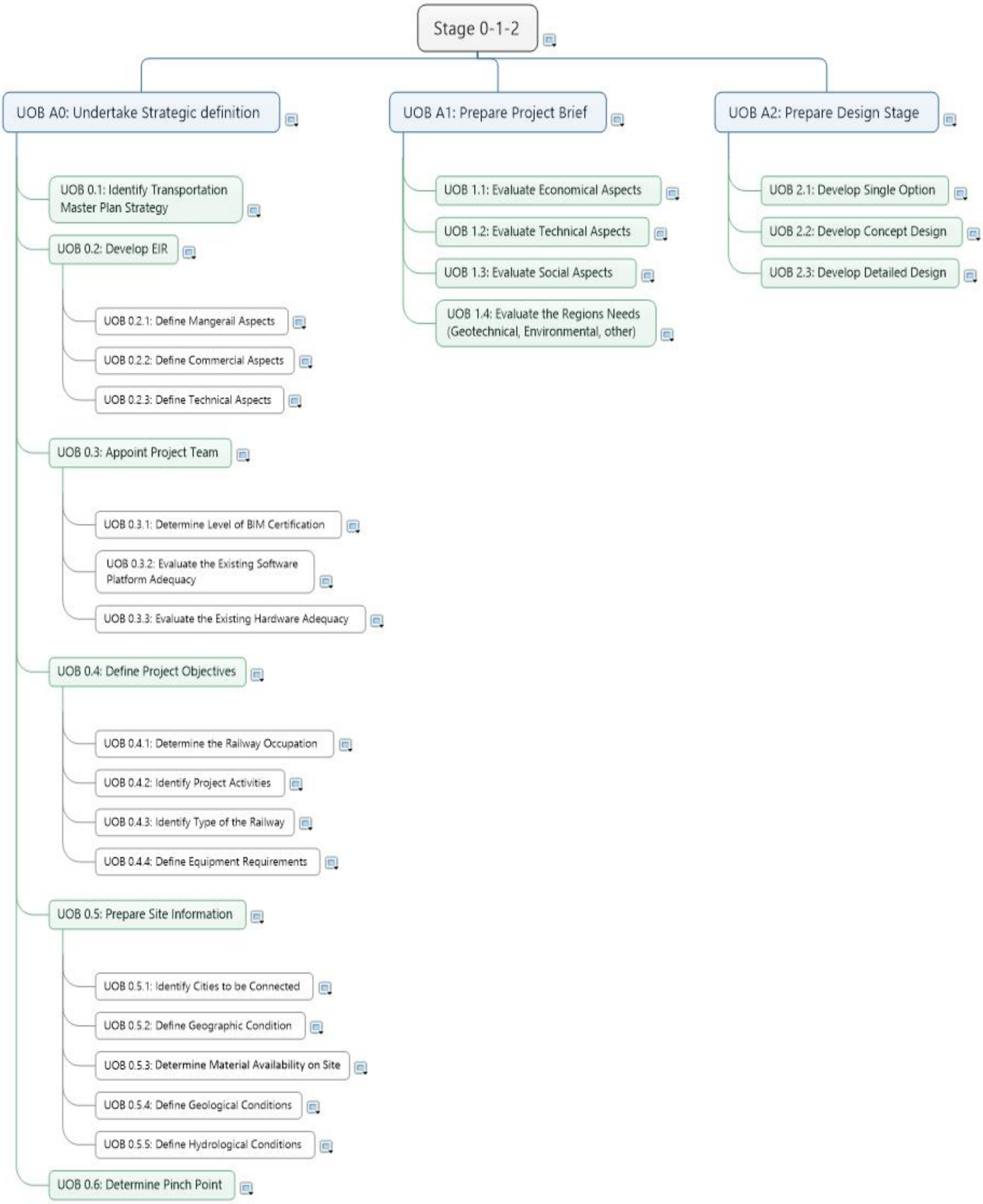


Figure 6-4: Hierarchical Relationships of Stage [0-1-2] Decompositions

6.2.1 Undertake Strategic Definition (UOB A0)

This stage is ultimately the first stage of the work, which is based on traffic analysis and public needs. Traffic and urban study consist of information such as Human resources, resources of agricultural and mineral, trade and commerce Pattern, industries located and projected, prospects of tourist traffic, existing transport facilities, locations of important government and private offices and planning for economic development of the area (II-3 BIM Manager, Chandra and Agarwal, 2007), while public or occupation needs consist of reasons behind building or renewing the railway. Finally, business cases imply that it is very important at the outset of the project to establish clients' requirements, project objectives, the purpose of the project, the type of the project, investigations, activates, responsibilities and roles of the project stakeholders will be demonstrated. All the mentioned basis has been introduced through several activities (Figure 6-5); Identity Transportation Master Plan Strategy, developing employer's requirements, team appointments, defining project objectives, preparing site information, and determining pinch point. Each of these has been illustrated in the coming sections. (Interviewee II-8 Assistant Professor of Railway Engineering)

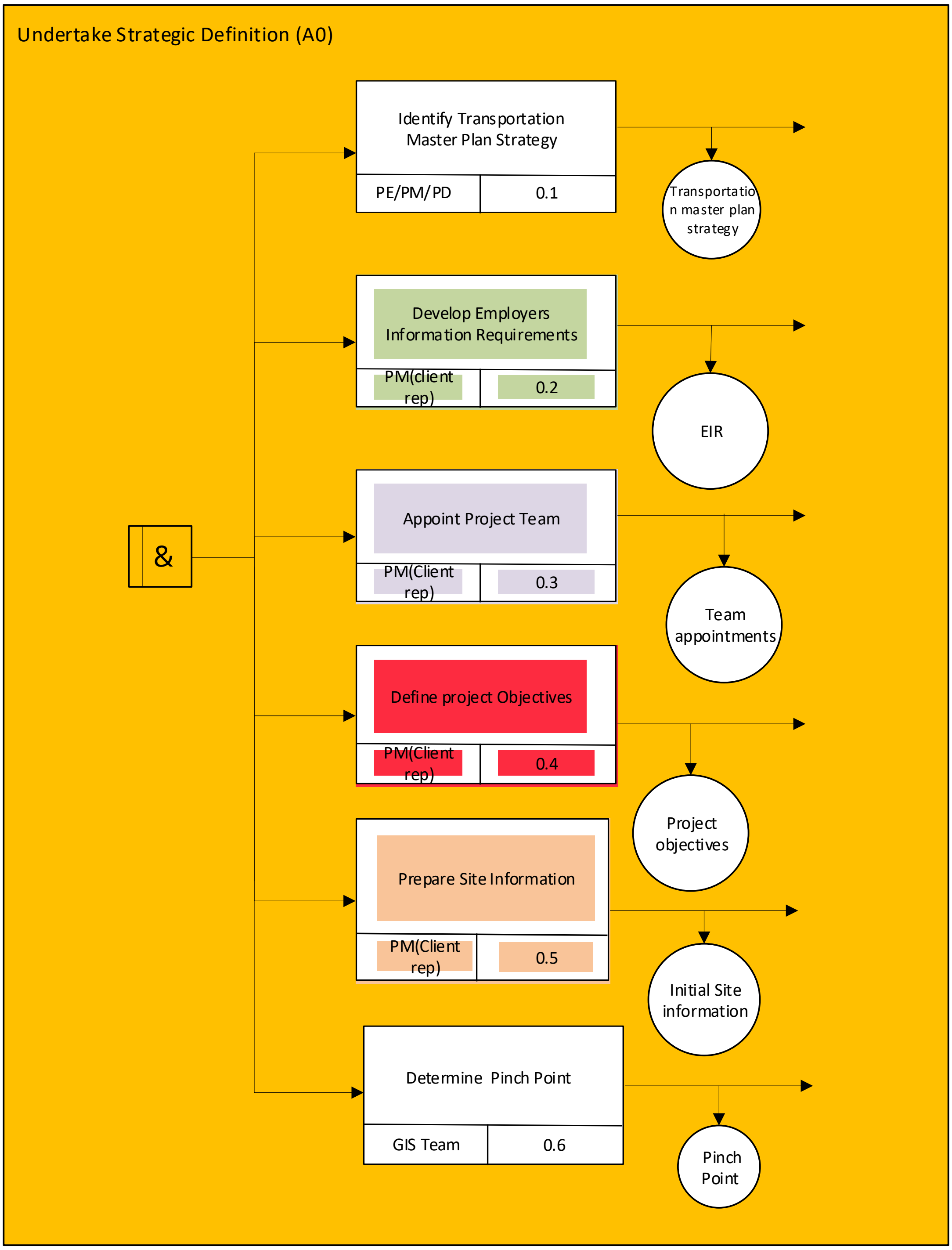


Figure 6-5: Undertake strategic definition Decomposition Diagram

6.2.1.1 Transportation Master Plan Strategy (UOB 0.1)

Several definitions for the master plan strategy will be obtained from the interviews. For example, interviewee (II-8 Assistant Professor of Railway Engineering) defines it as “a plan used to predict transportation demand size and distributed it on the different transportation facilities and determines the from 10 to 20 years”. Interviewee (II-8 Assistant Professor of Railway

Engineering, II-9 Senior Civil /Highway/Infrastructure Design Engineer) demonstrates the master plan strategy as a planning stage of the region (city, town,… etc..) which worked on the major transportation mean for the city or town to predict the needs to develop projects based on it. Therefore, the master plan strategy is crucial for identifying the demands and if there is a need for a project or not. As well as defining the type, size, and the location of the project. This master plan is defined by the urban planning authority which means for the government as future plans or development plan for the specific regions. (Interviewee II-9 Senior Civil /Highway/Infrastructure Design Engineer)

6.2.1.2 Develop Employers Information Requirements (EIR) (UOB 0.2)

EIR is defined by the UK BIM standard PAS 1192-2 (BSI, 2013) as a "pre-tender document setting out the information to be delivered, and the standards and processes to be adopted by the supplier as part of the project delivery process" (p.4). It notes that the "EIR should be incorporated into tender documentation to enable suppliers to produce an initial BIM Execution Plan (BEP)" (p.10). The EIR aim to clear definition of the user's information needs of the early stage of the BIM process and to provide a collaborating mechanism to enable project stakeholders to communicate, manage and deliver client's requirements. Even though, an obvious EIR required to set the processes and standards for the suppliers to be adopted during the whole project lifecycle (Hafeez et al., 2016).

Interviewee (II-1 BIM Consultant) defines EIR as information requirements through which the level of detail or level of development of the required information for the specific project will be identified, and it should be followed by all the stakeholders. The same interviewee emphasised that the EIR is very significant for any project and its steps differ from one project to another depending on the nature of the project information. Interviewees (II-2 Head of BIM and II-1 BIM Consultant) add that these requirements are set by the clients to which level the BIM model of the project could be developed, and which current and future needs for a different facility for a period of time which ranges information is needed. As a result, plenty of time and effort are saved; for example, when the stakeholders considering information out of the scope of the project and not required by the clients. Therefore, the concept of the EIR can be summarised as a guideline or standard set by the clients to determine the client's requirements in terms of the level of details and the standards which make the output of the project clear for all the participants to work on. In other words, to ensure that each participant works within the project scope. (II-1 BIM Consultant, II-2 Head of BIM).

According to the interviewees (II-1 BIM Consultant, II-2 Head of BIM, II-6 Architecture and Construction Manager) and (BSI, 2013) EIR consists of three major categories (Figure 6-6) (discussed below): Managerial, commercial and technical aspects and each of these main categories classified into different subcategories as illustrated in the next sections (Figures in Appendix F). Furthermore, these aspects can be performed in parallel (soft gate). They pointed that EIR very important to be set at the begging of the project to overcome collaboration challenges (section 5.4.1), to ensure that the work is within the scope of the project objectives, roles, responsibilities and delivering information are clear from ahead of project commencement, as (interviewee II-2 Head of BIM) suggested “be very prescriptive and explain exactly what information is needed when using an EIR etc.”.

The EIR is needed to avoid responsibilities duplication through ensuring that the project contract in such a way including the information requirements (BSI, 2013). The EIR aspects provided by the clients or who represent the clients (i.e. clients or who representing responsibility).

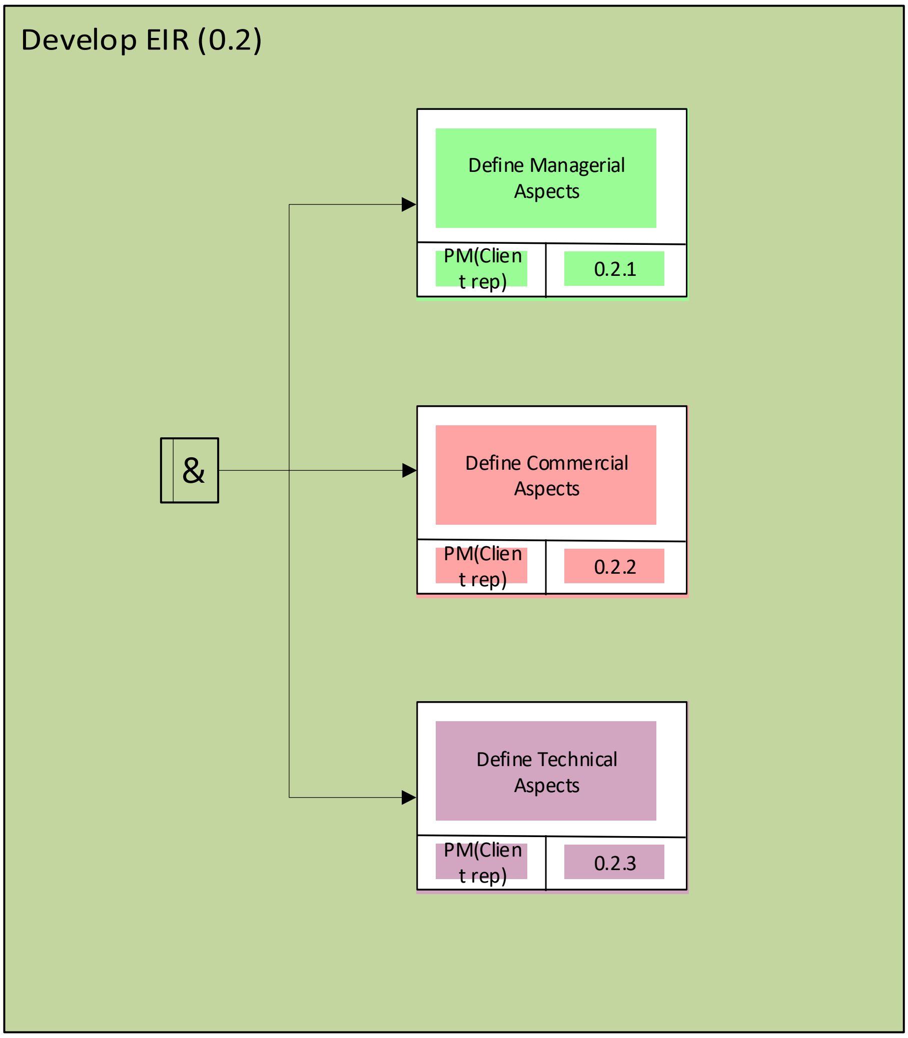


Figure 6-6: Develop Employers Information Requirements (EIR) Decomposition Diagram

- Define Managerial Aspects (UOB 0.2.1)

This activity includes identifying BIM standards, coordination strategy (bidders' proposal requirements to manage the collaboration process), developing a project programme and preparing contracts. These items vary from one project to another based on the clients' requirements (interviewee II-1 BIM Consultant, II-9 Senior Civil /Highway/Infrastructure Design Engineer), (BSI, 2013).

- Define Commercial Aspects (UOB 0.2.2)

Commercial aspects consist of preparing a business case study, identify budget allowance, regulation requirements, determine land equation requirements, and define deliverables. (Interviewee II-3 BIM Manager).

- Define Technical Aspects (UOB 0.2.3)

The last aspects of the EIR are technical aspects which include identification of the collaboration process (bidders' proposal requirements to manage the collaboration process), identifying software and hardware requirements. As well as identification of data exchange formats and LOD (needed to distribute the model and deliver it according to the required protocol). In addition to the above mentioned, the determination of competency requirements is needed. It should contain competence assessment details, and which must be responded to by the bidders. Furthermore, changes to related tender documentation (BSI, 2013).

6.2.1.3 Appoint Project Team (Team Appointment) (UOB 0.3)

Team appointment is part of undertaking strategic definition by clients or the clients' representative. A process during which the project team (which includes the BIM team and GIS team) determines the level of BIM certification and evaluate the adequacy of the software and hardware. The clients will accordingly determine the required team members' competencies. (Interviewees II-3 BIM Manager, II-7 Senior Quality Control Engineer)

6.2.1.4 Define Project Objectives (UOB 0.4)

According to the interviewees (II-1 BIM Consultant, II-3 BIM Manager), project objectives include several activities such as determining the occupation of the railway by client representative (e.g., project manager). Clients or their representatives are also responsible for identifying the type of the railway (passenger or freight) (interviewees II-3 BIM Manager, II-9 Senior Civil /Highway/Infrastructure Design Engineer) and for defining the equipment requirements. The project team is responsible for identifying project activities. All these activities can be performed at the same time (soft gate).

6.2.1.5 Prepare Site Information (UOB 0.5)

A part of defining the EIR is providing information about the site to facilitate the upcoming stage. Different stakeholders are participating to identify different activities. For example, the role of the clients is to identify the points or cities that need to be connected. Whilst, GIS experts (part of the GIS team) are responsible for defining the geographic condition. The Architect (part of the

BIM team) determines the source of materials. Defining the geological conditions is the role of the Geologist. Finally, hydrological conditions defined by a hydrologist. It is worth mention that all these activities are conducted in parallel, which means there is no dependency on each other. (Interview II-7 Senior Quality Control Engineer, II-8 Assistant Professor of Railway Engineering, II-10 Project Manager)

According to the Oxford English Dictionary, a *pinch point* is "a place or point where congestion occurs or is likely to occur, especially on a road. The transport secretary has set out plans to ease traffic jams at ninety-two pinch points. Determination of pinch point is performed by the GIS team. The pinch point is a benchmark of the all general information about the delivered site to be as a connection point to set the project on it (interviewee II-10 Project Manager).

6.2.2 Prepare Project Brief (UOB A1)

A feasibility study considers a part of the brief's requirements. Interviewees (II-3 BIM Manager, II-8 Assistant Professor of Railway Engineering) described the assessing process of scheme design as coming below. These activities can be conducted simultaneously without affecting each other (soft gate) but at the same time, the stakeholders remain aware of other activities. Feasibility study covers several aspects such as economic, technical, social, environmental and Geotechnical aspects by different stakeholders (Figure 6-7).

1- The evaluation of the economic aspects conducted by Quality Control Engineer which addressing the financial benefits and cost related to project development.

2- At the same time, the Technical Office Engineer starts to evaluate the technical aspects which consist of geological information. For example, types of soil strata and the rocks nature, business location, technology needed and, materials needed and labour.

3- Evaluation of the social aspects performed by the Human Resources Manager.

4- Project manager performed the BIM Execution Plan (section 6.2.3)

5- Finally, an environmental engineer is responsible for evaluating the regional aspects (environmental, Geotechnical and others). The areas of concern through this evaluation are earthworks and foundation for the structure, limited value to the selection of the route. Furthermore, the alignment which should normally avoid the flooded area and considered the climatic conditions and etc. After completing each activity, the responsible stakeholder submits a report to the project manager. After all, evaluations are completed, a meeting will take place to check the criteria according to the clients' requirements and the master plan. The participating parties in this collaboration meeting include a planner, a quality control engineer, technical office engineer, human resources manager, and project manager. However, almost all interviewees (II-3 BIM Manager, II-6 Architecture and Construction Manager, II-5 BIM Engineer) pointed that these parties are changeable and not fixed depending on the projects and most times are assigned to different companies as railway projects considered as megaprojects. Megaprojects are costly and time-consuming in accordance with the results of checking the criteria, a report is forwarded to the clients to make the decision on starting the next stage (develop possible route options) (hard gate which the process will stop until a final decision is taken for starting the next stage).

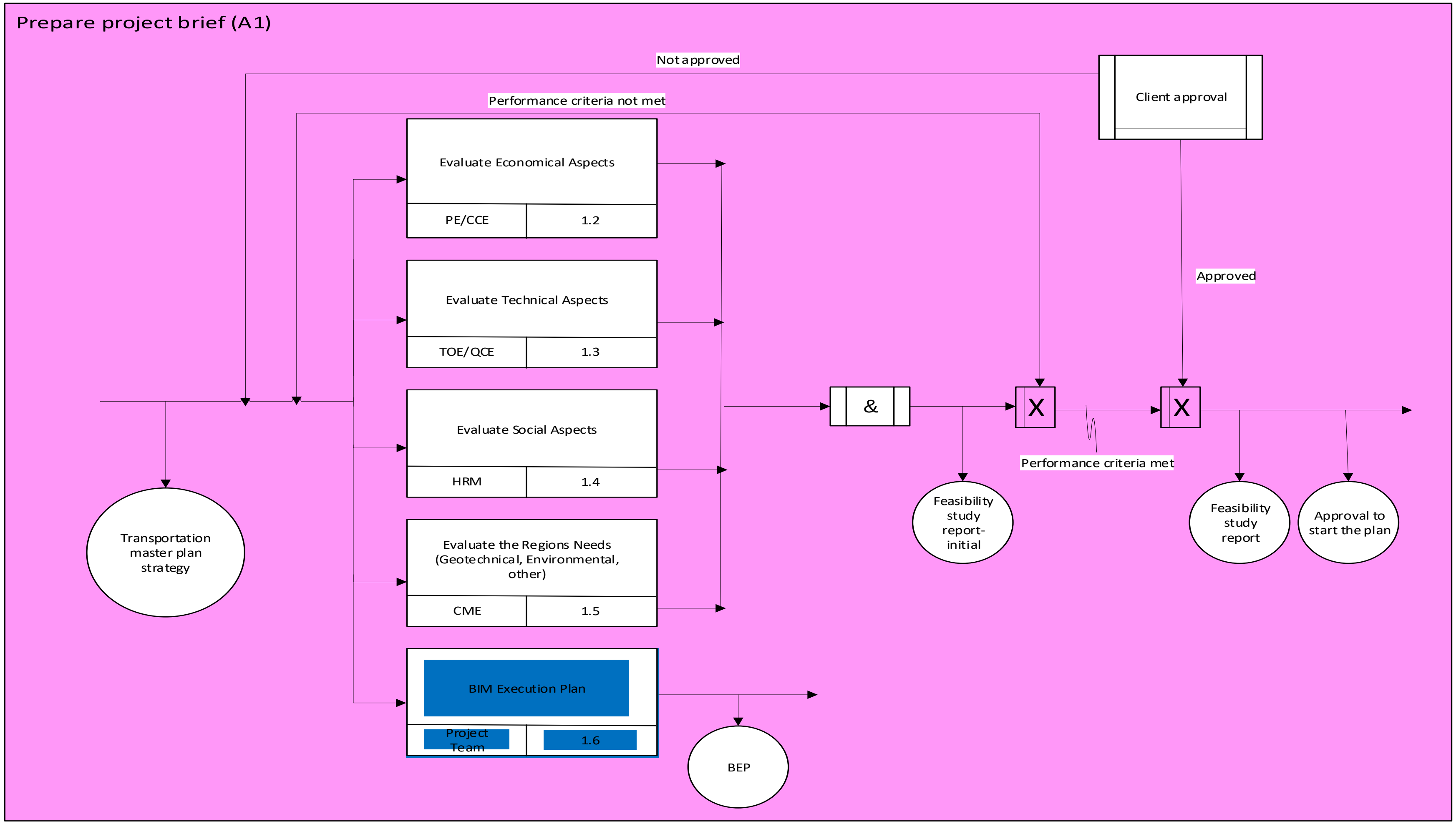


Figure 6-7: Prepare project brief Decomposition Diagram

6.2.3 BIM Execution Plan (UOB 1.6)

The BEP is the plan used to address the issues in the EIR, and it submitted first at the pre-contract stage. Then at the post-contract stage, the BEP is developed to give more detail on how BIM will be used by suppliers to deliver the project (BSI, 2013). Interviewees (II-1 BIM Consultant, II-2 Head of BIM, II-3 BIM Manager) reported that BEP is necessary to make sure that the requirements within the EIR are achievable for the employers. From the interviewees' perspective (II-1 BIM Consultant, II-2 Head of BIM, II-3 BIM Manager), BEP consists of several activities as follows (Figure 6-8):

1- The project manager (client's representative) provides a description of the project and identify the project directory. However, developing a project programme performed by the project team. As a result, the project manager develops design responsibility with information exchange from identifying the project directory and developing the project programme to start the next step which is developing a communication strategy.

2- Project team starts to develop a communication strategy. This consists of defining critical decision points, from which the required information exchange will emerge. At the end defining the deliverables.

3- After identifying BIM and GIS software, the project team determines software interoperability.

4- Determine the software interoperability and developing a communication strategy, the project team will be able to develop BIM and GIS manual to be used by all the participants during the whole lifecycle of the project.

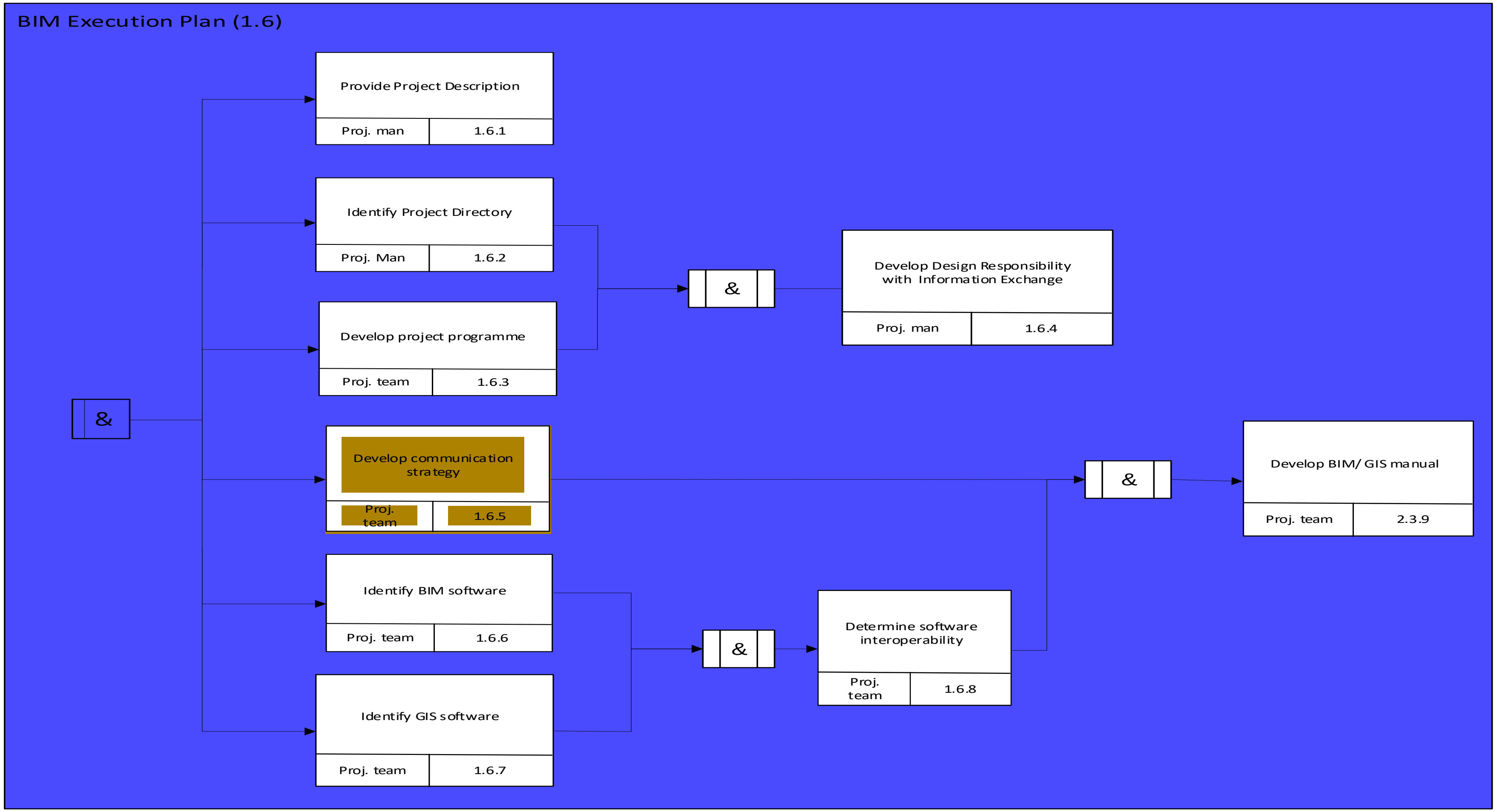


Figure 6-8: BIM Execution Plan Decomposition Diagram

6.3 Detailed IDEF3 Process Decompositions [stage 2]

To develop a BIM action plan, six essential elements emerged from the literature: (i) the strategy, (ii) usages, (iii) process, (iv) information, (v) infrastructure, and (vi) personnel (CIC, 2011). This section illustrates the usages of model/BIM; in other words; tasks assigned to design roles; deliverables based on the model (Succar, Saleeb and Sher, 2016), the requirements of information and coordinating them into a comprehensive process for railway route design. A process model was developed in IDEF3 which includes tasks or Units of Behaviour (UOBs) for BIM and GIS-collaboration purposes, which are executed using BIM and GIS. The following sub-sections show the findings from the interviews, literature review using the CDM (Klein et al., 1989) to elicit knowledge from the experts to determine the IDEF3 processes and sub-processes at a detailed level (Mayer et al., 1995), for the design stage. Figure 6-9 below demonstrates the hierarchical relationships of the discussed UOBs' decompositions in this section come from Figure 6-3.

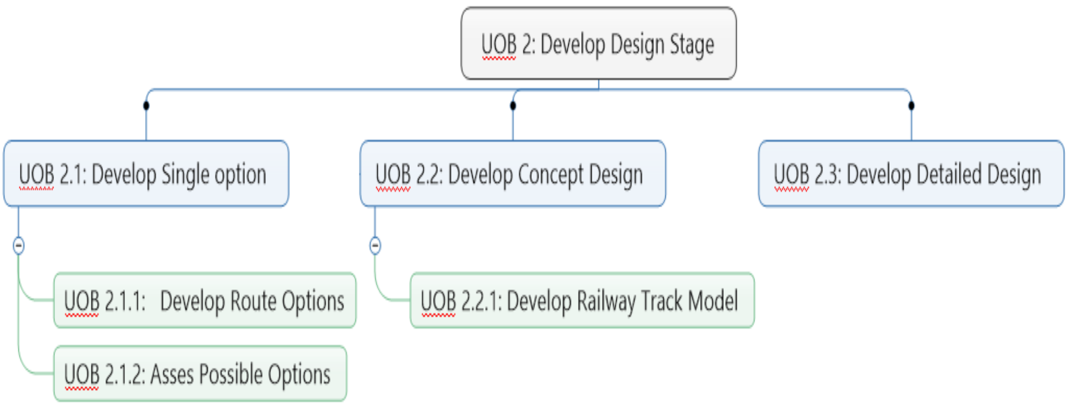


Figure 6-9: Hierarchical relationships of the decompositions of stage 2

"Scenario" is used in the IDEF3 (discussed in section 4.11) which is considered as the basic organising structure to establish the focus and the boundary conditions for describing the process. This is the motivation behind the fact of tending humans to describe what they know whether the activities they have experienced in an ordered sequence or noticed within the context of the particular scenario or specific situation (Mayer, Painter and DeWitte, 1992).

Moreover, the design of the IDEF3 provides a medium to capture the description of the facts by the experts of the domain regarding how their systems work. From one of its strengths the ability to combine several scenarios and viewpoints in a single diagram while being permissive of partial or incompatible descriptions (Mayer, Painter and DeWitte, 1992). Through the IDEF3 decomposition diagram, the sequencing and the structure of the collaboration process are presented. As a result, the developed IDEF3 diagrams in this research revealed the relationships identified between the usages of the BIM and GIS enabling collaboration, the gateways and the critical decision points. Objects are shaped from the information required (inputs) and the information shared (outputs) of the function. The presentation of the decompositions is following a hierarchical manner, in which the descriptions of the high-level are coming first and followed by detailed descriptions.

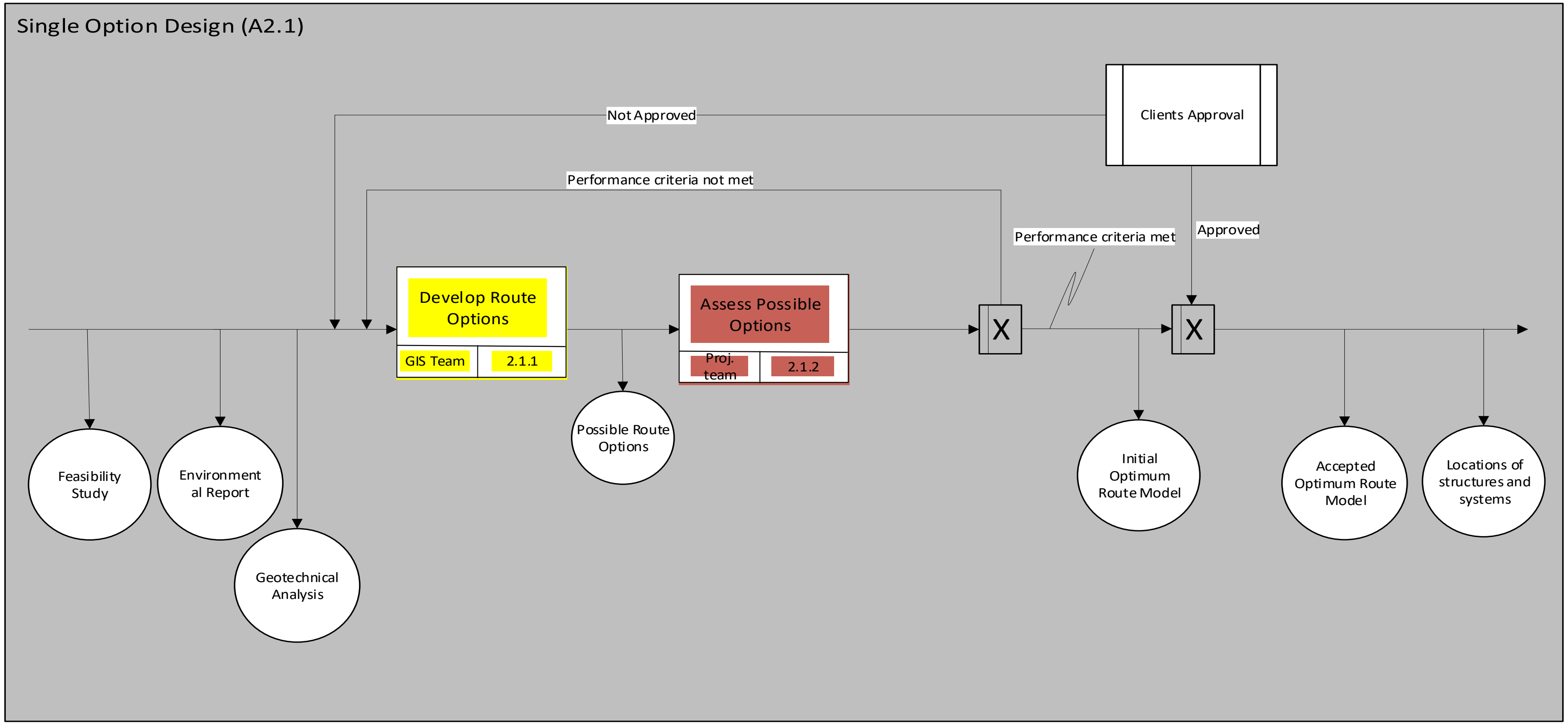
6.3.1 Develop Single Options (UOB A2.1)

After preparing a feasibility study, an environmental report and a Geotechnical analysis report and following the client's approval of the plan; the next step started which is a very significant stage (interviewee II-3 BIM Manager). At the end of this stage, the optimum route of the railway will be identified after several processes. GIS is the most important tool used for several reasons. The main reason is that GIS provides any information needed such as the whole picture of the area that the railway needs to be constructed there with no need for field visits. The second reason is that it is easy to obtain possible options for the route to be the preferable one and ready to assess. Finally, any information obtained from GIS can be saved and accessed at any time needed. Therefore, in the future or if something changes and information is needed; it can be easily provided without any problem. Overall, a huge amount of time and cost can be saved. Also, GIS makes decision making both precise and easy. Furthermore, this information will be stored in the database for the future in the construction and maintenance phase without needing the responsible stakeholders or investigating in case those stakeholders leave their work for any reasons (interviewees II-3 BIM Manager, II-2 Head of BIM, II-8 Assistant Professor of Railway Engineering, and II-6 Architecture and Construction Manager).

Interviewee (II-8 Assistant Professor of Railway Engineering, II-3 BIM Manager) illustrated the steps of this stage as follows and showed in Figure 6-10:

1- GIS team provides developmentally route options (illustrated in the next section (develop route options). The output from this step is possible to route options which will be ready for assessment.

2- By the project team, these possible options will be assessed (illustrated in section 6.3.1.2). After the assessment process is being done for these options opposite to the criteria that need to be met. If performance criteria are met, then it will be reported to the client to receive the necessary approval. If performance criteria are not met, then the step of developing route options needs to be repeated. In case the client approval got the accepted optimum route, the model will be made in addition to the specifying the locations of structural and systems. If clients do not approve those options, the process needed then to be returned to develop route options steps and repeated.



Railway track:
Superstructure
Track panel: Rails, sleepers, Elastic pads.
Track bed layers: Ballast, Sub-ballast.

Substructure: Formation layer, Subgrade

Figure 6-10: Develop Single Options Decomposition Diagram

6.3.1.1 Develop Route Options (UOB 2.1.1)

The process of this stage presented in Figure 6-11 and illustrated as below and according to the interviewees (II-2 Head of BIM, II-3 BIM Manager, II-8 Assistant Professor of Railway Engineering, II-9 Senior Civil /Highway/Infrastructure Design Engineer):

1- Collecting topographical maps about the area where it is planned to construct a railway. This is done by using GIS tools such as ArcGIS or from Google maps which are performed by the GIS team and some of these maps can be obtained from associated parties such as governmental sides.

2- According to the available information (feasibility, Geotechnical, and environmental) railway corridor will be planned on the existing maps using both BIM and GIS tools performed by GIS specialist and BIM team. During the planning process is should Bearing in mind the criteria. For example, the attraction points, the cities that need to be connected, and if environmental conditions suitable for planning these corridors or not.

3- After identifying the corridors and planning them, the GIS team starts to identify locations of structural engineering and systems. For example, the Civil Engineer will determine if the route will be overpass or underpass depending on the terrain. Furthermore, identify the locations of the tunnels (by Tunnelling Engineer) and the bridges (Structural Engineer) according to the geographical, hydrological, and environmental analysis. While identifying the stations' locations depends on the feasibility study, attraction points, social aspects, or for trade or business purposes and it is the role of the Civil Engineer. Finally, calculate the quantities of the cut and full of the proposed route by Quantity Surveyor. Thus, the decisions to identify the alternative will be easy and accurate.

4- At the end of this stage, the alternatives of corridors will be prepared by the Project Manager, Planner, BIM and GIS Team to be ready for clients' review to get the approval.

5- Clients will review the alternative options and in the case of the agreement, the alternatives will be ready for assessment in the next step. Otherwise, the steps will be repeated by collecting topographical maps.

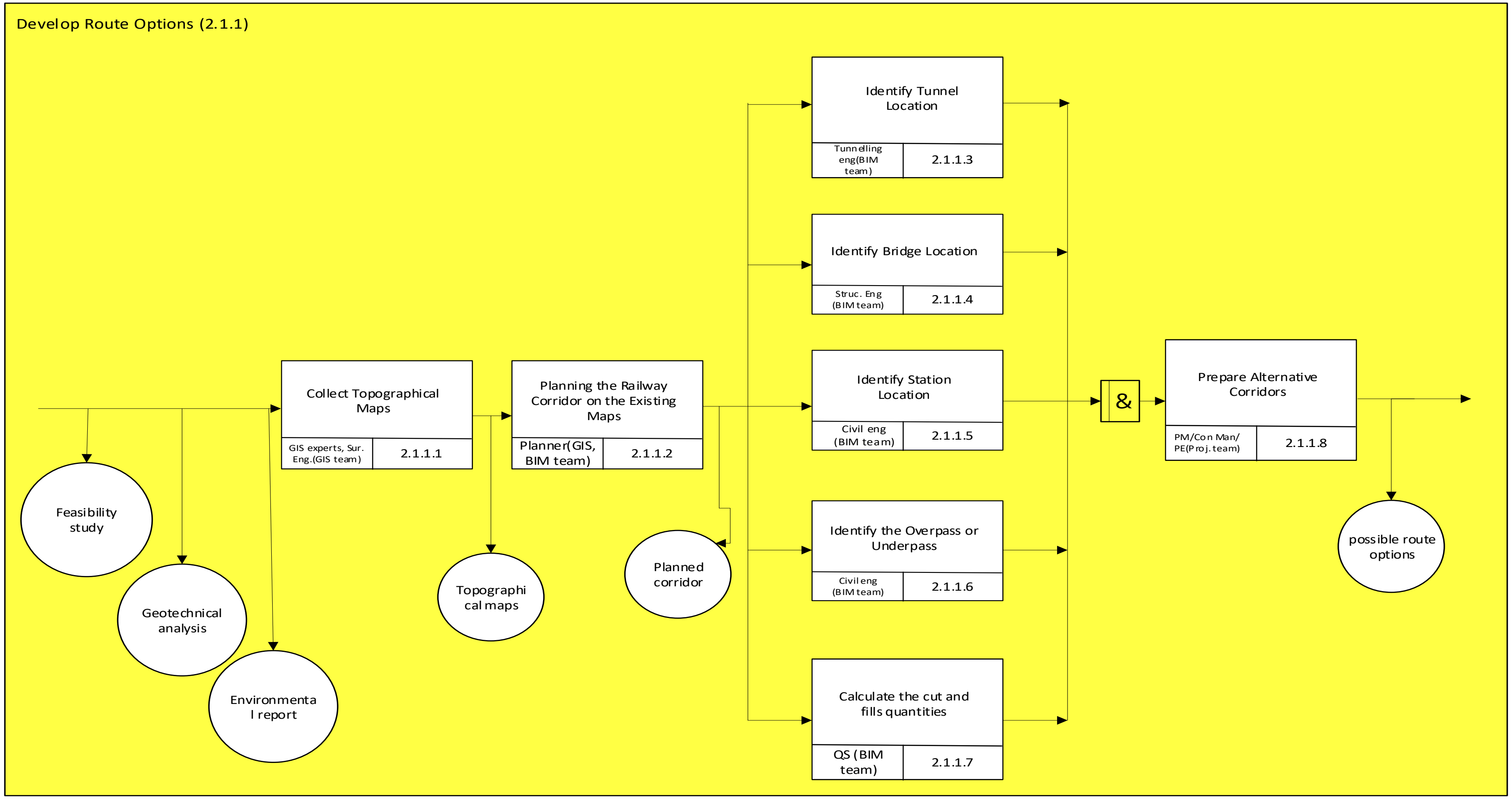


Figure 6-11: Develop Route Options Decomposition Diagram

6.3.1.2 Assess Possible Options (UOB 2.1.2)

Interviewees (II-2 Head of BIM, II-3 BIM Manager, II-8 Assistant Professor of Railway Engineering, II-9 Senior Civil /Highway/Infrastructure Design Engineer) indicated that in this step, alternatives are ready for assessment according to the criteria to eventually reach the model of the optimum route with the locations of the structures and systems after being approved by the clients. The following points demonstrate the steps of this stage (Figure 6-12):

1- Designers and Landscape Engineers (DLE) start to develop a 3D model for the possible route options using BIM tools such as Revit to assess them.

2- Geological Engineer assesses the geological condition that is available from GIS.

3- Urban Plan Authority performed the analysis of land acquisition. Urban Plan Authority should be taking into consideration the land and if approval is needed or not. If the land needs to be bought and is that necessary or not because changing the railway alignment is difficult as it involves costly structures, difficult to get additional land for a new alignment. Then the route model using BIM tools is developed. Identifying the land can be identified using GIS tools the land acquisition work should start within enough time to complete the legal and financial requirements and own the land to start the construction works. The land acquisition process is based on the land acquisition act and with the help of the government (Chandra and Agarwal, 2007).

4- Environmental Engineer assesses the environmental impact of the constructed line such as natural life, wildlife, agricultural areas, forests, and natural resources.

5- Civil Engineer (BIM Team) checks if the resources accessible to the proposed constructs route such as materials and equipment. Easy accessibility of resources saves a huge amount of money instead of spending money on preparing the way to make the arrival of the needed resources to the site to facilitate the construction works

6- Noise impact is a very important factor to be assessed to define the optimum route. Noise Engineer (or Sound Engineer) uses information from GIS to define the most places affected by the noise and which route have less impact and the possibility to reduce it.

7- Interfacing and Network Engineer performed the analysis of the network and interfacing. Networks consist of roads, cables, pipelines, streams, arteries, metro and etc. For example, interfacing with other existing networks, identify locations of drainage systems and gravity, etc. Network analysis can also include finding the best route in terms of consuming less time and money through various stops passing using GIS. Furthermore, minimising travel cost by finding the closest facility. Moreover, generate the closest facility and consume less time path through driving direction. Consequently, generating the alignment will be the best, accurate and far away from the interfacing problems. (Padaya, Juremalani and Prakash, 2017)

The above steps happened in parallel to the whole proposed route. However, the estimation of the initial cost will not start until the entire analysis process is completed. After the completion of the analysis process, the Quantity Surveyor with Cost Consultant starts to estimate the initial cost. Then at the end of this step, the report of cost estimation will be ready. A meeting is held, attended by the project team to check if the model and the assessment meet criteria. If the criteria are met, then a meeting is held to receive the clients' approval. In case, the criteria are not met, or/and the clients don't approve the models, the assessment process should be repeated.

As a result, the project team and clients can decide easily and effectively which proposed route is the optimum one according to the cost estimation report and the related assessment. Therefore, the locations of the structures and the systems will be allocated and ready to be designed in the next step.

The criteria here in this step to be met are that the route should connect the needed cities, passed from attraction points that highlighted in the feasibility study. Also, the route should pass from lands that belong to the government, which mean no need to own it from the public. Furthermore, no need for demolition of cultural or historical sites. Moreover, easy access to the resources, having a smaller number of tunnels, bridges, and full and cut. Finally, ensure the cost of the proposed route under the budget and achieve the target; thus, saving a huge amount of money. Based on these criteria the optimum route can be easily selected.

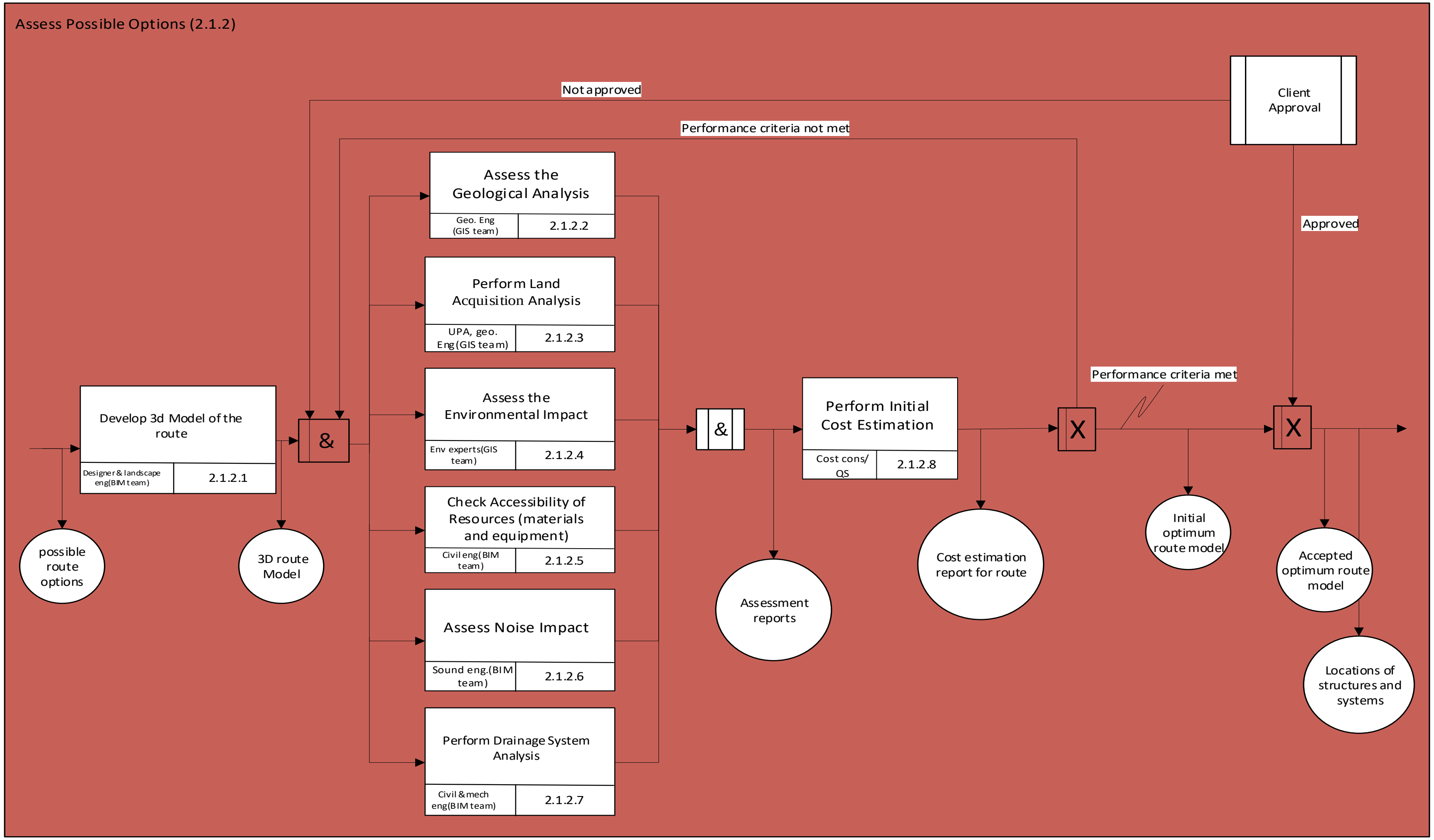


Figure 6-12: Assess Possible Options Decomposition Diagram

6.3.2 Develop Concept Design (UOB 2.2)

Interviewee (II-3 BIM Manager, II-10 Project Manager, and II-7 Senior Quality Control Engineer) described that, in this stage, the BIM team starts to develop a BIM model for railway track, civil engineering structures, and systems. Then the meeting is held to check the criteria and the next meeting to receive the clients' approval. The criteria in this stage will be different according to the railway that has been constructed. The different standard can be followed based on the country, project, aims and objectives that should be achieved from this railway. The outputs of this stage will be optimised BIM model for the track, civil engineering structures, and systems (Figure 6-13).

6.3.2.1 Develop Railway Track Model (UOB 2.1.1)

Designing of the railway elements varies and changes over time and from one project to another based on the purposes and the target of building a given railway.

To start the design process of this stage, several things should be available from previous stages such as the accepted route model, clients' requirements, specifications, and cost information. The process is as follows and shown in Figure 6-14:

1- The BIM team starts to determine the types of a track panel according to the requirements and based on the standard. For example, what is the type of sleepers that is capable of carrying the required bearing capacity for the specific speed. The output of this step will be a report on track panel types and specifications (rail, sleepers, and elastic pads).

2- In parallel, the BIM team determines the types and specifications of track bed layers (ballast and sub-ballast) and substructure (formation layer and subgrade) to get the report of both track bed layers and substructures.

As a result, the BIM team (architecture) will be able to start developing a BIM model for the track panel, track bed layers, and substructures respectively. The output is a BIM arch model for track panel, track bed layers, and substructures.

3- Project team visualises the model, checks the clash detection and coordinate the models. If the models are successfully coordinated, the models are then uploaded to the BIM team a check the criteria, otherwise, the associated parties will be notified to solve the coordination issue and suggest solutions.

4- Here at this point, these models should be checked to ensure if the performance criteria are met or not. This is can be conducted by using a collaborative environment to share these models and to meet for checking the criteria with other participants such as consultants, architectures, BIM developers, EMP and model coordinators. If the performance met the criteria requirements, these models will be submitted to the clients to receive approval, and the arch model will be ready by then. If the performance criteria are not met or the clients don't approve the models, the process will be subsequently repeated from the beginning of determining types of track panel, track bed layers and substructures.

5- After this stage finished and agreed, the next stage began to start to develop the models of each element: railway track, civil engineering structures, and systems by BIM Team (Figure 6-14).

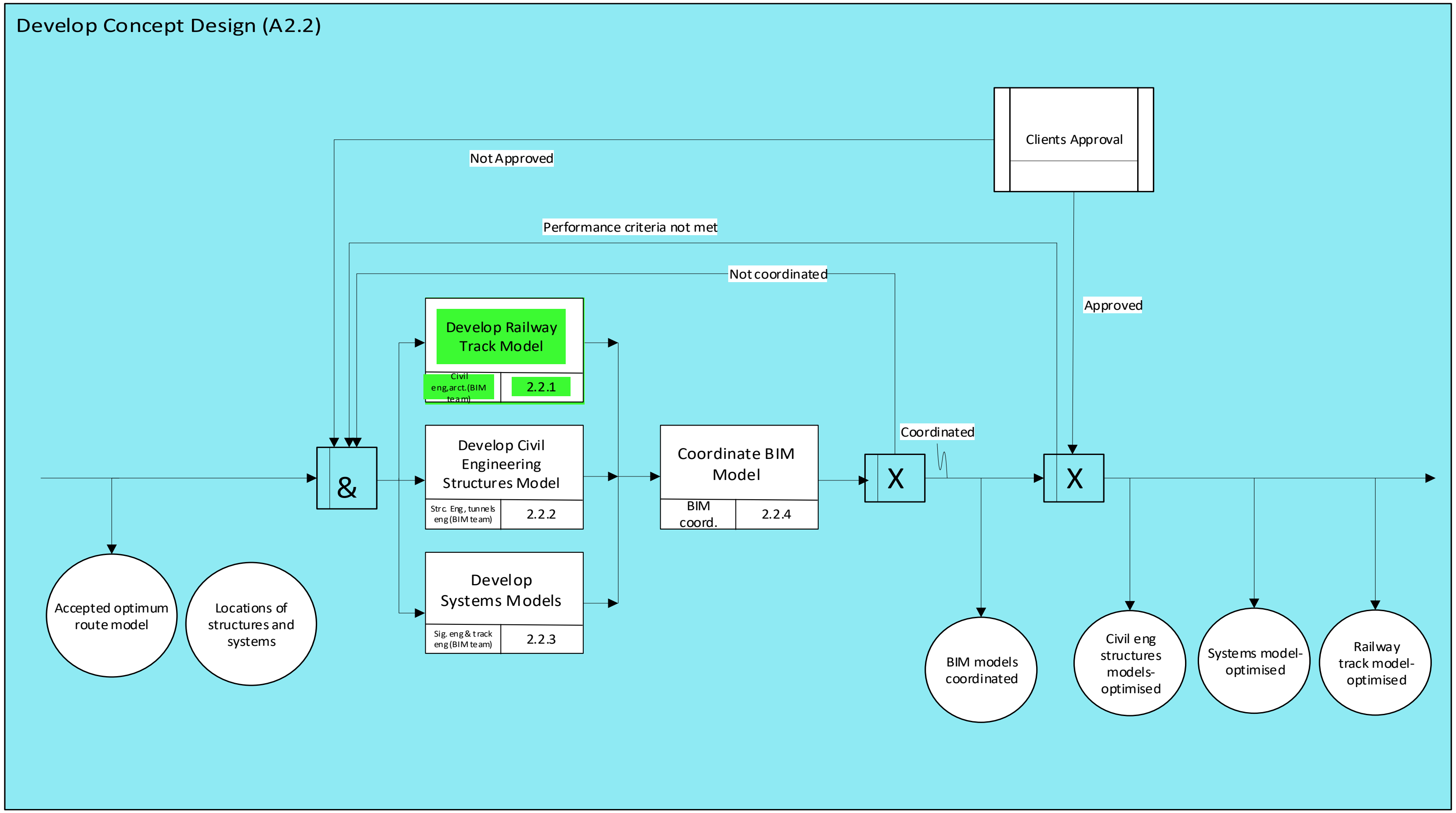


Figure 6-13: Develop Concept Design Decomposition Diagram

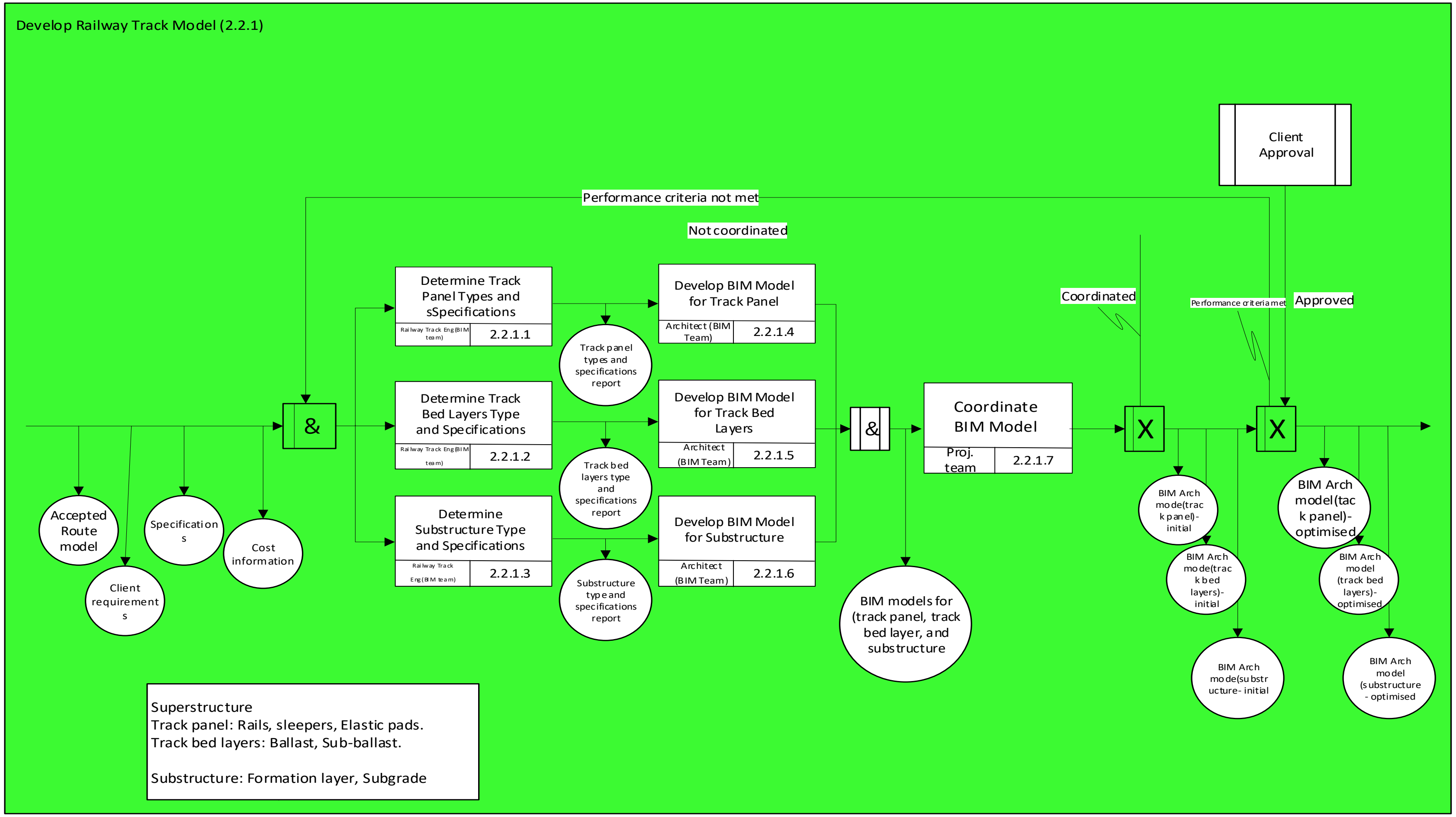


Figure 6-14: Develop Railway Track Model

6.4 Summary

This chapter presented the activities that need to be followed at the design stage to achieve effective collaboration, which leads to providing the right information at the right time. The IDEF0 and IDEF3 process modelling notations (Mayer et al., 1995) are utilised to prescribe the process of providing and sharing information by providing the tasks, and the participants to whom those tasks are assigned, with the inputs, the outputs (deliverables) during the design stage of the railway projects. As well as defining the soft gates for the decision points. Furthermore, IDEF process models can use the logical decisions and the commands as the service layer of a workflow management system delivering the BIM and GIS-enabled collaboration. Analysis of the interviews' responses was the basis of explaining the above process following CPW. In order to ensure the workability of the developed process model, a validation process (focus group, and interview) has been conducted (chapter 8) by using an industry user-friendly software called 4project. Followed by presenting final IDEF process models which revised according to the feedback and recommendations received from the participants during the validation process.

Chapter 7 : Discussion

7.1 Introduction

This chapter discusses the themes emerging from this research and presents them in the context of the literature.

The main sections of this chapter discussed the questionnaire results followed by two rounds of in-depth interviews and then validation, and how the findings relate to the literature to produce the process model for BIM and GIS-enabled collaboration in the design stage of the railway project. The last section is a chapter summary.

7.2 Potential BIM and GIS in the Railway Project

Several recent studies focused on integrating BIM and GIS in different functions in both building and infrastructure as demonstrated in the literature (section 3.7 and 3.8). However, the literature revealed that there was a research gap regarding the usage of BIM and GIS collaboratively in railway projects. For example, (Bensalah, Elouadi and Mharz, 2018) argued that BIM remains a tool designed initially for the purpose of buildings rather than infrastructure. Therefore, the need for investigations arose to establish an understanding around BIM and GIS, and collaboration in terms of definitions, area of applications and the importance of their integration. Furthermore, it was necessary to establish the state of the art of using BIM and GIS and the potential of utilising them in an integrated way railway project.

When this research started in 2015, there were few publications describing research into the integration of BIM and GIS for railway projects, particularly to improve collaboration. Some examples of using the integrated BIM and GIS in a different area are illustrated in the literature (chapter 3, section 3.8). Yet, interestingly, research in the collaboration area using BIM and GIS rapidly increased year by year (Song et al., 2017) which is a strong evidence proving that there was a gap in this area that needs to be filled especially after the significant increase of using BIM and GIS and BIM mandates in several countries following the UK.

Still, there remains a lack of establishing a process for this integration in a railway project as Garber (2009) stated that it is necessary to re-think the existing collaboration processes. Therefore, this research has attempted to fill this research gap.

The questionnaire results indicated that there is a lack of experiences of BIM and GIS in railway projects. However, this research started in 2015 where BIM was less established and the use of BIM and GIS was mainly in building (73.1%) rather than infrastructure (12.2%) according to the research conducted by (Ma and Ren, 2017). This research has additionally shown a lack of training and learning courses about BIM and GIS as according to the questionnaire results, many of training programs were mere self- training rather being sponsored by the companies that implemented BIM and GIS. However, maybe if the government or companies take the responsibilities of that training, the awareness and experiences in BIM and GIS are likely to increase. Thus, will increase the challenges of achieving effective collaboration. This is consistent with previous studies such as (Oke et al., 2018) which concluded that lack of training is considered one of the challenges to achieving digital collaboration. Several recent research studies illustrated that the experiences of BIM and GIS have shown a rapid increase compared to several years ago when these technologies emerged (Oke et al., 2018, Barazzetti and Banfi, 2017). Obviously, this is a significant sign that awareness in BIM and GIS has been correlated with the training.

Furthermore, the findings from the questionnaire showed the most popular software used for BIM and GIS. Where AutoCAD and Revit are used for BIM, ArcGIS is the most common GIS tool. This is consistent with other findings from (Ma and Ren, 2017). Nevertheless, there are other software applications more related to infrastructure (or horizontal construction such as railway) such as Infraworks, and QGIS (Ma and Ren, 2017). However, 11.4% of respondents used Bentley, which is a positive indicator of conversion towards implanting BIM tools. This is because Bentley is marketed as a BIM platform (Bentley, 2003). Nevertheless, the software used for infrastructure is different than that used for building.

Another significant finding from the questionnaire is to identify the plan and design stages as the stage where BIM and GIS are most used. This consistent with other studies (Ma and Ren, 2017) that BIM is used in the design stage and GIS is used mostly for the planning stage. Zhu et al., (2018); Ma and Ren, (2017) stated that BIM provided the 3D model and can be used throughout the Lifecycle of the construction projects, while GIS is used to analyse and visualize problems-related to the location in geospatial science, environmental science, and natural resource management. Thus, the obtained results showed the reliability of the responses. In terms of integrating BIM and GIS-based collaboration, 37.7% from the responded integrated BIM and GIS for less than 2 years. This comes with results from recent studies such as (Zhu et al., 2018) which indicated that integrated BIM with GIS trend-forward from only 3 studies in 2009 to 313 studies in 2017. This reflects the significance of this area and the growing interest of the researchers regarding this topic.

On the other hand, the most interesting findings were the benefits and challenges of BIM and GIS and its integration-based collaboration. The ultimate benefits from the questionnaire were understanding the role within the team, collaboration, availability of the data needed and exchange of information. Many studies have identified the benefits of BIM and GIS integration in the same area, for example, collaborative design and visualization, and engineering (Wang, Hou, Chong, Liu, et al., 2014). Recently, the research regarding BIM and GIS has shown a rapid increase for different purposes in planning, design, construction, operation, and demolition (Rabia and Farooq, 2014; Ma and Ren, 2017). Though there are many studies and research continuing to be published, there is still a lack of research in infrastructure (Ma and Ren, 2017). Furthermore, collaboration is the most important aspect which is considered as the pillar that any project base on it to achieve the project objectives as the analysis of the questionnaire using regression analysis showed (chapter 5, section 5.1.4). (Ren et al., 2011; Motawa et al., 2007;

emphasised that the advantages of collaboration are productivity optimisation, cost minimisation and reducing mistakes. BIM and GIS are potential to achieve collaboration because the essential benefits of BIM are collaboration (Liu, 2014; Ma and Ren, 2017). As a result, using GIS with BIM will lead to effective collaboration and improves efficiency, saving time and money (Liu, 2014; Ma and Ren, 2017). Therefore, this research focuses on collaboration and the ways to achieve effective collaboration, but that needs more search and investigations.

There are many challenges to achieve effective collaboration from the findings concluded from the analysis of the results (chapter 5 section 5.1.4). The biggest challenges were access to the data needed, clash detection, exchange information, and reduced cost consequently. These also similar with challenges that have been indicated the previous studies and mentioned in the literature (Liu and Issa, 2012, Isikdag, Zlatanova and Underwood, 2013, Karan et al., 2015). As a result, more information about the collaboration issues needs to be addressed to define them and investigate solutions to overcome them.

7.3 Identification of Collaboration Issues and Potential Solutions

According to the questionnaire results and its analysis, more investigations are needed in order to identify the collaboration issues, challenges and attempt to determine the best solution/s to tackle them. To achieve these objectives, two rounds of in-depth interviews were conducted with the participants who have experience in BIM, GIS and railway projects (as described in chapter 4 section 4.12). Although the analysis of the second round, followed logically from the first round, the data from both rounds of interviews contributed to developing the process model. Collaboration issues and suggested solutions were the main concern during analysis. The results showed that answers from the second round were in a line with the first round and supported the information from the preceding questionnaire and the literature review, as the coming sections will illustrate.

Interview results have been analysed using thematic analysis (Aronson, 1995; Braun and Clarke, 2006) and content analysis (Elo and Kyngäs, 2008). Very significant issues have been identified throughout the interview by highlighting the trends, how collaboration has been used in their companies, what was influential or detrimental to collaborate, what challenges minimise the opportunities to collaborate effectively. Most issues of effective collaboration in the design stage of railway projects were managing the information to get the right information at the right time for the right purpose followed by resistance to change and interoperability. This aligns with the challenges identified by (Anumba et al., 2008) that the design team prefers to use their own terminology or technology. Kjartansdóttir et al., (2015) revealed that collaboration is the heart of BIM with the right process and tools, however, to create the right environment to share information, cultural and behavioural change is required. The letter added that delivering the right information at the right time in the right format leads to better decision making and delivers activities more efficiently and effectively. However, to achieve collaboration is needed to enable all stakeholders to work according to the same precise and updated information. Furthermore, Oke et al., (2018) and Zeng et al., (2012) highlighted that the collaborative process provides a secure, protected procedure, which enables just the right individuals to access the information at the right time. This is concordant with the interviews' findings presented in section 5.4.2.

The questionnaire data showed that *interoperability* was an important issue in collaboration because collaboration requires interoperability and collaboration is the most important issues of integration. This was supported by the subsequent interviews (section 5.4.1) (Interoperability was also a significant accept of the CPW, as discussed in the next section). The highlighting of *interoperability* is consistent with research studies by (Oke et al., 2018, Talebi, 2014). Oke et al., (2018) concluded that to collaborate, the information needs to be interoperable. Although these mentioned studies address the issues to collaborate within BIM, issues of GIS-enabled collaboration and/or collaboration specifically for railway project, were not directly addressed in the literature. Therefore, this research mainly focused on developing BIM and GIS-enabled collaboration in the design stage of railway projects.

7.4 Developing CPW for the Design Process of the Railway Project

Solutions are necessary to reduce these challenges. For such purpose, several suggestions have been produced from the analysis of the interview data (chapter 5 section 5.4.2, and section 5.4.3). After having categorised the responses and drawing out common themes running throughout the data, a process model was formulated to achieve effective collaboration. This aligns with previous studies as described by Dorador and Young (2000) when they stated that the process model is important to provide the designers with high-quality information on which to base their decisions. The same suggestions emerge from the interview findings which indicated that to achieve this process several steps (requirements) are needed. The findings from the interviews revealed that the first significant step to tackle these challenges is establishing a plan of work specifically customised for railway work to be conformed to by participants for effective collaboration. This was interesting, in line with previous studies such as Zanni (2016), who demonstrated that the lack of familiarity with BIM standards such as RIBA, CIC through conducting a workshop. The next step was to identify the activities or actions for this process model and to define the participants and decision points.

The developed CPW provides a clear process of railway-based collaboration. It is not specific to any organisation or existing process, yet it combines the features of the RIBA Plan of Work and GRIP Stage to create all the requirements needed for effective collaboration. Furthermore, the CPW is intended to be clear and easy to follow for each involved party, showing the role and responsibilities of the involved parties. These steps are considered very significant as the findings indicated (section 5.4.3).

The developed CPW is concerned with collaboration, setting out the derivable and the information needed. While deliverables are the main concern by other plans of work (such as RIBA Plan of Work, CIC, and BSRIA Design Framework for Building services) which the focus not on deliverable only, but additionally gives details of the design activities that lead to deliverables (Churcher and Richards, 2011). Government Soft Landings (GSL) align with RIBA, powered by BIM, which is developed to champion better outcomes for the built assets in the UK during the design and construction phase to ensure that they achieve value throughout their operational life cycle (BIM Task Group, 2013). Other plans of work such as PAS1193 process concentrate on the operational phase, as it is two parts of PAS1192 which support BIM level 2 in the delivery phase (BSI, 2014a). Therefore, CPW focuses on the process of collaboration, while other plans on focus deliverables.

It seems that research regarding the explanation of a clear process for collaboration in railway is very rare in that area of study. Idi and Khaidzir (2018) recommended that in the future research can be focused on reviewing and exploring the theoretical framework of design collaboration, while practically a number of companies already adopted different types of software to achieve collaboration. For instance, Crossrail utilises a common data environment called eB to share and exchange information collaboratively (May, Taylor and Irwin, 2017). Therefore, this research fills this research gap by developing a process model based on a development plan of work for railway design stage as illustrated in the next sections.

7.5 Identification and Definition of BIM and GIS Process Model Components

According to the findings from the first round of the interviews; a process model was suggested, and fully formulated. Due to the lack of a comprehensive process of BIM and GIS-enabled collaboration for the design stage of railway projects, it is required to re-think of the existing collaboration processes (Garber, 2009). Therefore, to move towards collaborative design using new technologies (i.e. software, hardware, and networks), the components and processes of BIM and GIS-enabled collaboration are needed to be specified. This incorporation faces the challenge which is the coordination of all available elements that are necessary to achieve the optimum results (Ruikar, Anumba and Carrillo, 2006). Data analysis (using content and thematic analysis) for the second round of the interviews (chapter 5 section 5.5) divided the process of the design stage into three main elements: railway track, civil engineering structure and systems. This is the same division of the railway infrastructure by Pyrgidis (2016) which also emerged in the literature review (section 2.2).

It has been found that the process model for BIM and GIS-enabled collaboration consists of key players' roles and responsibilities, tasks (BIM and GIS Uses), BIM and GIS-based deliverables, and critical decision points for collaborative process design to enable BIM and GIS technologies to reach their full potential. These components are essential to collaborate effectively and change information easily because the responsibilities are clear, and each participant knows their role for each task in the process model. Idi and Khaidzir (2018) point out that areas such as team, activities, task, tools, strategy, requirements, technology, management and materials are the unique features of design collaboration. Thus, leading to sharing the information synchronously or/and asynchronously and making an effective decision.

The lack of research in the collaborative process may be attributed to the fact that most research focuses on BIM and GIS in terms of technology and interoperability (Azhar, 2011; Bazjanac, 2008) and tools in automated decision-making (Schlueter and Thesseling, 2009; Geyer, 2012; Gerber and Lin, 2014). While, the theoretical process or the process of how to collaborate is missing (Zanni, 2016). Therefore, a process model was developed using integrated definition IDEF0 (KBSI, 1993) and IDEF3 (Mayer et al., 1995) structured diagramming techniques of the BIM and GIS-enabled collaborative process for the design stage. This process obviously defined the roles, responsibilities, and competencies that are essential to achieve the collaborative design. Moreover, the outcome of the research provided an appropriate scoping of BIM and GIS usages, and deliverables for the early design stages, integrated within the developed CPW. Thus, the development process model can be used to facilitate collaboration. This aligns with the UK Government's Level 2 BIM mandate (Cabinet Office, 2011). Finally, the research outcomes have been validated through focus groups and interviews where a CDE platform frequently used in industry (Viewpoint for Projects) has been utilised (chapter 8 section 8.2). The most important key to achieving effective collaboration within the process model is to serve how to facilitate the synchronous and asynchronous communication within a centralised system (CDE).

As a result, this research attempted to provide a process model to facilitate collaboration among the participants in the design stage process for railway projects. This process model provides participants with their roles, responsibilities, tasks, deliverables and decision points.

7.6 Summary

This chapter discussed the themes emerging from the research within the context of literature with a particular focus on BIM and GIS to improve collaboration in the design stage of railway projects which lead to developing a process model.

The background of BIM, GIS and collaboration in project lifecycle have been discussed where BIM and GIS can enhance collaboration when used effectively.

Subsequently, the status of using BIM and GIS was being discussed in terms of experiences, benefits, challenges and the stage most needing usage of BIM and GIS; followed by discussing the findings of the first round of interviews which were the issues that reduce the opportunities of effective collaboration and the potential solutions to tackle these issues. The outcomes were identifying the effective collaboration requirements which developing a CPW. Moreover, the outcomes of the second round of interviews consisted of effective collaboration requirements, which include the development of the process model of BIM and GIS-enabled collaboration in the design stages of railway projects. The next chapter presents the validation process of the research outcomes.

Chapter 8 : Validation of Research Outputs and Model Refinement

8.1 Introduction

This chapter presents the validation of the process model to establish the validity of the research outcomes through a focus group and interviews with industry experts. Section 8.2 presents the validation process and the strategy for presenting the IDEF models to the participants. The second section presents the feedback received from the focus group followed by the interviews. The third section presents the amended IDEF process model for BIM-GIS enabled collaboration, addressing the recommendations made by the industrial participants. Finally, Section 8.5 summarises the main findings of the Chapter.

8.2 Validation Process

Based on the iterative nature of the research study (Meredith, 1993; Gay and Weaver, 2011) which followed mixed methodology, the research outputs (process model of BIM and GIS-enabled collaboration) was validated through a focus group followed by interviews and document analysis. The focus group was conducted face-to-face with industrial experts when the IDEF process model was presented using the Viewpoint Collaborative Data Environment. The subsequent in-depth interviews followed the same procedure as the focus group to obtain more feedback from different companies (section 4.12).

Viewpoint for Projects was used to demonstrate the IDEF0 and IDEF3 process models. *The viewpoint* is a Common Data Environment frequently used in actual projects (and all CDEs generally offer similar functionality). Translating the IDEF0 and IDEF3 models into Viewpoint protocols was felt to be a good practical implementation of the theoretical models, which would enable their evaluation. Therefore, this provides crucial evidence of the workability of the theoretical process models developed as a contribution of this research and how it is applicable to the industry use.

Viewpoint for Projects is an online collaborative platform that can be used at both organisational and project-based levels. The reasons for using this software to validate the process model have been demonstrated in Table 8-1 below. The most important features led to make the viewpoint for project the most proper software to validate this research findings, is this software collaboration based. It supports sharing any kind of files, not just BIM files, in addition to content a ready workflows templet to manage the project.

Table 8-1: Advantages and disadvantages of Viewpoint and BIM 360 (FERNANDES, 2013, Viewpoint for project, 2016)

Software / Features	Viewpoint for project	BIM 360
Advantages	- Provides all team members a collaborative document control solution for achieving streamlined processes and clear communication. *-Achieve True Collaboration* Realise a real collaborative partnership with project stakeholders regardless of native software. - Mitigate Risks Reduce your potential for project delays, mistakes and costly claims. - Immediate Results Easily access critical business information at any phase of the project lifecycle. - Include templets workflows to manage the project. - Share any kind of files	this provides a somewhat basic level of collaborative sharing, viewing and commenting. Allowing non-Revit project users to access project design data, and is accessible using desktop, web and mobile devices. Real-time Revit work-sharing means teams can work on the same model and stop wasting time uploading, syncing, transferring or waiting on large files.
Disadvantages	- Lots of option available in the competitive software market. Without brand marketing. - Too much functionality/too many reports (software needs to be modified to cater to company's needs) "double-clicking	-It does not include workflows templets to manage projects. - Share BIM files only

In this research, the most used functions of this software were the workflows from which the process of the work can be clearly demonstrated for all involved parties. The workflow consists of boxes with different names (on the left side of the screen) according to the purposes of use. For instance, document, task, decision, discussion, notification, and etc as shown in Figure 8-2. There is a link between the boxes to show the flow of the workflow with a small notification box with a coloured sign illustrating what the next box is for. Figure 8-1 shows an overview of the workflow start window.

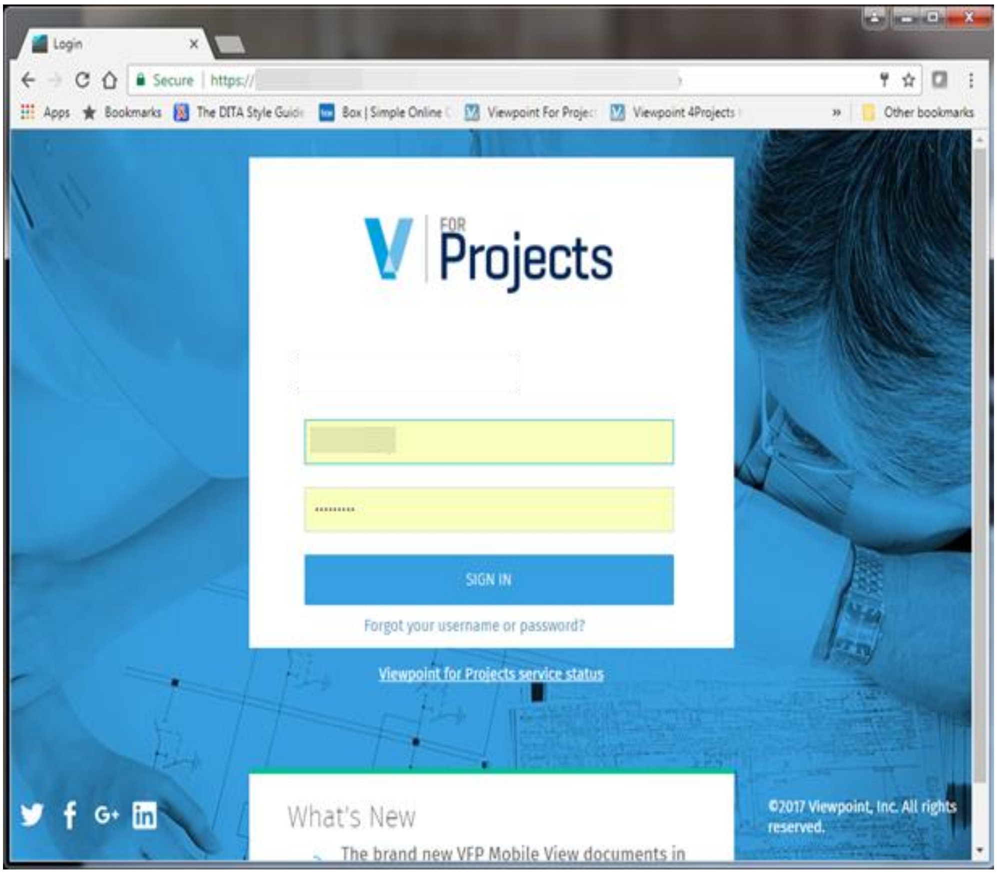


Figure 8-1: The viewpoint view

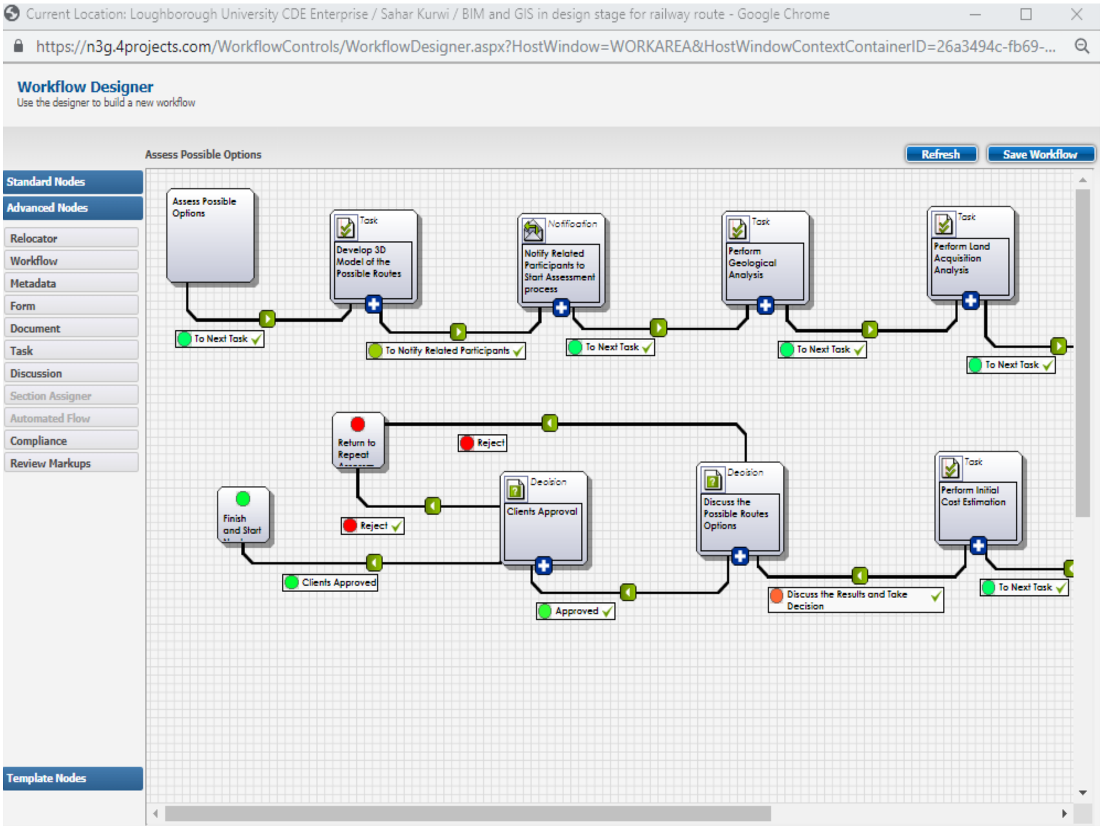


Figure 8-2: Example of workflow in Viewpoint project (adapted from the viewpoint web)

8.3 Focus Group and Interview with Industrial Experts

One focus group was formed of industry experts who specialise in BIM, GIS and Railway. The number of participants was three from the company and two from the research team. While the number of focus group participants should be between 4-12 and last about 5 (Saunders, Lewis and Thornhill, 2016). The fewer participants and the shorter time of the focus group can be justified because the experts who participated in this research were the heads of each department of BIM and GIS which they have all the related information and experiences about the process in the design stage. In addition, their company already implementing BIM, GIS, and CDE.

After the focus group, one in-depth interview was conducted through Skype with industry experts in railway project who have experience in both BIM and GIS. The interview took 2 hours and the discussion is illustrated by focus group discussion.

8.3.1 Focus Group and Interviews' Structure

The focus group was convinced in one of the biggest railway companies on 25/04/2018. That railway project had already adopted BIM and GIS in their work. The meeting took approximately two hours. At the beginning of the meeting, the participants were provided with the following documents: (i) participant information sheet, (ii) consent forms, (iii) a handout of a slide presentation describing the model, (iv) questionnaire (illustrated in Appendix E).

First, the purpose and structure of the meeting were explained. Then, the presentation was given to explain the research problem, aim, objectives, and the components of the process model. Then the various levels of the process model were discussed one by one in details. Eight diagrams were presented and after seeing each, a discussion was had, and each participant was asked to complete a section of the questionnaire which evaluated that diagram. The meeting was audio recorded with the participants' permission.

The questionnaire handout (Appendix E) consisted of an introduction and two sections. The first section asked for background information about the participants and their company which consisted of four main questions. The second section consisted of the eight questions, collecting feedback questions for each diagram of the development workflow, utilising Likert Scale questions, in addition to a box for additional comments.

8.3.2 Participants Experience

The information about the participants in the focus group and the interviews are summarised in Table 8-2 below. The first section of the questionnaire handout consists of four main questions. Participants were asked to indicate their current role(s) at the company. Each participant was allowed to tick more than one role. The participants' experiences consisted of various areas such as engineering and architecture. The year of experiences of the participants ranged from 2 to 10 years for each BIM and GIS.

The software tools for BIM and GIS that participants had previously utilised in their company are Bentley MicroStation, Bentley AECOsim, Autodesk Navisworks and Trimble SketchUp are the most tools used in BIM. While for GIS, ESRI was the most tools used.

Table 8-2: Participants information

Industrial Participants code	Roles occupied	Background	BIM experience	GIS experience
I-A	Client/Client Adviser. BIM Manger/Coordinator	Engineering	6-10	6-10
I-B	GIS manager	Transportation	6-10	>15
I-C (from the Interview)	BIM and GIS manager	Engineering	15	15

8.4 Process Model Evaluation

Section three of the questionnaire solicited the feedback on developed workflow. The workflows were presented using Viewpoint workflows.

Viewpoint consists of folders, documents, and workflows. All enables all project information and documentation to be accumulated in one repository. Teams and specific participants are assigned a specific role within very specific constraints and project specifications.

8.4.1 Research Output Importance and Relevance

All participants recognised the need for structured and standardised BIM and GIS-enabled collaboration. The main principles that this process should follow were established from the focus group discussion (in order to achieve effective collaboration process) as: (i) clear definition of collaboration objectives before design, implementation and delivery, (ii) iterative process of building design (iii) concurrent parallel tasks, and (v) clear standardised rules with an amount of customisation for bespoke projects. The participants believed that automation of workflow management, for collaboration, can assist in achieving project objectives in the most economical way possible in terms of time, cost, and effort.

All participants considered the research output to be well-structured, clear, relevant, comprehensive, and easy to understand and navigate. However, the sequence of the boxes was not very clear to them because it was a screenshot, not a real programme due to time constraints. Furthermore, they acknowledged its significant value as a guideline for considering the most critical aspects of the design process and also for communication between the design team for better alignment. The details of their evaluation along with recommendations for improvement are discussed in the following sub-Sections. The final refined model is then presented in Section 8.4.4 of this Chapter.

8.4.2 Adequacy and Usefulness of the Process Model

There was a considerable agreement about the usefulness and the feasibility of the process model for effective collaborative design, but with some amendments. For example, I-A Client/Client Adviser; BIM Manager/Coordinator said:

> *"It is interesting about merging RIBA and GRIP to develop a process model for collaboration, you are filling a gap really here and that is so interesting. This is because these plans are focused on deliverable not really focusing on collaboration. These workflows were effective and engaging because they are getting to realise that you have to collaborate".*

Furthermore, the participants and the interviewee indicated that the benefits of these workflows are showing consistency, uniformity, and standardisation as a means of communicating across a project.

8.4.3. Suggestions for Improvement of the Process Model

The workflows were presented by Viewpoint workflows and IDEF0 and IDEF3 processes. The handout had been sent a few days earlier, therefore the participants had an idea about it at the time of the focus group. However, they reviewed the workflows as a whole before making any suggestions. Each workflow was discussed in detail. As a result, according to the feedback and comments received from the focus group participants and interviewee, the model was amended. The following subsections present recommended alterations and additional activities to the model.

8.4.3.1 General Recommendations

The opinion explicitly expressed by the focus group participants was that they found the workflows very well presented and interesting. However, some few recommendations were made. Participant (I-C) suggested focussing on the clarity of presenting the relationships of the parallel activities. Meanwhile, the participant (I-A Client/Client Adviser; BIM Manager/Coordinator) recommends adding iteration loop in case the related parties agreed or disagreed with the decisions.

Overall comments were made regarding the consistency of the workflows with each other. This can be attributed to the fact that the presentation of the workflows was by the screenshots, rather than giving participants to chance to interact with the real program, which made it a little difficult to follow the flow. Furthermore, the CDE platform (Viewpoint for the Projects) is practical and very easy to use, but inviting all the participants as authorised users of a demonstration project using that workflow would have been impractical. Therefore, the researcher started with an explanation of the screenshots instead of involving them online. The alignment has been the screenshots and underlying IDEF models was clear, but the Viewpoint workflows were easier for an industrial practitioner to grasp. While, in the Viewpoint, the alteration produced by emails and metadata box (section 8.4.3.4/C).

8.4.3.2 Level 1 Decomposition

No change was suggested by participants regarding IDEF0 Level 1 decomposition (presented and explained during the presentation). Level 1 consisted of “Undertake Strategic Definition”, “Prepare Project Brief” and “Prepare Design Stage” that followed the developed CPW from this research.

8.4.3.3 Level 2 Decompositions

Level 2 decompositions consisted of further details of “Undertake Strategic Definition”, “Prepare Project Brief” and “Prepare Design Stage”. Due to limited time, some of the tasks from level 3 were integrated into level 2 and presented in the same figure. The purpose was explained, and the tasks and levels were clearly demonstrated which made all the figures clear and easy to understand.

Two figures (Figure 8-3 and Figure 8-4) presented level 2 named “undertake strategic definition” and “prepare project brief”.

All participants agreed that these workflows are very useful and can be adopted in the future for planning the design stage with some modifications for several reasons. First, it provides the project path with existing workflows or processes as stated by participants (I-B GIS Manager). The second reason is that this process model identifies key stakeholders, roles and responsibilities (I-B GIS Manager, and I-C BIM and GIS Manager).

For decomposed “Undertake Strategic Definition” shown in Figure 8-3, participants (I-B GIS Manager) suggested to change activity “determine pinch point” to “determine constraints” and other participants agreed with that, which is more general and include all possible constraints.

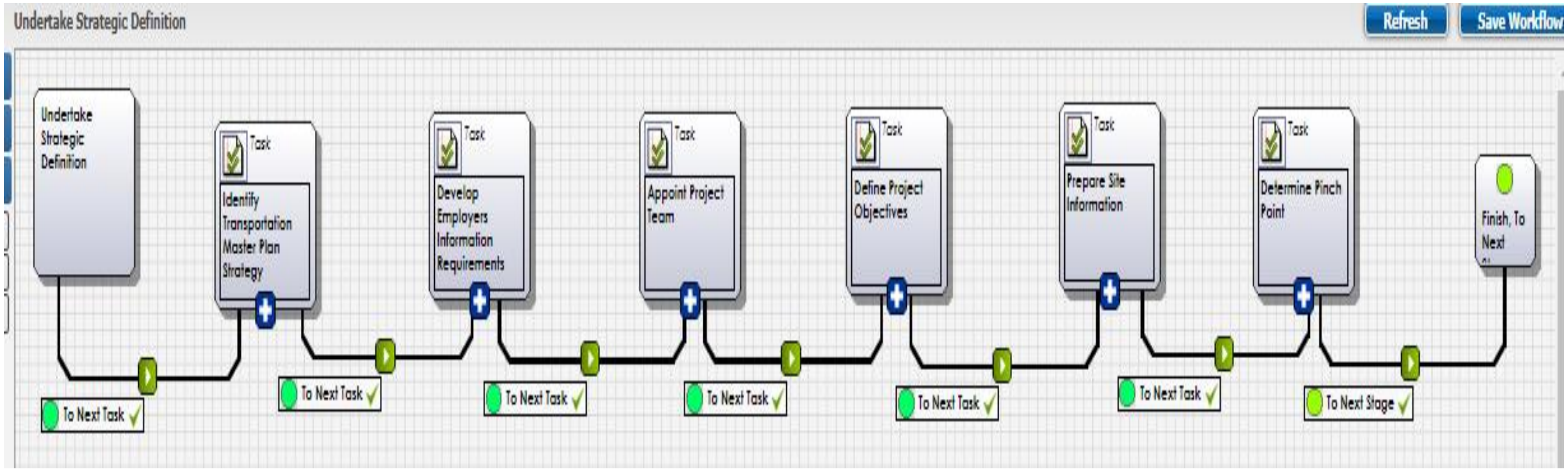


Figure 8-3: Undertake Strategic Definition

Figure 8-4 illustrates the decomposed “Prepare Project Brief” which few changes have been made to by the participants. One important suggestion made by the participant (I-A Client/Client Adviser; BIM Manager/Coordinator) is to add “Risk Management” activity as it is a critical issue. Furthermore, rename activity “Evaluate Regions Aspects” to more comprehensive meaning “Evaluate Environmental Aspects”. Moreover, interviewee (I-C BIM and GIS Manager) argued that in engineering design the feasibility should be phrased as “value engineering” when a design concept and proposals are submitted to make a comparative analysis to choose the best option which is related to a better environmental impact. So, maybe it is better to rename feasibility study to value engineering (I-C BIM and GIS Manager)

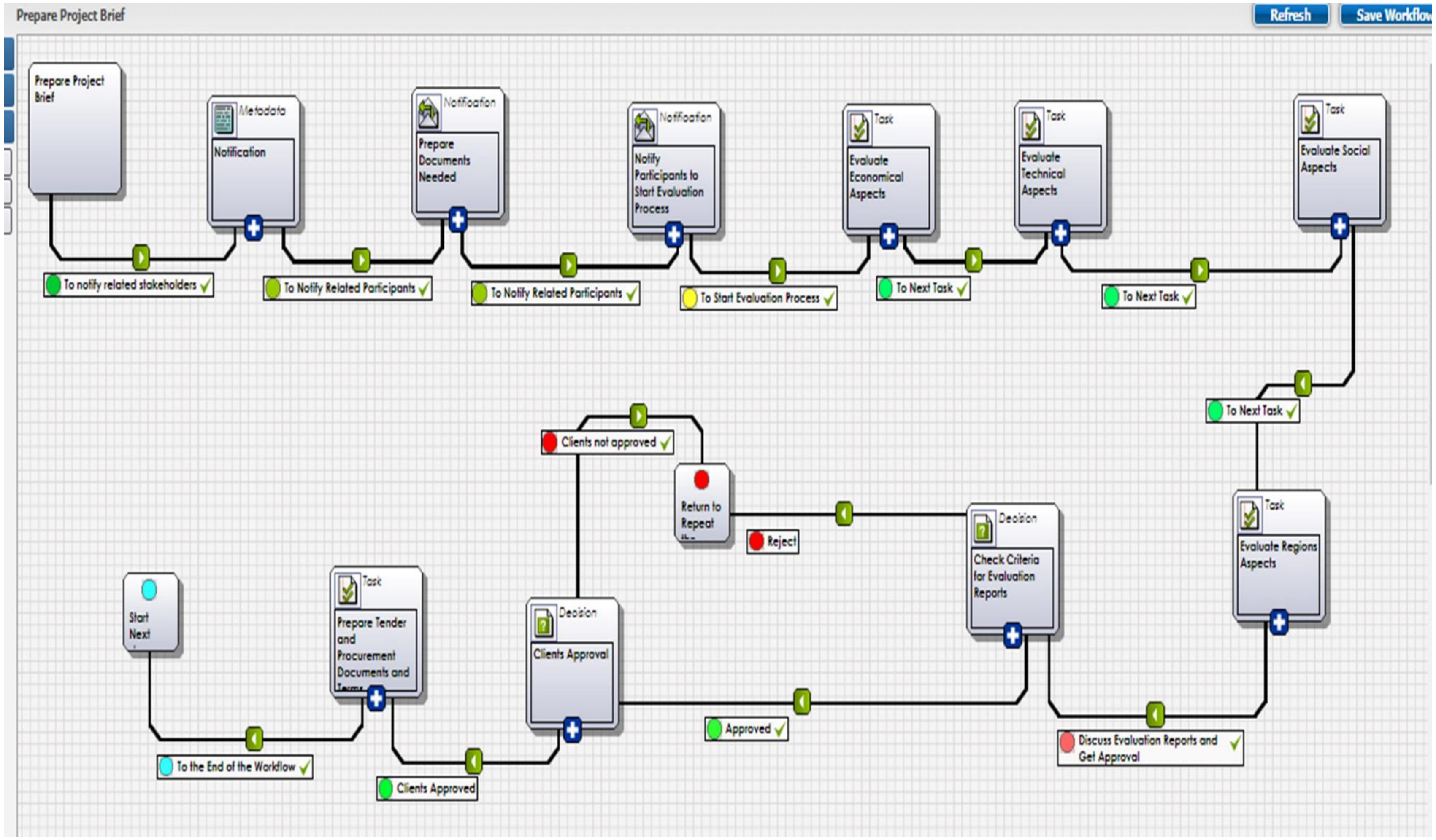


Figure 8-4: Prepare Project Brief

8.4.3.4 Level 3 Decompositions

Three figures Figure 8-5, Figure 8-6, and Figure 8-7 present level 3 decomposition.

A- Develop Employer's Information Requirements

The general feedback of the participants aligned with the interview opinion that some of these tasks may occur in parallel. Then the researcher agreed and demonstrated that the process model already allows the tasks to occur in parallel (Figure 8-5).

All participants stated that the workflow in this stage will provide very useful information despite (I-A Client/Client Adviser; BIM Manager/Coordinator) arguing that this workflow may be constructed around the software rather than around the process. While participant (I-B GIS Manager) commented that at this level the workflow is about identifying the requirements and responsibilities by saying "At this level is about identifying the requirements and who can do what, what the relationships between parties". Furthermore, participants (I-A Client/Client Adviser; BIM Manager/Coordinator) illustrated that this workflow could be useful to remind the participants of the process they need to follow.

However, some modifications were suggested. For example, the participant (I-B GIS Manager) suggested that the task "Identify Collaboration Process" should be included in "Define Managerial Aspects" because collaboration is more about getting participants to understand the relations between various components and various people. Meanwhile, the participant (I-A Client/Client Adviser; BIM Manager/Coordinator) recommended some iterative working where feedback takes and return to an earlier stage. (I-A Client/Client Adviser; BIM Manager/Coordinator) added, for example "Defining Commercial Aspects" could easily change "Technical Aspects". Furthermore, all participants agreed that the task under the name "Risk Management" is necessary to be added to this level for managing change control since the risk is related to technical decision making in design (I-A Client/Client Adviser; BIM Manager/Coordinator).

On the other hand, the interviewee (I-C BIM and GIS Manager) emphasised the importance of clarity and warned about the consequences of unclear tasks.

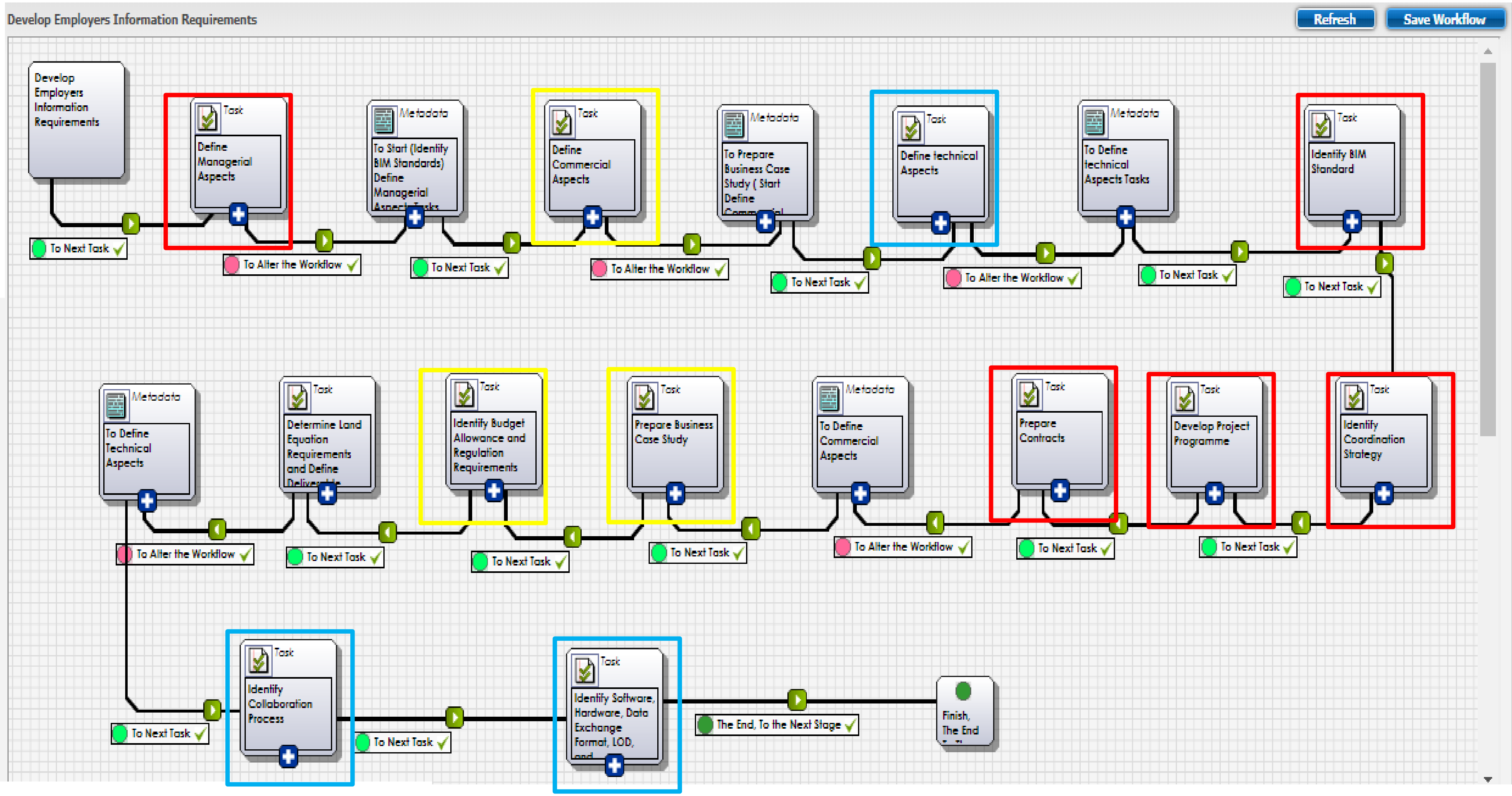


Figure 8-5: Develop Employers Information requirements

B- Team Appointment, Project Objectives, and Site Information

Figure 8-6 presents the three tasks in level 3 in details: team appointment, project objectives and site information (tasks for the first activity (team appointment) start first without naming the activity). All the details of these tasks have been presented in the same figure. The opinion of the participants around the benefits of this workflow in this stage allowed data to be collected in an interoperable manner (I-B GIS Manager), while (I-A Client/Client Adviser; BIM Manager/Coordinator) comments that it helps to set out the requirements in principle which parallel with (I-B GIS Manager) arguments that the benefit of this workflow is identification of the required information.

Even though the feedback was generally positive, some modifications were suggested. For example, all the participants agreed that a task “Determines the Level of BIM Certification” is not a mandatory task, as it can be optional because realistically it is not a big driver (I-B GIS Manager). The most important driver of the project is its objectives because after defining the project objectives the process of other tasks will be pointed clearly (I-A Client/Client Adviser; BIM Manager/Coordinator) and achieve everything you are planning for (I-B GIS Manager). Another change in wording regards task “Identify Connected Cities” to “Identify Connected Locations or Points” as the railway projects may not be between cities specifically; therefore, locations or points are more proper (I-A Client/Client Adviser; BIM Manager/Coordinator, I-B GIS Manager). Furthermore, they recommended changing task “Define Geographical Condition” to more generally “Define sub Service Conditions” to include all conditions such as geographical, physical and land use conditions. Moreover, (I-A Client/Client Adviser; BIM Manager/Coordinator) emphasised to include a feedback loop in the workflow to assist with the interdependency of mainly design influences. For example, “Hydrological Conditions” could have significant changes in project activities and site information.

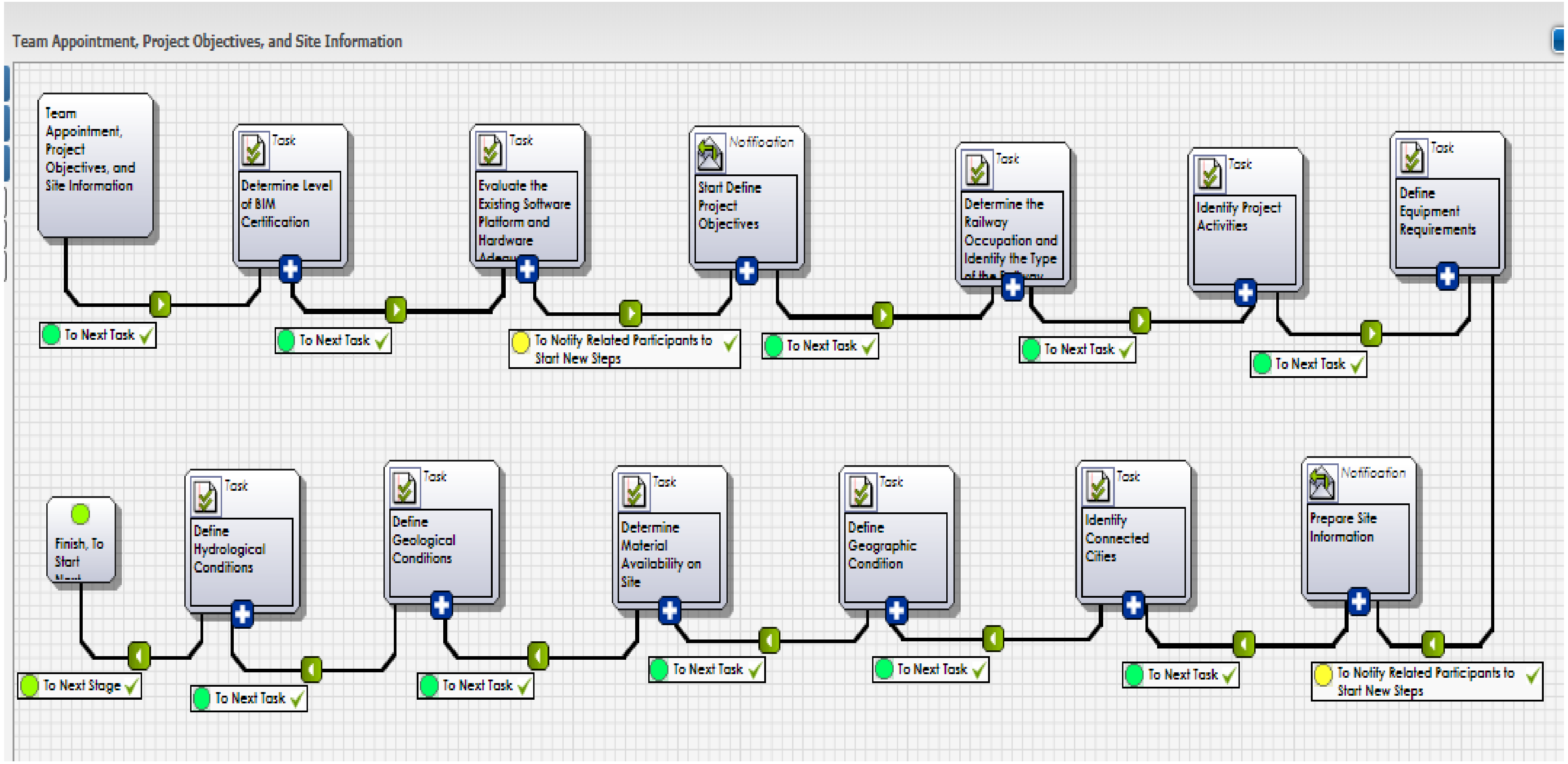


Figure 8-6: Team Appointment, Project Objectives, and Site Information

C- BIM Execution Planning (BEP)

Figure 8-7 illustrates BEP in detail, including level 4 of the task “developing communication strategy” in detail presented in red boxes. Metadata has been used to alter the workflow to perform the related tasks to task “Developing Communication Strategy” and returned to complete the rest of the workflow.

BIM execution planning is about how the information will be collected, managed and delivered to the client from the contractor (I-A Client/Client Adviser; BIM Manager/Coordinator, I-B GIS Manager, I-C BIM and GIS Manager). Participant (I-A Client/Client Adviser; BIM Manager/Coordinator) pointed out that existing work BIM in the BEP means many different things. (I-A Client/Client Adviser; BIM Manager/Coordinator) suggested to replace BIM execution plan for information execution plan by saying

> *“But I know when we talk about execution plan the usefulness of having is about understanding how data and information need to be used in the creation of the design of infrastructure so that's why it is good to have an information execution plan”.*

Participants and the interviewee stated that the place of the workflow should be changed, and it is better to be within technical aspects. This is because some tasks in BEP need to be identified prior to other tasks, such as identifying software tools before collection site information which depends on software tools. Interviewee (I-C BIM and GIS Manager) argued that popular design authoring collaboration tools such as Autodesk and Bentley are already having a standard format such as IFC. Therefore, identifying software tools and its formats is just to determine the version of the software which may differ and validate that with the client.

Some changes were suggested rewording some tasks. For example, (I-B GIS Manager) suggested using the standard instead of the manual in the task “Develop BIM and GIS Manual”. The reason for such suggestion is that the meaning of standard here is standards of working on a specific project, not notional one (I-B GIS Manager). Another significant suggestion from (I-A Client/Client Adviser; BIM Manager/Coordinator) feedback, is to make this workflow useful it needs feedback loops. For example, the task “Define Critical Decision Points” may influence “Develop Project Program”.

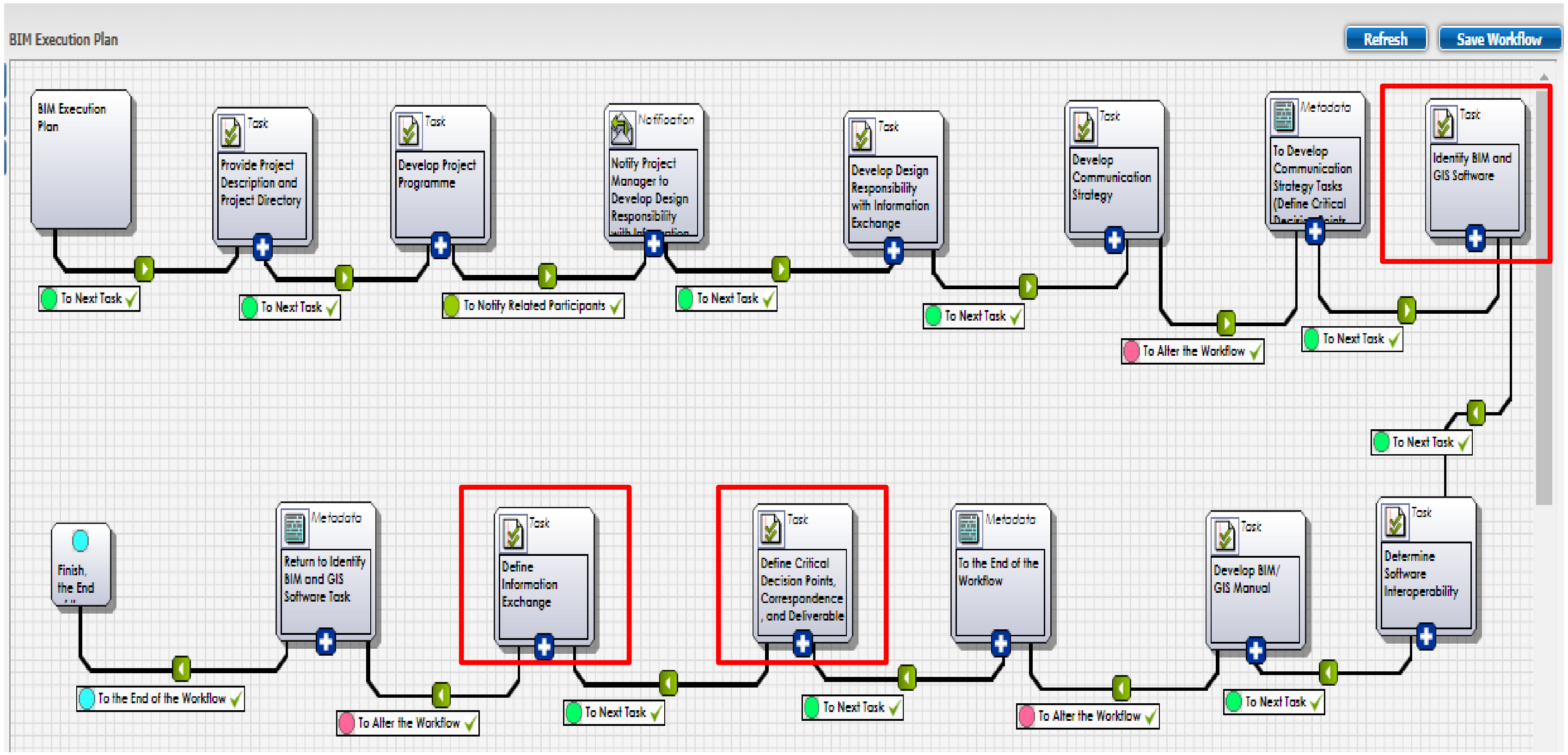


Figure 8-7: BIM Execution Plan (BEP)

8.4.3.5 Level 4 Decompositions

Level 4 consisted of three figures presented in the focus group meeting and interviews. Very few modifications have been suggested from the participants because they agreed with the contents and the links.

A- Develop Possible Options

This workflow presented in Figure 8-8. The overall opinion about this workflow was positive. For example, interviewee (I-C BIM and GIS Manager) pointed out that here the process becomes clearer indicted to start the actual design even when the process is not necessarily the same based on the type of the railway project. While the argument was around putting this workflow within the feasibility study, which is part of the project brief. (I-A Client/Client Adviser; BIM Manager/Coordinator) reported that the feasibility study having the options and assessments by saying

> *"I would be doing the route options in the feasibility as part of feasibility and they would be going into the report and sometimes we talk even about feasibility reports briefly. I can not go that way because of ….. So, you start developing your route options and that comes out in your feasibly. So, in your feasibly is saying what is feasible and you could end up with three things that are not feasible and three that are feasible in your options and then you can say my recommendation is this. Therefore, I think you feasibility study will be having your options and your reassessment, and your feasibility will be making your recommendations from which you can then develop your railway model."*

Some recommendations have been suggested to make the workflow more effectively. (I-A Client/Client Adviser; BIM Manager/Coordinator) and (I-C BIM and GIS Manager) indicated that the level of details needs to be carefully determined based on the type of railway projects. Furthermore, environmental impacts need to be added for further assessment (I-A Client/Client Adviser; BIM Manager/Coordinator).

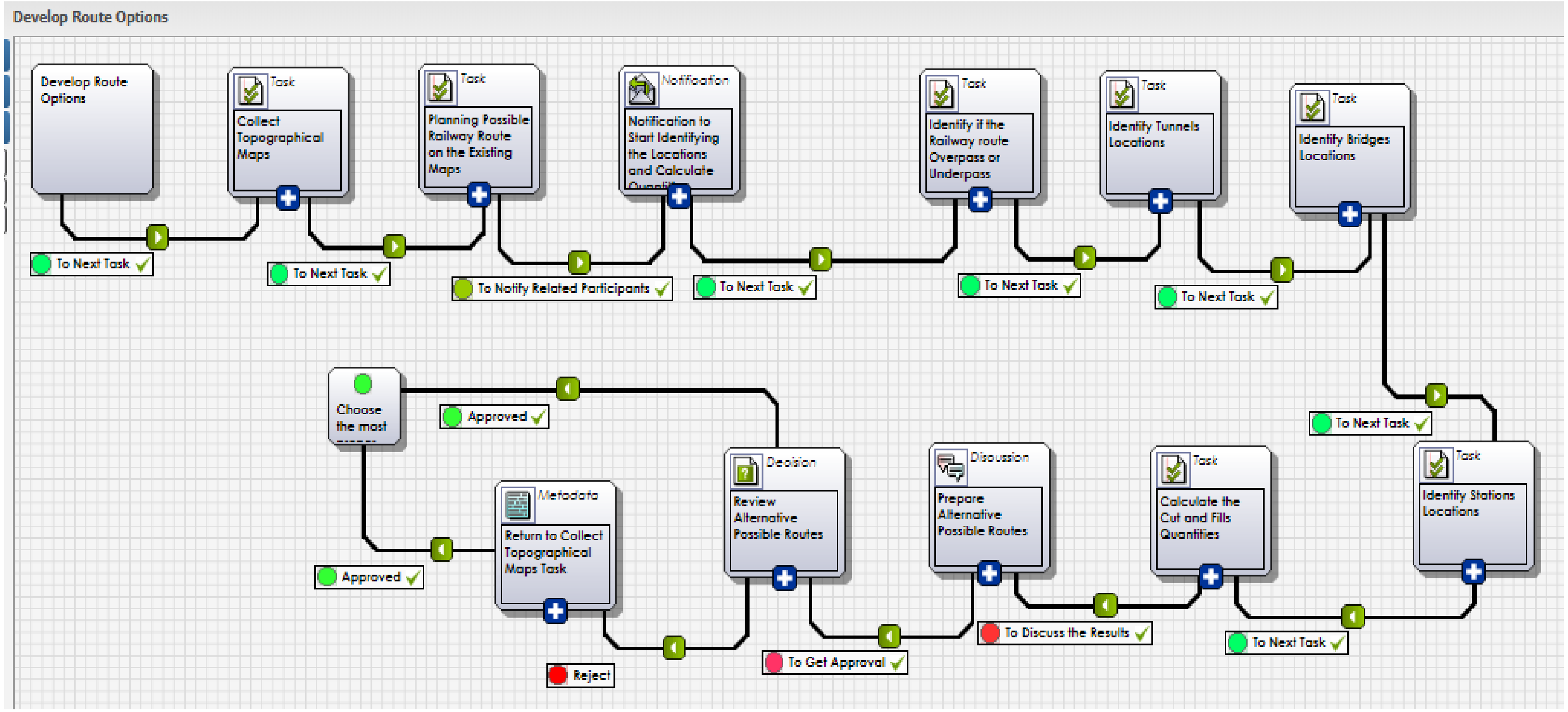


Figure 8-8: Develop possible options

B- Assess Possible Options

This workflow presented in Figure 8-9 which shows the assessment of the possible route options from the previous workflow. The aim of this workflow has been demonstrated which at the end the optimum route will be chosen if not the process will be returned to the beginning to develop other option.

Nevertheless, participants showed their interest in the workflow, some arguments raised during the discussion with the participants. For example, the participant (I-A Client/Client Adviser; BIM Manager/Coordinator) quite agreed that this workflow covers the main design criteria for route development. However, a participant (I-B GIS Manager) pointed out that the assessment process of the possible route is a part of preparing route options and a part of the feasibility study. This aligns with the interviewee (I-C BIM and GIS Manager) argument, that this assessment could be a part of the feasibility study.

Some amendments have been suggested. Participant (I-B BIM and GIS Manager) suggested replacing word 3D in the task “develop a 3D Model of the Possible Routes” to visualization as he states

> “*3D was definitely required I think it is very useful to have, but not something mandatory. This is because I think visualizations imply the softer you know the urban landscape not just the infrastructure while the 3D model usually implies hard steel and concrete”*

Participant (I-A Client/Client Adviser; BIM Manager/Coordinator) *added, “Do not limit your workflow to 3D because word visualization can be 4D models of any our sites because we are using the 3D models for progress control”*. Also, the participant (I-A Client/Client Adviser; BIM Manager/Coordinator) recommended adding the “Risk Assessment” task in this stage. Furthermore, he comments that the “Discuss Possible Route Options” task might be better as “Route Option Assessment Analysis” where a comparison workflow could be used to review route.

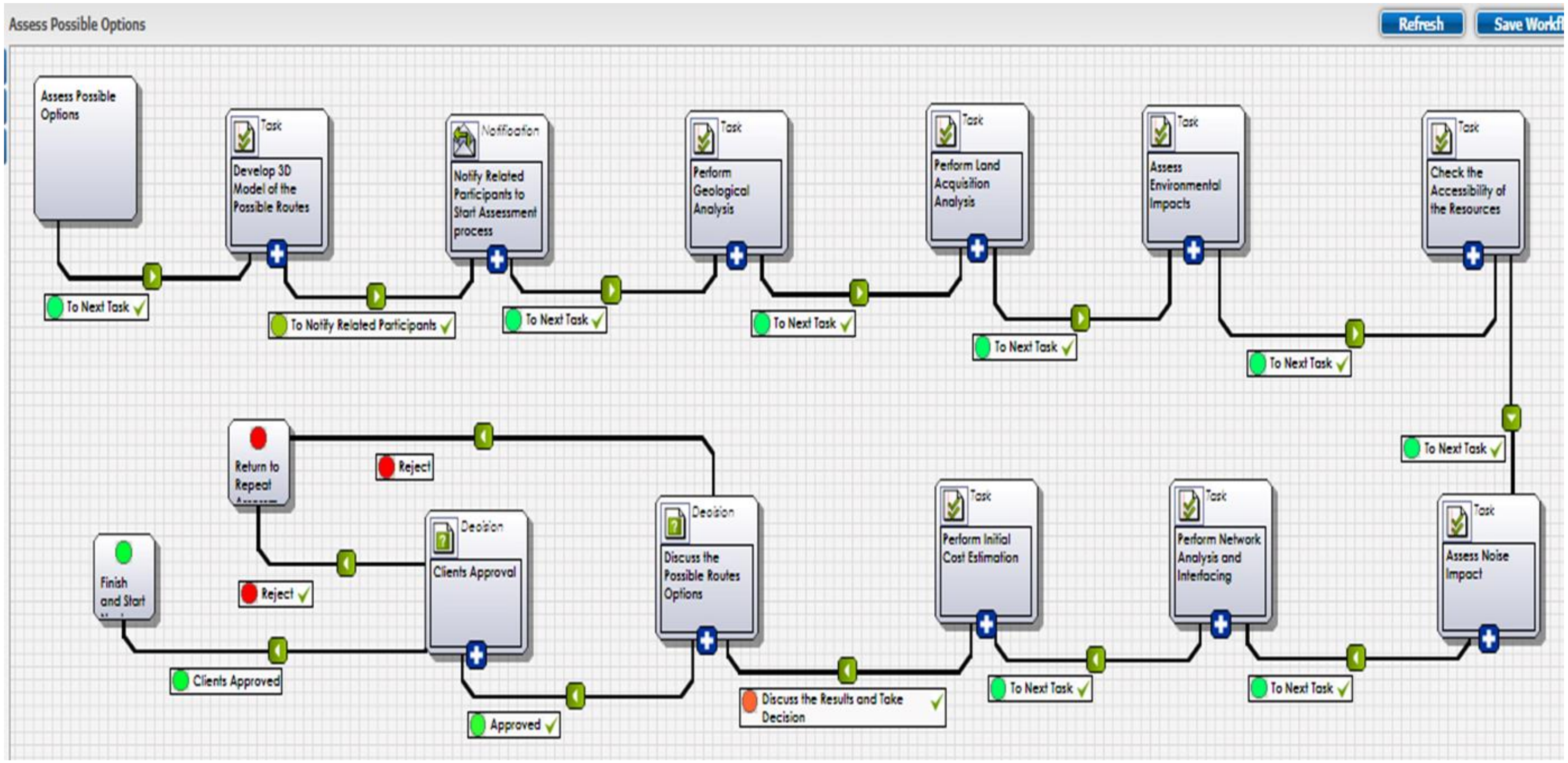


Figure 8-9: Assess possible options

C- Develop a Railway Track Model

The workflow shown in Figure 8-10 shows the railway track model development from level 4 decomposition. In this workflow occurs after the optimum route has been selected from the previous step (workflow), the development of the railway track starts.

Participants and the interviewee showed their interest and agreement in this workflow. For example, the participant (I-A Client/Client Adviser; BIM Manager/Coordinator) comments that this workflow works because it has good “return” loops for non-acceptance. Similarly, another participant and the interviewee agreed that the workflow is understandable and easy to follow. Even though the participant (I-A Client/Client Adviser; BIM Manager/Coordinator) suggested adding a task to confirm the business case and initial assumptions/requirements have been met and risks mitigated.

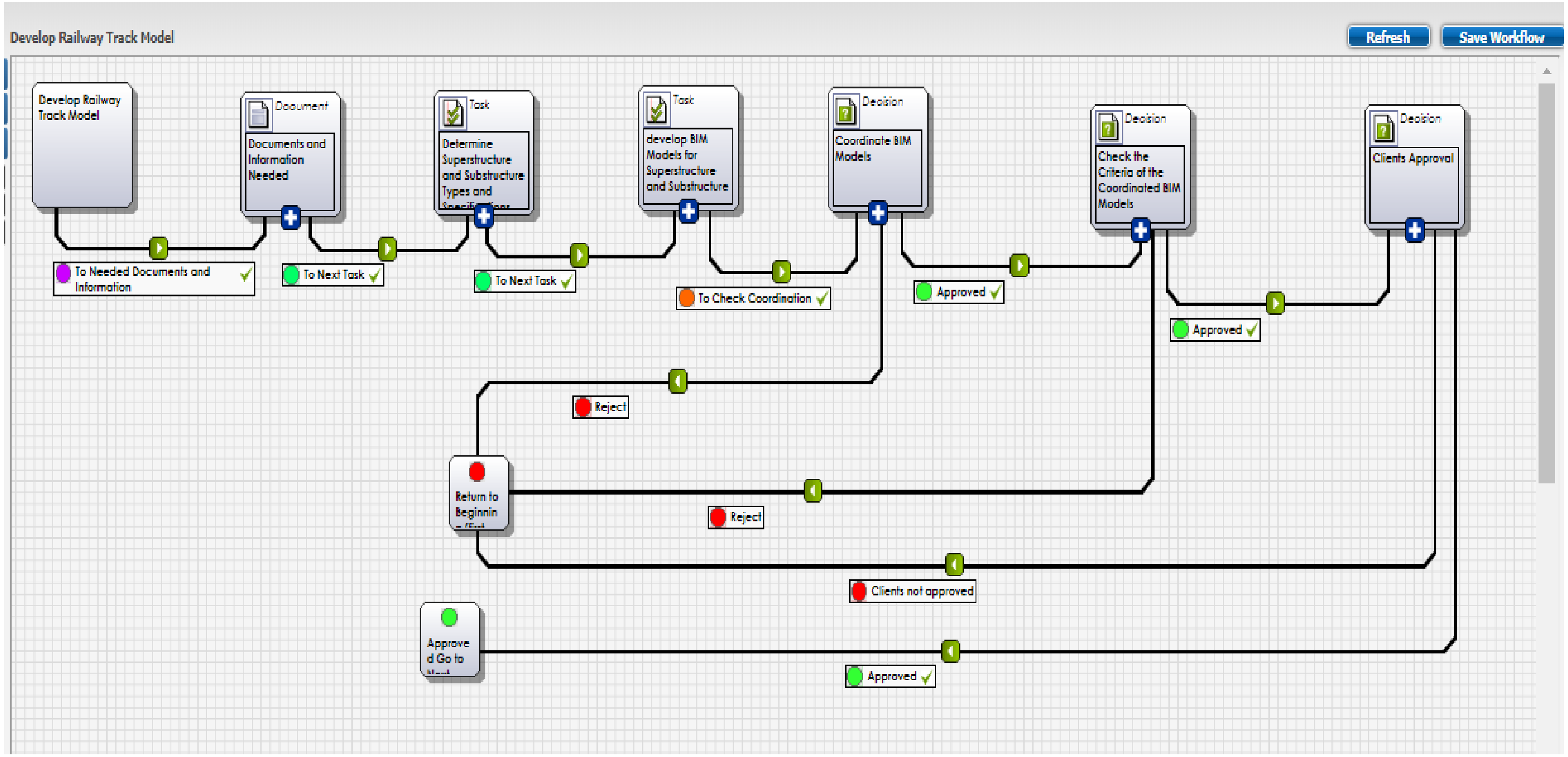


Figure 8-10: Develop a railway track model

8.4.4 Amended IDEF Process Model and Definitions

In this section, the presentation of the final process model (level 1 – 4) is presented, which was amended based on the recommendations made through the industry validation and the interview (the decompositions are following colour code and the levels in the figures are accordingly breaking down). Then reflected and applied on the theoretical process model (IDEF) which consisted of four-level hierarchies. Level 1 represented the high-level IDEF0 process model decomposition aligning with the developed CPW hard decision gates, and colour-coded accordingly. Level 2 contained the sub-processes decompositions of the Level 1 process. Level 3 contained the decompositions of the Level 2 processes and level 4 contained the decompositions of the Level 3 processes. Levels 2, 3, and 4 (IDEF3) provide granularity that demonstrates which functions are performed by each role, parallel activities, and soft gates.

The complete IDEF process model (before the final refinements) can be found in Appendix F (Levels 1-4). The four levels of IDEF decomposition diagrams presented in Figure 8-11. The diagrams presented a simplified description of BIM and GIS-enabled collaborative relationship (as UOBs) for the collaborative design process. The inputs (information required) and outputs (information shared) of the functions revealed as objects. The states of the objects (e.g. Initial, Optimised, Approved, Shared) change as they are altered by the function.

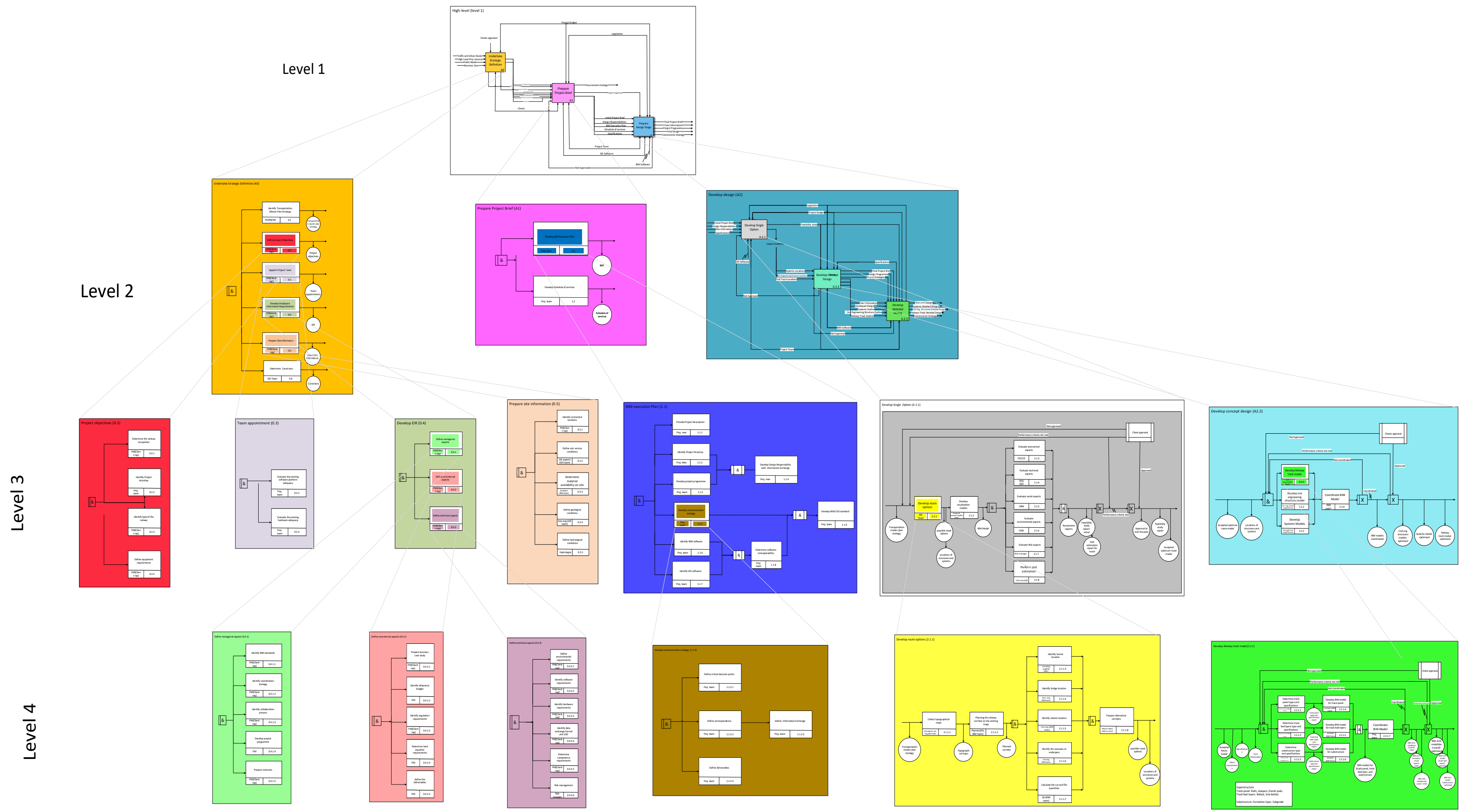


Figure 8-11: IDEF process model's master-map showing hierarchical relationships between processes and sub-processes (colour coding)

8.4.4.1 Stage 0: Strategic Definition - NEED

UOB 0 "*Undertake Strategic Definition*" shown in Figure 8-12 is level 2 decomposition needing the inputs shown in the level 1 hierarchy model. The inputs consist of traffic and urban study, high-level project sources, public needs and client's aspirations. Then the sub-processes (UOB 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6) are performed in parallel. The strategic brief is the output of this function which includes project objectives, team appointments, Employer's Information Requirements (EIR), site information and constraints shown in Figure 8-13.

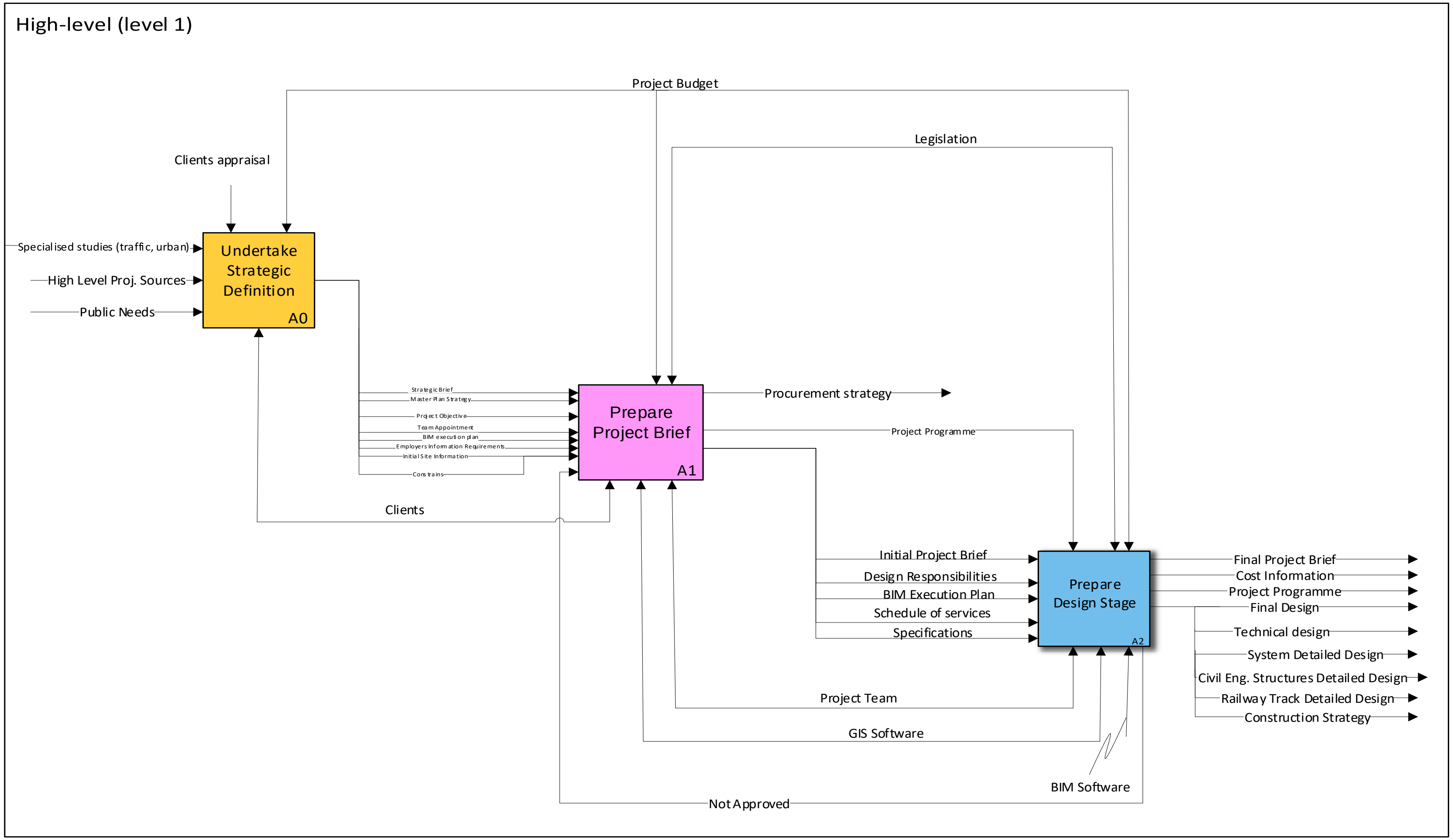


Figure 8-12: Level 1- IDEF Process Decomposition Diagram

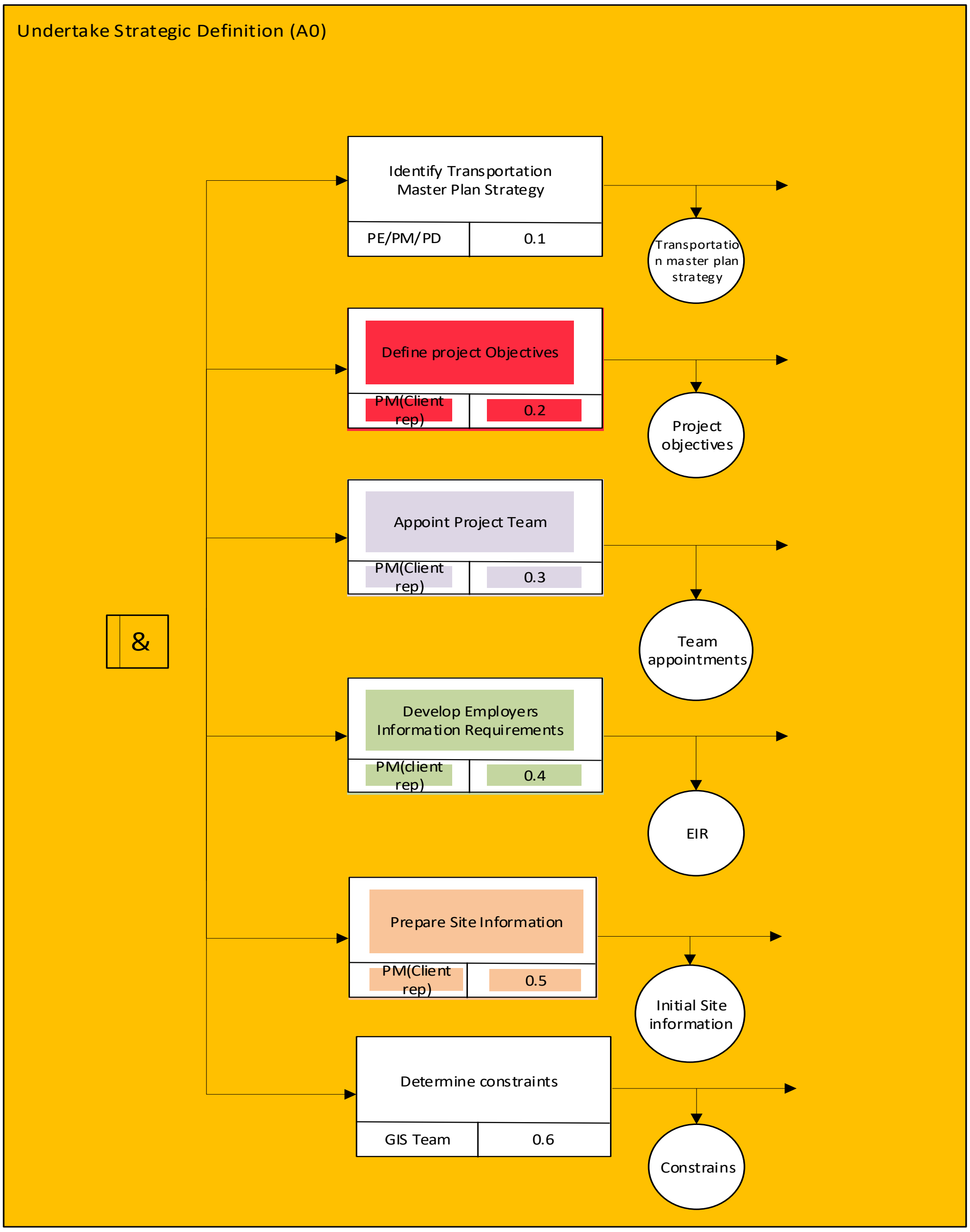


Figure 8-13: level 2-IDEF Process Decomposition Diagram (A0)

8.4.4.2 Stage 1: Preparation and Brief - EXECUTION

The decomposed UOB 1 "*Prepare Project Brief*" shown in Figure 8-14 requires the (UOB 0)'s outputs as inputs. Developing a BEP (UOB 1.3) and Schedule of services (UOB 1.1) based on the information contained in the EIR. The EIR will be the project manager responsibility if the clients do not provide it (EIR).

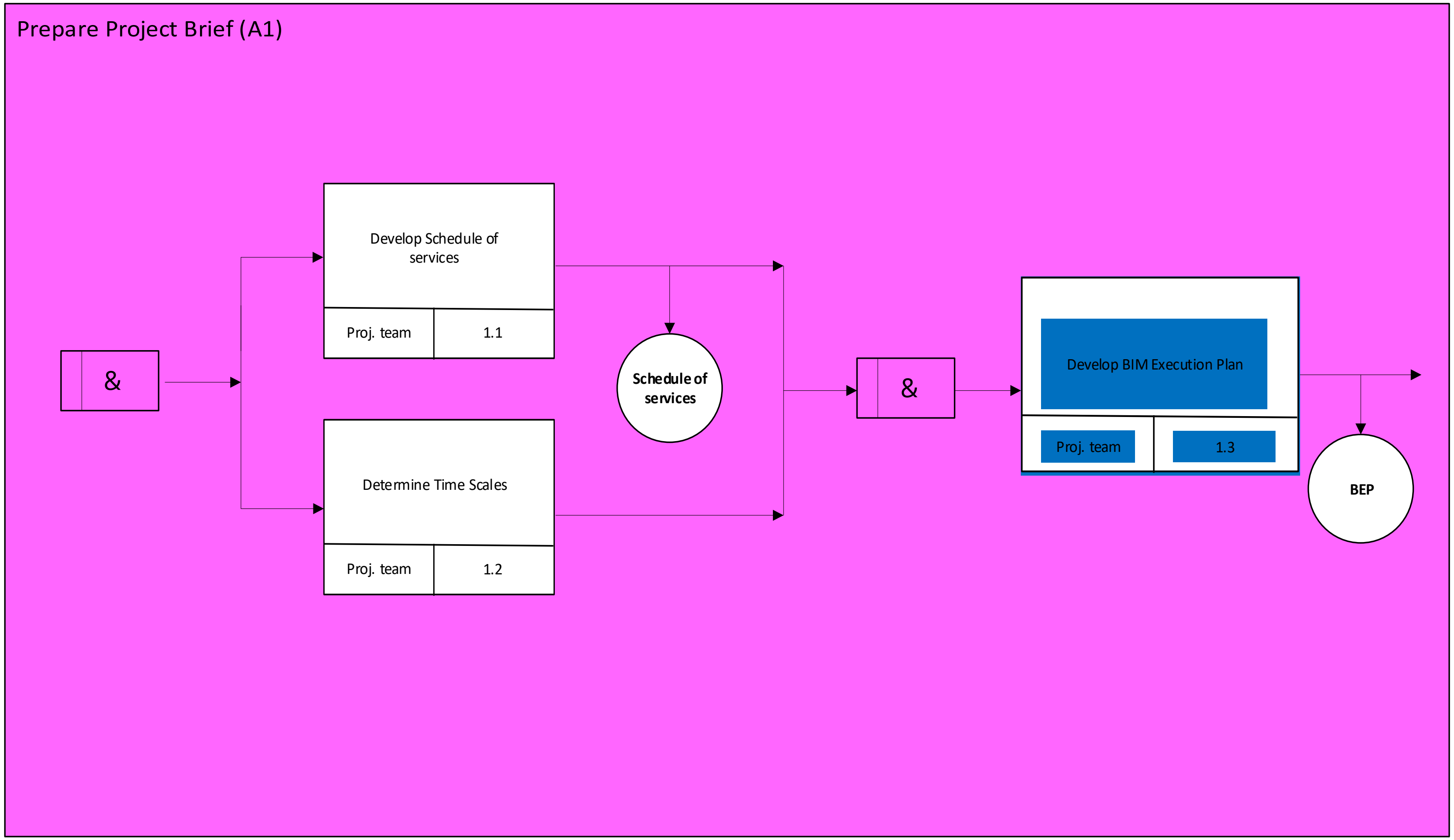


Figure 8-14: Level 2-IDEF Process Decomposition Diagram (A1)

8.4.4.3 Stage 2: Design Stage – DELIVERY

After completing the requirements and definition phase, the occupancy requirements, and site information was available for use. This stage is considered as a process, and divided into three main phases which consist of loops of design and assessment Figure 8-15: (i) develop a single design; (ii) develop a concept design and (iii) develop the detailed design. The structure of the functions of UOB 2.1, 2.2, 2.3 is illustrated in Figure 8-15.

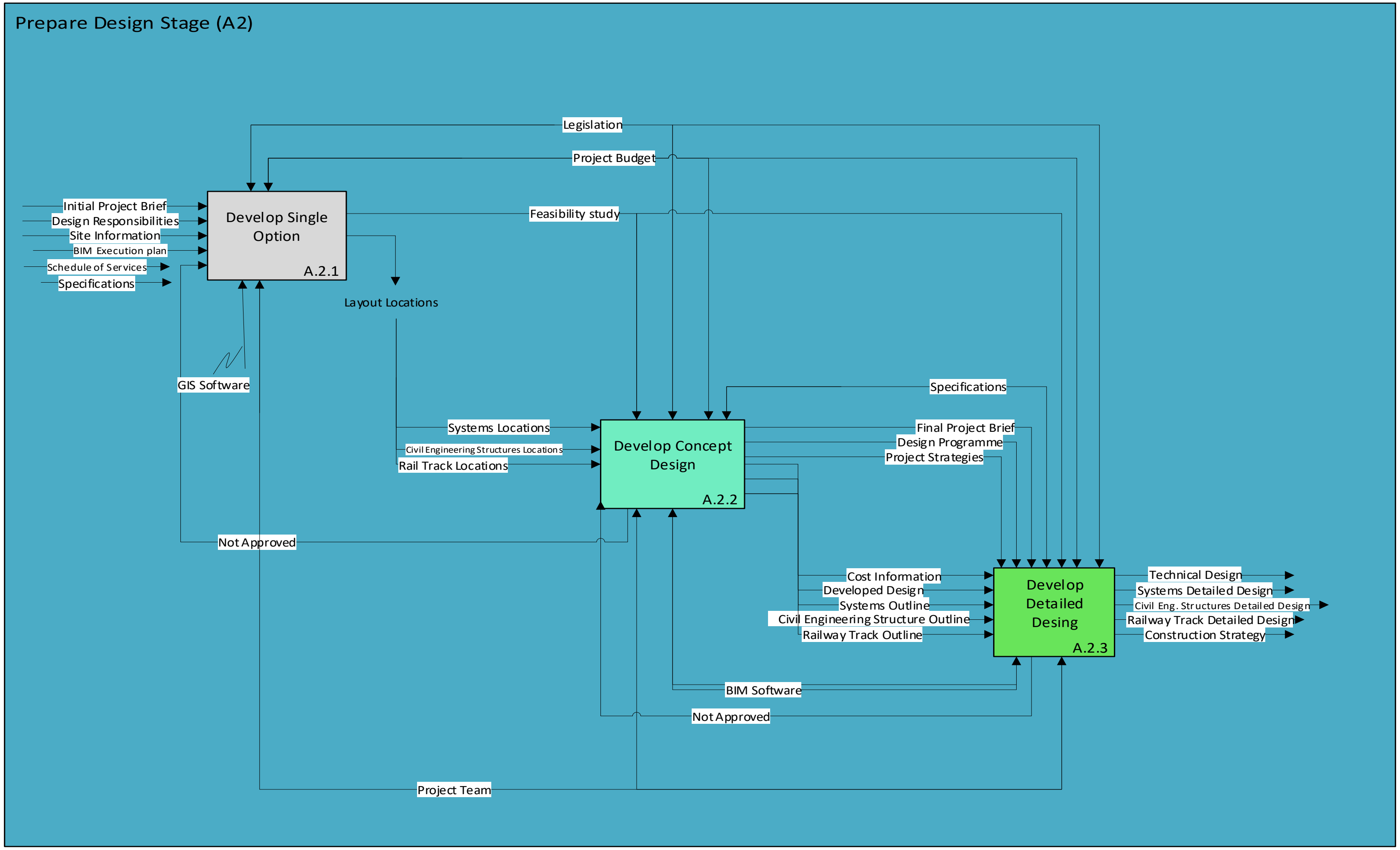


Figure 8-15: Level 2-IDEF Process Decomposition Diagram (A2)

UOB 2.1 “Develop Single Option” is the critical step in which the possible routes will be examined and checked for feasibility. The aim of this task was to develop possible routes and then asses them to obtain the optimum route. Furthermore, the feasibility of the project and the estimated cost whether they are within the project objective and budget allowance or not. This UOB 2.1 has been further decomposed to Level 3 hierarchy UOB (2.1.1, 2.1.2, 2.1.3, 2.1.4, 2.1.5, 2.1.6, and 2.1.7) shown in Figure 8-16. UOB 2.1.1 also decomposed to level 4 hierarchies (Figure 8-17), this decomposed were to reveal the process of developing the route options and identify the details and locations of the structures and systems of the railway (tunnels, bridge, drainage systems, etc.)

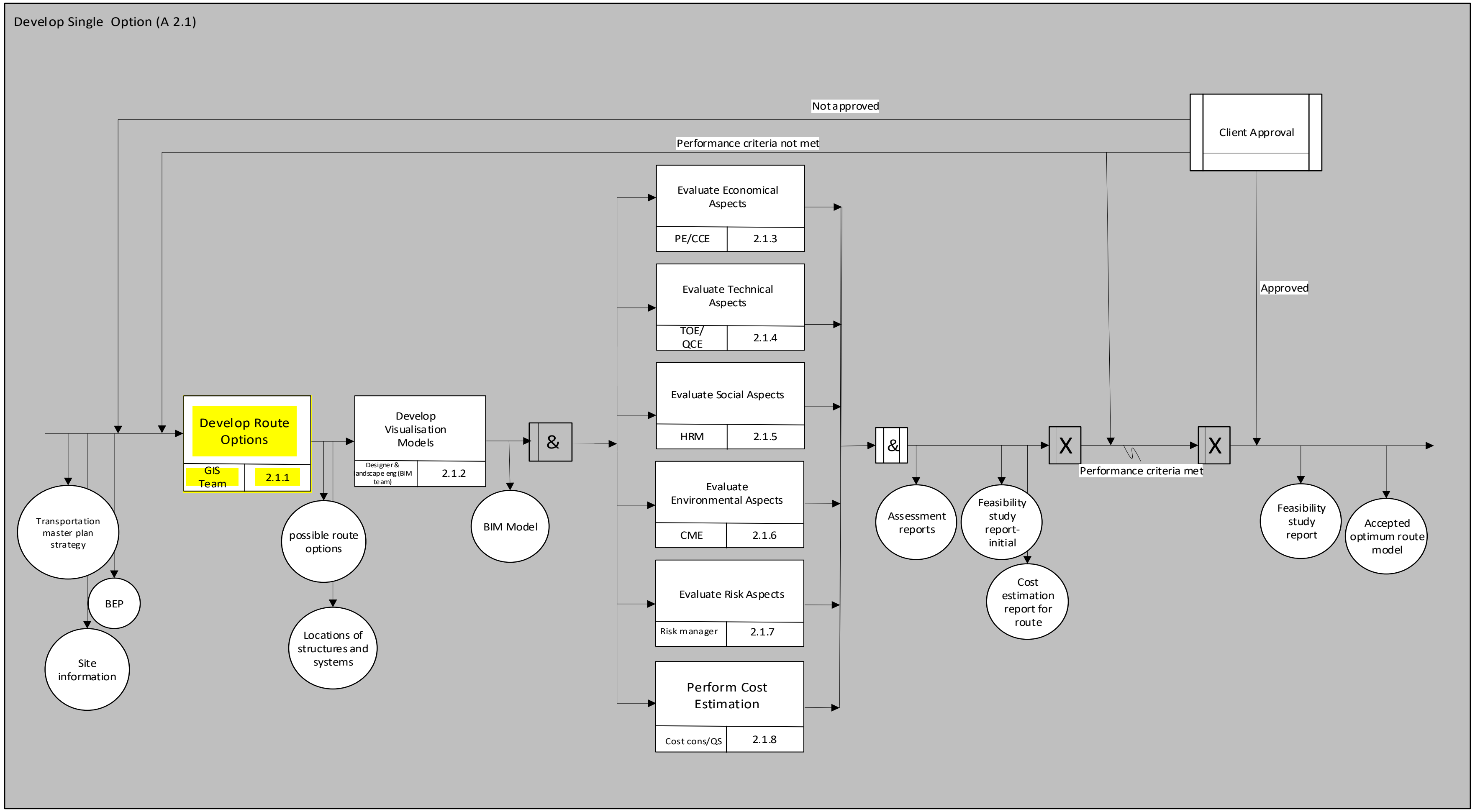


Figure 8-16: Level 3-IDEF Process Decomposition Diagram (A2.1)

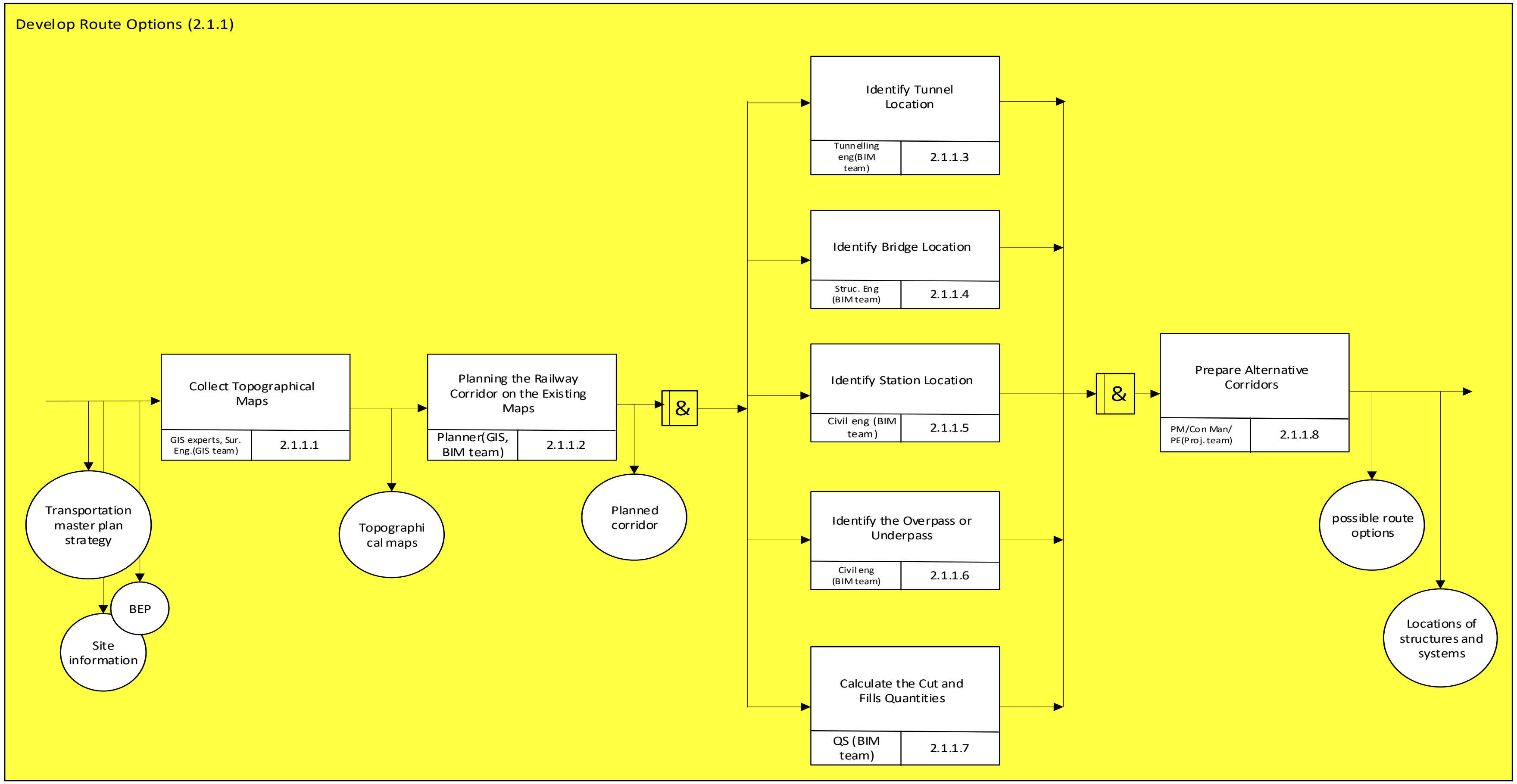


Figure 8-17: Level 4-IDEF Process Decomposition Diagram

UOB 2.2 “Develop Concept Design” showed the process of the initial design of the railway. This process starts with determining the specification of the railway (track panel, superstructure and substructure). Then followed by developing the BIM model for the railway to coordinate them and check the criteria to get the client approval for the detailed design. This level divided into four functions (UOB 2.2.1, 2.2.2, 2.2.3, 2.2.4) and UOB 2.2.1 have been further decomposed to Level 3 hierarchy (figure 8-18).

UOB 2.3 “Develop Detailed Design” consists of designing the railway in more details which are based on the development of the BIM models from a concept design. The detailed design of railway means the in-depth specified information such as the rail manufactory, the type of material, the thickness and the diameter of the tube if applicable which depends on the project objective and the type of the railway.

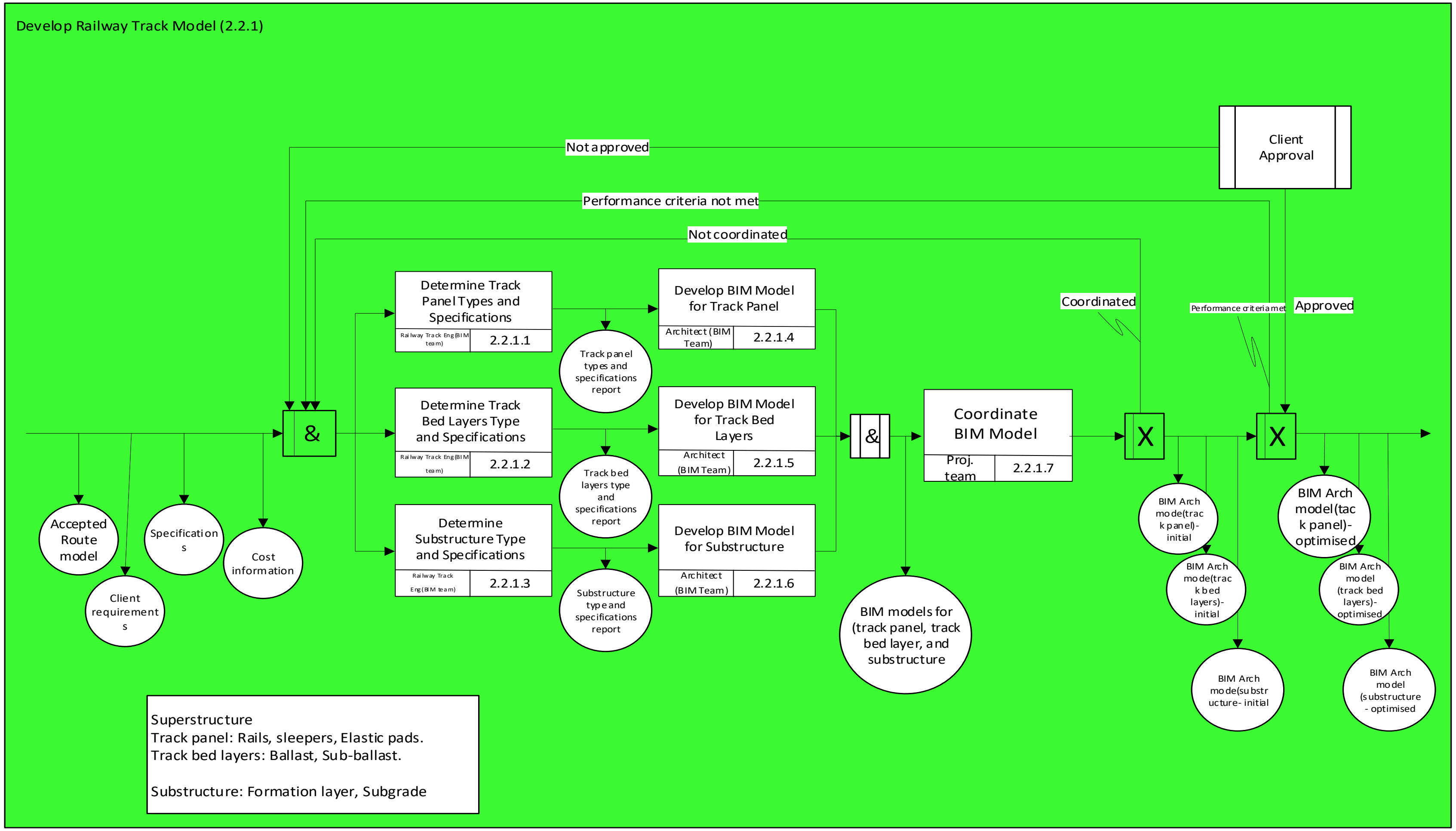


Figure 8-18: Level 4-IDEF Process Decomposition Diagram

8.4.4.4 Critical Decision Points

In PAS1192:2-2013 (BSI, 2013) the identification of decision points is discussed as a critical aspect of the BIM process. In the review of phase gate, decision points comprise two types of gates; hard-gate and soft-gate (section 5.5.3). When decisions are taken, timing is crucial to saving time and cost to avoid re-working. Thus, the right information should be delivered at the right time. This practice is challenging to achieve project objectives without increasing the cost and causing a delay in the project programme. When the critical decision points are identified, it assists to determine the loops of an iterative design process. For collaborative design, when a mapped process that can be audited with soft and hard gates, quality assurance would be provided that the project objectives would be met.

Junctions in the IDEF3 model used to provide the soft gates in the process of integrating considerations and criteria at the right time. For example, when the process may need iteration, the "Exclusive-OR" Junctions [X] correspond to decision points in the process. Furthermore, in function (A 2.1) Figure 8-16 in the synchronous and asynchronous "AND" Junctions [&] mean that by the end of task "develop visualisation model" (UOB 2.1.1), and begin of functions (UOBs) 2.1.3 to 2.1.8, but not necessarily at the same time; however, once they are all completed, they are a part of the "Assessment Report", "Feasibility Study Report-initial" and "Cost Estimation Report for Route".

8.5 Summary of the UOBs and information delivered during the development plan of work

The information summarised from the IDEF diagrams to provide a summary of the workability of the process model for collaboration (WHY, WHO, WHAT, HOW). Table 8-3 summarised each UOB for each decomposition level in terms of inputs and outputs. Table 8-4 to identify the delivery information about the decomposition level 2 (A2) shown in Figure 8-15, which include the main design process. Each UOB consisted of the function name followed by WHY (the purposes), WHO (role, competencies/training, and collaborators) and WHAT (information requirements, inputs-outputs), and HOW (creation/processing, software tools, and communication methods).

Table 8-3: Summary of Information Requirements of UOBs

Information Requirements
<u>Level 1 Decomposition</u> **Inputs of UOB A0** • Specialised studies (traffic, urban ...etc (see Chapter 6, Section 6.2.1) • High-level project sources (Occupants' needs (e.g. comfort and health): activities, functions, number of people, equipment, personal preferences, acoustic requirements, identification of environment pollutants (noise, air pollution), budget allowance estimation, timeframe). • Public need: the reasons or the purpose behind the railway (renew or construct a new one) which may include strategic considerations, political considerations, developing of backward areas, connecting new trade centres, and shortening existing rail lines. **Outputs of UOB A2** • Final Project Brief • Cost Information • Design Programme • Final Design - Technical Design - System Detailed Design - Civil engineering structures Detailed Design - Railway Track Detailed Design - Construction Strategy
<u>Level 2 Decomposition</u> **Outputs of UOB A0** • Strategic Brief • Transportation master plan strategy. • Project objectives Team Appointments**:** Authorities, consultants/contractors, operators, Client/Client Adviser, Architect/Lead Designer, Landscape Architect/Ecologist, Structural Engineer, Civil Engineer, Geotechnical Engineer, Interface and network analysis engineer, Environmental Expert, Tunnelling Engineer, Railway Track Engineer, Signalling Engineer, Cost Consultant, quantity survey, BIM team, BIM Manager/Coordinator, GIS team, Projects team. • Employers Information Requirements (EIR): managerial, commercial, technical • Initial site information. • Constrains

Level 2 Decomposition **Outputs of UOB A1** • BIM Execution Plan (BEP): description of the project, project directory, contractual tree, design responsibility matrix and information exchanges, project programme, technology strategy (software, hardware, and training), communication strategy (i.e. meetings, types of meetings, queries, data exchanges, format, and transfer mechanisms), CAD/BIM standard (i.e. coordination strategy, standards, coordination, collaborative process, reviews and quality control), and change control procedures. • Schedule of Services • Initial Project Brief • Procurement strategy
Level 2 Decomposition **Inputs of UOB 2.1** • Initial Project Brief • Site information • BIM Execution Plan • Schedule of Services • Specifications: specifications of the railway needed to be based on the project objectives and the purpose of the railway. **Outputs of UOB 2.3** • Detailed design of railway infrastructure in terms of: - Technical design - System detailed design - Civil engineering structures detailed design - Railway Track detailed design • Construction strategy
Level 3 Decomposition **Inputs of UOBs 2.1.1** • Transportation master plan strategy • BIM Execution Plan. • Site information **Outputs of UOBs 2.1.1/input of 2.1.2** • Topographical maps: maps for the possible route in the area. • Possible route options • Locations of structures and systems **Outputs of 2.1.2/ inputs of 2.1.3 – 2.1.8** • BIM Model: developing BIM model for the possible route to and ready for assessment.

Outputs of 2.1.3 – 2.1.8
- Assessment report: to identify the optimum route from the options.
- Feasibility study.
- Accepted optimum route model.

<u>**Level 3 Decomposition**</u>

Inputs of UOBs 2.2.1-2.2.4
- Accepted optimum route model.
- Locations of structures and systems.

Outputs of 2.2.1-2.24
- BIM model coordinated
- Civil eng structures models- optimised
- Systems model-optimised
- Railway track model-optimised

<u>**Level 4 Decomposition (A2.2.1)**</u>

Inputs of UOBs 2.2.1.1 – 2.2.1.3

- Accepted route model
- BIM model for the railway (coordinated) (track, structures, systems).
- Project objectives: the purpose of the railway and client requirements.
- Specifications: for the needed railway and according to the regulations and standards.
- Cost information: estimated cost and budget allowance.

Outputs of UOBs 2.2.1.1 – 2.2.1.3/ inputs of 2.2.1.4-2.2.1.6
- Specifications reports: detailed required for the detailed design of the railway way (track panel, trackbed layer, superstructure and substructure).

Outputs of UOBs 2.2.1.4-2.2.1.7
- Design Drawings (optimised BIM models): architecture, technical, and mechanical for the (track panel, trackbed layer, superstructure and substructure).

Table 8-4: Summary of Delivery of information during developed plan work from this research (Concept Design)

UOB	WHY	WHO	WHAT	HOW
UOB 2.1: Develop single options	Developing single options is the most important task during the design process. From this task, the optimum route will be selected which save a huge amount of money, time, efforts, land equations	This role needs to have the ability to very well understand and read a GIS map and analyse the spatial data and model the options to determine the most appropriate one. This task is undertaken by the GIS team, BIM team, PE/CCE, TOE, QCE, HRM, CME, Risk managers, QS.	This information comes from GIS or from the government. Such maps will save efforts which can be obtained without any site visiting. The output from this analysis is the optimum route with the location of the railway structures, systems and feasibility study.	GIS software has the ability to provide such maps and information about and around the area that need to construct or renew a railway line and utilise them to develop a topographical map about the area. Then develop a BIM or GIS model to show all route options and assess the options against the criteria and budget allowance to choose the optimum route which met the criteria and serve the project objectives.
UOB 2.2: Develop concept design	This task is crucial before starting the construction stage. This task will provide the drawing and the design model for the project which they will be followed in the construction stage to avoid reworking and determine the possible clashes before constructing them. Furthermore, provide the project with drawing to be ready for inputting and defining the detailed for the project.	BIM Team and BIM coordinator are responsible for this task to develop the models and coordinate them.	The information required for this task is shown in **Error! Reference source not found.** (outputs of A2.1). the outputs are the developed design and the outline of the project (track, structures, and systems), design responsibilities to coordinate the BIM model.	Project models are developed using BIM software such as Bentley, Rivet, infra work for the optimum options. The design consists of the optimised architecture, technical, mechanical drawings. For cost estimation, BIM software can be used such as Tekla
UOB 2.3: Develop detailed design	In this task to determine the detailed design of the developed design in the previous task (UOB 2.2)	BIM team (Architect, railway track engineer) are undertaking this task to add the details to the design	The information required for this task is the output from the previous task (UOB 2.2). also, project objectives cost information and specifications for the (track panel, track bed layer, superstructure and substructure)	Using the specifications and following the project objectives and with the availability of the standards, drawing of the project (track , structures, and systems) detailed (for example, diameter of the derange systems, thickness of the track penal, the thickness of the track bed, type of the track bed layers, bearing capacity and so on) will be easy to be added. Then checked these detailed with the criteria set out by the clients such as loads, types of the railway, types of the materials, manufactory of the materials

8.6 Summary

This chapter presented the validation process of the research outputs through conducting a focus group with experts in the big company whom already implementing BIM, GIS, and common data environment followed by an in-depth interview with a BIM and GIS expert. An industry-friendly software has been utilised to present the collaborative design process named (viewpoint for the project).

During this process, the received feedback illustrated the significance of the research outcomes which provided a timely solution to the problem of BIM and GIS-enabled collaboration for the design process. Therefore, the main principle that should be followed in this process as demonstrated which is: a clear definition of the project objectives before implementation and delivery, a clear process of collaboration through discussing the activity results and iterative process of the railway design and assess the options. Furthermore, frequent checks of the railway route options against a set of criteria.

The overall recommendations were few, the most important one was showing the significance of developing the CPW and how it fills a gap because it focuses on collaboration more rather than deliverables. Also, the suggestions and comments to amend the diagrams were minor, such as renaming some activities and adding some required activities (section 8.4.3). For example:

1- In IDEF0 level 1 Decomposition: no changes are recommended.
2- In Level 2: change the activity name from “Determine Pinch Point” to “Determine Constraints” and rename activity “Evaluate Regions Aspects” to more comprehensive meaning “Evaluate Environmental Aspects”.
3- In Level 3: delete the activity “Determine the Level of BIM Certification” as it is not a mandatory task, it can be optional.
4- Level 4: add “Risk Management” task/activity to the proper place to be evaluated as it is a critical issue.

Then the findings from the research and according to the received feedback have been synthesised to refine and revise the IDEF model after the validation process. These IDEF models presented a collaborative process of railway.

Chapter 9 : Conclusions and Recommendations

9.1 Introduction

This chapter provides the conclusions and recommendations drawn from the research findings. The main conclusion from each previous chapter of the thesis will be referred to. Then the second section presents the achievements of the research based on the research aim and objectives. In the following section key research contributions to existing knowledge is provided. Subsequently, the discussion of the research limitations is presented. The final section towards recommendations and further research.

9.2 The Main Conclusions Drawn from the Research

This section distils the main conclusions extracted during this research as follows:

A comprehensive literature review was performed in order to identify the research gap in existing knowledge. The literature review indicated that there is a lack of implementing BIM with GIS collaboratively in railway projects (chapter 2 and 3). A comprehensive review of the methodology and research design was presented to serve the research objectives (chapter 4). It was found that the mixed method (triangulation method) was the most appropriate method to achieve the research objectives. Therefore, an online survey (questionnaire) was conducted to assess the current status of BIM and GIS in railway projects, as presented in chapter 5.

The questionnaire findings addressed several important aspects, such as there is a lack of experience of BIM and GIS and the importance of training. The most popular software was AutoCAD and Revit for BIM, ArcGIS for GIS. Furthermore, the most stages for implementing BIM (design stage) and GIS (planning and pre-planning stage) were identified. Moreover, the survey findings concluded that more investigation required to identify the collaboration issues and suggestions to overcome them. For these purposes, two rounds of interviews were conducted, presented in chapter 5 and 6. A Collaborative Plan of Work (CPW) (collaboration based) was developed from the first round of in-depth interviews to facilitate the process of developing a process model. This plan of work is customised for railway projects. An IDEF process model was developed after identifying the components of the process model, which was a collaboration-based, were through conducting the second round of in-depth interview. To validate the workability of the process model, an industry user-friendly CDE platform (Viewpoint for the project) was used (chapter 8). Findings revealed the importance of the process model and confirmed that the CPQ actually provides the parties involved in the design process with guidance on how to collaborate.

9.3 Achievements of the Research Aim and Objectives

The aim of this research was to improve collaboration between participants through integrating BIM and GIS to manage information to get the right information to the right stakeholder at the right time for the right purposes. The following sections discuss how each objective was achieved.

9.3.1 Achievement of the First Objective

The first objective was "*To review the collaborative working railway sector and explore the current practice of BIM and GIS in railway design stage to identify the main problems in collaborative design management*". This was accomplished through the literature review and presented in Chapter 2.

In Chapter 2, a comprehensive literature review was performed on the importance of the railway infrastructure and why it required attention (section 2.2- section 2.4). Furthermore, collaboration requirements were examined (definition, types, drivers, design process, and design management) (section 2.5- section 2.6.3.5). Moreover, present Integrated Collaborative Technologies (section 2.8) and plans of work (section 2.6). Further investigation based on the fulfilment of the first objective was required to investigate the state of art in BIM and GIS to identify the gap in existing knowledge. From the literature review, the research problem has been identified which there is a lack of research to address it (section 7.2).

9.3.2 Achievement of the Second Objective

The second objective was "*To examine the use of technological advancements state of the art in BIM and GIS to identify the gaps in knowledge for collaborative design.".* This was presented in chapter three and accomplished through a literature review.

A comprehensive literature review on BIM and GIS to identify the background of these technologies considered as a potential for the improvement of collaboration. Detailed background and BIM and GIS (section 3.1 and section 3.5.1) were provided along with their applications (section 3.4 and section 3.5.2) in different stages throughout the project lifecycle. Next, the differences between BIM and GIS were presented (section 3.6) and how they can be integrated together (section 3.7). Then the applications of this integration on different stages throughout the project lifecycle were demonstrated (section 3.8), 3.8.1, 3.8.2 and 3.8.3). Moreover, reviewing of literature about BIM and GIS integration for collaboration were presented (section 3.7).

Overall, it was acknowledged that there is a lack of studies on the collaborative process in railway projects. However, the reasons behind this lack need to be investigated. Therefore, further investigation was required to assess the current practice of BIM and GIS and examine its potentiality to improve collaboration in the design stage of the railway (chapter 5).

9.3.3 Achievement of the Third Objective

The third objective was "*To assess the current practice of integrating BIM and GIS in railway projects.*

". This was accomplished through the questionnaire, presented in chapter 5.

Currently, BIM has been implemented across the project lifecycle for visualisation, clash detection, enhancing communication, managing information, decision making, coordination and collaboration (section 5.1.3). On the other hand, GIS facilitates the decision-making process, improve the availability of data, collaboration, and clash detection (section 5.1.3). Likewise, integration BIM with GIS has many benefits: managing information, collaboration, increase design quality, relationship and stakeholders (section

5.1.4). Current techniques and tools by integrating BIM and GIS have been utilised to enhance construction and design issues, including sustainable design and reducing waste (Liu, 2014). However, there are a few approaches, techniques that attempt to provide a process to collaborate effectively in the design stage of railway projects specifically (section 5.1.4) (section 7.2).

Findings from the questionnaire were employed to investigate collaboration issues and the potential solution to overcome these issues.

9.3.4 Achievement of the Fourth Objective

The fourth objective is/was *"To develop a 'BIM-GIS' process model for effective collaboration for the design stage of railway projects".* This was accomplished by performing two rounds of in-depth interviews and was presented in chapter 5 and 6.

The findings of the first round of interviews identified the main issues of effective collaboration during the design stage of the railway project. For instance, managing information to get the right information at the right time for the right purposes, and resistance to change (section 5.4.1).

The interview findings suggested that using a process model may help to address the collaboration issues (section 5.4.2). Nevertheless, this process model required a plan of work for the railway and collaboration based. Therefore, CPW was developed from a combination of the early RIBA Plan of Work and GRIP Stages stage: 0 (Strategic Definition), stage 1 (Preparation and Brief), and stage 2 (Concept Design), which was developed from the interview findings (section 5.4.2). Furthermore, it needs clarification of the process component, tasks, role and responsibilities to fulfil the potential of the process model using BIM and GIS. Therefore, the interviewees argued that these requirements need to be addressed.

Findings obtained from the first round of the interviews were employed to identify the process model requirements. To achieve that follow up the second round of interviews were conducted to identify the process model component (section 5.5.1), role and responsibilities (section 5.5.1.2), tasks (section 5.5.1.3), deliverables and information requirements (section 5.5.2), and decision points section (section 5.5.3).

Therefore, from the findings extracted from the interviews, literature review and the questionnaire; a process model was developed to improve collaboration to manage the information in order to get the right information for the right purposes (chapter 6).

9.3.5 Achievement of the Fifth Objective

The fifth objective was *"To validate the proposed process through engagement with participants and to develop guidelines for implementation of this process model*". This was accomplished through conducting a focus group and interviews and it is presented in chapter 8.

The aim of the validation of the process model was to determine the clarity and the workability of the process model. The results of the validation process indicated that the process model has a clear structure and flow. It also confirmed that the content is appropriately presented as well as it is an industrial friendly. The process model is improved and revised based on the suggestion made by the validation participants (section 8.4.3). The process model validation identified that this process model is the most appropriate for clarifying the collaborative process in line with the developmental work of the plan.

As a summary, all the participants from the first stage (the questionnaire) till the final stage (validation process) were very satisfied with reading the aim of this study and they considered this process model as a very crucial to provide a collaborative process and managing the information. Furthermore, they emphasise that this process model really fills a gap by demonstrating how to collaborate instead of just technical issues, especially as it follows an untied plan of work (CPW) (section 8.4.2).

9.4 Contribution to Knowledge

This research has argued that the most significant challenges to deliver a successful railway project within the planned targets were collaboration and managing information (chapter 1). This research makes three contributions to knowledge:

1) Theoretical understanding of BIM, GIS and collaboration. 2) A Collaborative Plan of Work (CPW). 3) A process model for BIM and GIS-enabled collaboration in the design stage of railway projects.

The literature review revealed that there is a lack of collaboration between participants in the project. Therefore, it has been confirmed that the absence of the right information at the right time to make critical decisions are the most common challenges to achieve collaborative design (DTI, 2007). Even though, to tackle these challenges, it is required to provide the participants with a guideline to demonstrate the process of collaboration and how to collaborate, exchanging information and making critical decisions. Due to lack of studies regarding a clear process of collaboration in railway, this research attempted to fill this gap by developing a process model illustrating the design process in terms of; tasks, role and responsibilities, deliverables, information requirements, and critical decision points. Furthermore, this process model aligns with the development of the plan of work (CPW) resulting from a combination of the RIBA Plan of Work and GRIP stages to be comprehensive for the design stage of railway projects. This CPW focuses on the collaboration process and managing information. Hence, the process model will facilitate the collaboration process and where the BIM and GIS are used, in addition to making the right decision at the right time.

9.5 Limitations of the Research

There are several limitations in this study that need to be acknowledged. On one hand, the research studies related to collaboration in the railway were few, which makes building a strong foundation of the research problem challenging. Hence, the research was somehow exploratory, to assess the current status of BIM and GIS in railway projects. The sample of the questionnaire was limited to professionals experienced in BIM and GIS, and such professionals were challenged to find. The reasons were rooted in the recent adoption of BIM and GIS which resulted in few experts in these technologies in the railway area.

Furthermore, the railway sector is very significant, and their projects less than building projects, so they are busy and time-limited. As a result, the challenge of finding experienced professionals was faced.

On the other hand, the formed focus group consisted of four participants from a single organisation/project, due to the difficulty of getting more participants even with contacting and sending invitations to more than 100 possible participants. However, the results obtained from the focus group (group interviews) and the follow up interviews were quite adequate to validate the process model and refine it. A more thorough validation would entail applying the proposed CPW process to a real project and measuring its impact. However, this exercise was not possible within the scope of a PhD project due to lack of resources and accessibility to railway projects.

9.6 Recommendations for Future Work

The findings of this study can be utilised as a base for further research in many areas. There are some recommendations such as encouraging companies to provide involved parties in the design stage with proper training in BIM and GIS. Furthermore, conducting awareness courses, workshops, and events to identify the benefits of collaboration and the opportunities it can offer.

1- The research could be extended to study the entire lifecycle railway projects (beyond design). For example, a process model of collaboration in the construction stage, operation and maintenance.
2- Follow up research is required to develop a process model for the other CPW such as "*Develop Detailed Design"* and "*Construction*", "*Handover and Project Close-Out*" and develop an IDEF diagram in detail.
3- The process model may be applied practically from the start of any new railway project to approve the workability in a real project to examine the long-term efficiency.
4- Further research is required to merge other plans of work such as GSL and compare the results and define the most realistic one.

9.7 Final Remarks

This research programme is the first to identify a lack of BIM and GIS-enabled collaboration as a critical issue at the design stage in railway projects. To address this issue, we developed strategies/solutions to ensure effective collaboration. A process model has been suggested to provide this effective collaboration. However, developing this process model appeared to require a specific collaborative plan of work (CPW). The letter was then developed; consequently, the process model and its components have been developed using IDEF technique. Importantly, the workability of this process model was then validated using Viewpoint for project software. The outputs/findings of this research programme have important implications for railway projects; the developed process model is believed to achieve effective collaboration which in turn will improve efficiency, productivity and better decision making. However, future research requires further investigation on this.

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Appendixes

Appendix A: List of Publications

- KURWI, S., DEMIAN, P. and HASSAN, T.M., 2017. Integrating BIM and GIS in railway projects: A critical review. In: Chan, P W (Ed.) and Neilson, C J (Ed.), 33rd Annual ARCOM Conference, Cambridge, UK, 4-6 September, pp. 45-53.

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Demian, Peter
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Abstract: The railway plays a significant role in human life by providing safe, reliable, cost effective services, which are environmental and drive economic growth. Significant decisions are taken at early stage of rail projects which need effective tools to avoid rework and save time, cost and increase work efficiency. Indeed, the continuous upgrading of this sector is needed to respond to technological advances, environmental change and increased customer demands. Integrating Building Information Modelling (BIM) and Geographic Information systems (GIS) is promising since the scope of BIM usually does not extend beyond the footprint of the "building"; it does not provide geospatial data. Therefore, integrating BIM with GIS provides a complete picture of the project. However, this integration is challenging especially in rail projects as they are amongst the most complicated projects and numerous parties are involved in making important decisions. This paper reviews the literature regarding integrating BIM with GIS systematically, with the aim of analysing the need for this integration and its benefits. The paper highlights a lack of a clear guideline for collaboration in the railway project lifecycle and indicates the need for research to focus on this issue as well as the possibility of applying integrated BIM with GIS as a potential solution to improve collaboration for better decision among project participants.

ISBN: 9780995546318

Appendix B: The Questionnaire

Questionnaire

BIM/GIS Integration to Improve Collaboration in Railway Projects

Dear Participant,

The purpose of this questionnaire is to provide a review of the current status of integrating BIM (Building Information Modelling) with GIS (Geographic Information System) in railway projects. The results obtained from this questionnaire will be used as a part of a PhD study, at Loughborough University supervised by Dr. Peter Demian and Prof Tarek Hassan, that aims to develop a framework to improve collaboration in the design stage of railway projects.

Your participation is voluntary, and this questionnaire is intended to not take more than 20 minutes.

This research in being conducted in compliance with Loughborough University's research ethics policy and all information will be handled in confidence.

Thank you for taking the time to assist the researcher in her research. You have the opportunity to leave contact details at the end of this questionnaire to be sent a report of the results or to be engaged in subsequent phases of data collection.

If you are not happy with how the research was conducted, you can contact Ms Jackie Green, the Secretary for the University's Ethics Approvals (Human Participants) Sub-Committee:

Ms J Green, Research Office, Hazlerigg Building, Loughborough University, Epinal Way, Loughborough, LE11 3TU. Tel: 01509 222423. Email: J.A.Green@lboro.ac.uk

If you require additional information or have questions or comments, please contact the researcher at the number or the email listed below. If you prefer to complete the questionnaire online, it is available in the following link:

https://lboro.onlinesurveys.ac.uk/bimgis-integration-to-improve-collaboration-in-railway-pr-2

Sahar Kurwi
Email: s.kurwi@lboro.ac.uk
Mobile telephone: +44 7491138359

Note/ please, all questions indicated by (*) is required

1- General information

1.1 What is your profession/role? (*)

Structural Engineer	
Civil Engineer	
Project Manager	
Site Supervisor	
Quantity Surveyor	
Mechanical Engineer	
Electrical Engineer	
Architect	
Other	

If you selected other, please specify: (*)

1.2 How many years of experience do you have *in Railway projects*? (*)

No experience (0 years)	
< 2 years	
2-5 years	
6-10 years	
11-15 years	
> 15 years	

1.3 In which sector do you work? (*)

Public	
Private	
Other	

If you selected other, please specify: (*)

1.4 How would you describe the size of your company? (*)

Large (250 or more employees)	
Medium (50-249 employees)	
Small (less than 50 employees)	
I am not working	

1.5 What procurement methods are commonly used in your projects? (Check all that apply) (*)

Traditional	
Design-Build	
Cost Reimbursable / Cost Plus	
Other	

If you selected other, please specify: (*)

1.6 In which place of the world is your response based (i.e. where is your work predominantly based)? (*)

UK	
Middle East	
Europe	
North America	
Asia/Far east	
Other	

If you selected other, please specify: (*)

2- Applications of BIM and GIS in projects in general

2.1 How satisfied are you with the collaboration among the project teams? (*)

Not satisfied	1	2	3	4	5	Very satisfied

2.2 How many years of experience do you have in *BIM, GIS in general*? (*)

Years of experience	**BIM**	**GIS**
No experience (0 years)		
< 2 years		
2-6 years		
6-10 years		
11-15 years		
> 15 years		

2.3 Have you had training in BIM/GIS? (Check the one that best applies) (*)

	BIM	GIS
None/Self-training		
Industry led training		
College courses		
Other		

If you selected other, please specify: (*)

2.4 Based on your experience with BIM and GIS, how far do you agree or disagree with the following? (*)

Statements	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
The percentage of people using both BIM and GIS is increasing at your company.					
Your company is willing to invest in employees to learn both BIM and GIS.					
The private sector is implementing BIM much faster that the public sector.					
If BIM /GIS were implemented correctly, the process will result in better time, cost, quality, and environmental impact.					
Construction professionals are aware of BIM processes and that BIM is mainly a process, not just a software.					
Using GIS makes work easier.					
Using BIM makes work easier.					

3- Applications of BIM and GIS in Railway projects

3.1 How many years of experience do you have *in BIM or GIS in railway projects*? (*)

Years of experience	**BIM**	**GIS**
No experience (0 years)		
< 2 years		
2-5 years		
6-10 years		
11-15 years		
> 15 years		

3.2 For how many years has your organisation been implementing BIM/GIS? (*)

Years of experience	**BIM**	**GIS**
No experience (0 years)		
< 2 years		
2-5 years		
6-10 years		
11-15 years		
> 15 years		

3.3 In your organisation, in which stage do you use BIM/GIS the most? (*)

	BIM	**GIS**
Planning		
Design		
Construction		
Operation and maintain		
Other		

If you selected other, please specify: (*)

3.4 What BIM/GIS software/platforms does your organisation currently use? (*)

BIM		**GIS**	
AutoCAD		Arcgis	
Sketchup		Qgis	
ArchiCAD		Geomedia	
Bentley		Ekshayal Smart GIS	
Revit		Other (please specify)	
Tekla Structure			
Nevisworks			
Other (please specify)			

3.5 Based on your experience, how would you classify the benefit of using BIM/GIS in each of the following project stages? (scale 1-5, where 1=Not beneficial and 5=Extremely beneficial) (*)

	BIM					**GIS**				
	1	2	3	4	5	1	2	3	4	5
Pre- planning										
Planning										
Design										

Construction										
Operation and maintenance										
Other (please specify)										

3.6 Based on your experience, how beneficial is using BIM/GIS in the projects in terms of: (scale 1-5, where 1=Not beneficial and 5=Extremely beneficial) (*)

	BIM					**GIS**				
	1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Improving the design quality?										
Improving productivity of estimator in quantity take-off?										
Reducing the project overall cost?										
Reducing the project overall duration?										
Avoiding redesign issues?										
Increasing collaboration among participants?										
Detecting clashes?										
Increasing the speed of the project delivering?										
Reducing risks?										
Improving the availability of data?										
Better decision making?										
Other (please specify)										

3.7 In your organisation, how would you classify the degree of importance of the following challenges while adopting BIM/GIS in your projects? (scale 1-5, where 1=Not important and 5=Extremely important) (*)

	For BIM					**For GIS**				
	1	2	3	4	5	1	2	3	4	5
Lack of demand by clients.										
Time, cost required to train existing staff and lack of personnel skilled.										

Lack of interoperability.										
Lack of collaboration between involved parties.										
Time required to produce the models.										
Cost of employing additional staff.										
Other (please specify)										

4- Integrating BIM and GIS in design stage in Railway project

4.1 For how many years has your organisation been implementing BIM/GIS in integrated way? (*)

No experience (0 years)	
< 2 years	
2-5 years	
6-10 years	
11-15 years	
> 15 years	

4.2 In your organisation, for the giving functions, how would you classify the degree of importance for integrating BIM/GIS? (scale 1-5, where 1=Not important and 5=Extremely important) (*)

	1	**2**	**3**	**4**	**5**
Coordination					
Collaboration					
Visualisation					
Clash detection					
Decision making					
Other (please specify)					

4.3 To what extent do you agree with the following statements? (*)

	Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**
Integrating BIM/GIS is beneficial to the project.					
The number of persons working with integrated BIM/GIS during the last five years has increased.					
The current BIM/GIS workflow is optimised for					

better results e.g.: saving time and cost.					
Using integrated BIM/GIS delivers benefits to designers and engineers.					

4.4 What are the most programs/platforms you use for integrating BIM/GIS in design stage? (*)

BIM programs/platforms		**GIS programs/platforms**	
AutoCAD		Arcgis	
Sketchup		Qgis	
ArchiCAD		Geomedia	
Other (please specify)		Other (please specify)	

4.5 How important are the following issues/barriers in integrating BIM/GIS in the design stage in railway projects? (Scale 1-5, where 1=Not important and 5=Extremely important) (*)

	1	**2**	**3**	**4**	**5**
Interoperability.					
Absence of trust.					
Search and access to needed data.					
Privacy and data protection.					
Resistance to change.					
Lack of experience.					
Not suitable for projects.					
Lack of client demand.					
Visualisation.					
Clash detection.					
Collaboration.					
Exchange information.					
Less request from information.					
Improved decision-making.					
Reduced cost.					
Other (please specify)					

4.6 To what extent do you agree or disagree with that integrating BIM/GIS in the design stage could enhance the following? (*)

	Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**
Collaboration.					

Understanding of roles within a team.					
Relationship between the project partners (stakeholders).					
Collaboration, information exchange and knowledge sharing and awareness of project partners (stakeholder).					
Collaboration in terms of the heterogeneity and the size of a team.					
Accessibility of project's stakeholders to information.					
Accessibility of project's mangers to knowledge required in order to manage/control their job.					
Accessibility and capability of project's managers to identify, analyse, and mange/control errors.					
Quality of design.					
Project delivery time.					
Simulation, calculation and analysis.					
Ease and joy of working.					
Visual exploration of design.					
Other (please specify)					

4.7 To what extent do you agree or disagree with that integrating BIM and GIS could enhance the interaction between the project's stakeholders in terms of? (*)

	Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**
Learning					
Coordination					
Communication					
Decision making					
Other (please specify)					

4.8 Do you have any more information to share about integrating BIM/GIS that may rich this questionnaire to improve collaboration in design stage for railway projects? (Optional)

5- Personal information

This information is optional. Please provide these details if you wish to receive a report of the results or if you wish to be involved in subsequent interviews of other data collection.

Name of organisation	
Address	
Website	
Name of person completing	
Position	
Contact Phone Number	
Email	

Appendix C: First Round of the Interview Questions

Sahar Kurwi
School of Architecture, Building and Civil Engineering
Loughborough University
Leicestershire
LE11 3TU

Supervised by: Dr. Peter Demian
Prof. Tarek Hassan
Karen Blay

Integration BIM and GIS to Improve Collaboration in Design stage in Railway Projects

<u>Aim</u>

This interview is a part of PhD research aimed to develop a BIM/GIS-enabled collaboration process model in design stage of railway projects. The aim of this interview is to identify collaboration issues and challenges in design stage of railway project. As well as to identify suggestions and solutions to tackle these issues and challenges. It seeks to gather information from respondents upon their expertise knowledge and experiences on BIM, GIS and railway.

The length of the interview will be around 1-2 hours and all information will be handled in confidence.

Contact email: s.kurwi@lboro.ac.uk

Section 1: collaboration issues

1- What are the collaboration issues that may appear while design stage?
2- Why collaboration is needed?
3- Who are the participants that involved in design stage?
4- What are the steps that you are following to integrate BIM with GIS in design stage in your projects?
5- What are the specific requirements or prerequisites for integrating BIM with GIS in railway projects?
6- What are the most three important barriers/challenges to integrate BIM/GIS in your projects?

Section 2: Potential of BIM and GIS and Suggestions

1- Do you use BIM/GIS integration for collaboration?
2- What are the opportunities that BIM/GIS integration can offer for effective collaboration? How? Do you have any guidelines, quality procedure, process..etc?
3- In your opinion, how integrating BIM/GIS can be used to provide effective collaboration in design stage? How can you use it? Any suggestions?
4- What the standards, frameworks or guidelines does your company follow for integrating BIM and GIS?

Section 3: Personal information

- Name
- Position
- Your professional
- Years of experience
- Name of your company

Appendix D: Second Round of the Interview

Sahar Kurwi
School of Architecture, Building and Civil Engineering
Loughborough University
Leicestershire
LE11 3TU

Supervised by: Dr. Peter Demian
Prof. Tarek Hassan
Karen Blay

Develop a collaborative Process Model for the Design Stage of Railway Projects

Aim

This interview is a part of PhD research aimed to develop a BIM/GIS-enabled collaboration process model in design stage of railway projects. The aim of this interview is to identify and identify process model components. It seeks to gather information from respondents upon their expert knowledge and experiences on BIM, GIS and railway.

The length of the interview will be around 1-2 hours and all information will be handled in confidence.

Contact email: s.kurwi@lboro.ac.uk

Section 1: Design Process of Railway Projects

1. How do you start the process of the design in your company?
2. What are the tasks that design stage consists of? What tasks do you think should be existed?
3. Who is the stakeholder involved in the design process?
4. Who do you think the most important stakeholders that should be involved in the design stage? to which tasks?

Section 2: The uses of BIM and GIS In Design Stage

1. How you use BIM and GIS for design stage in your company?
2. For the tasks mentioned, please, how do use BIM and GIS for them? How do think should be used?
3. How the collaboration process is going on in the work in the design stage?

Section Three: The Components of the Process Model

1. In your opinion, what are the tasks that should design stage consists of?
2. Who do think the participants responsible for each task? What should be their role?
3. How do think the BIM and GIS should be used?

Appendix E: Validation Documents

Loughborough University

Focus Group Meeting Handout

Date: 25/04/2018

Integration BIM and GIS to Improve Collaboration in The Design Stage for The Railway Route

Dear All, thank you for taking time out from your busy schedule to contribute to the validation of developed workflows.

The developed workflows which seek to enhance collaboration (on a project employing BIM and GIS) at the design stage.

Outline		Time (min)
1	**Presentation**	7
2	**Discussion of the workflows**	1:45
Fig 1	Undertaking Strategic Definition	10
Fig 2	Develop Employers Information Requirements Workflow	15
Fig 3	Team Appointment, Project Objectives, and Site Information Workflow	15
Fig 4	BIM Execution Plan Workflow	10
Fig 5	Feasibility Study Workflow	10
Fig 6	Develop Possible Route Options Workflow	15
Fig 7	Assess Possible Route Options Workflow	15
Fig 8	Develop Railway Track Model	15
3	**End**	

Email: s.kurwi@lboro.ac.uk

1. Please, select (by ticking) your role/s in your organisation (select all that apply):

- ☐ Client/Client Adviser
- ☐ Architect/Lead Designer
- ☐ Landscape Architect/Ecologist
- ☐ MEP Engineer
- ☐ Structural Engineer
- ☐ Civil Engineer
- ☐ Geotechnical Engineer
- ☐ Hydrologist
- ☐ Cost Consultant
- ☐ Transport consultant
- ☐ Sustainability Lead/Consultant
- ☐ Cost Consultant Contractor
- ☐ Singling engineer
- ☐ Sustainability Engineer
- ☐ BIM Manager/Coordinator
- ☐ Lighting Engineer
- ☐ Public Health Consultant
- ☐ GIS manager
- ☐ Other (specify): ……………………

2. ***Please, select your Areas of expertise*** *(select all that apply):*

- ☐ Architecture
- ☐ Engineering
- ☐ Environmental Physics
- ☐ Sustainability
- ☐ Other (specify): …………………………………

3. ***Please, select the software tools for BIM and GIS*** *that you have utilised for railway route design (select all that apply):*

A- For BIM

- ☐ Autodesk Revit
- ☐ Bentley MicroStation
- ☐ Bentley AECOsim
- ☐ Graphisoft ArchiCAD
- ☐ Nemetschek Vectorworks
- ☐ Autodesk Navisworks
- ☐ Nemetschek Solibri
- ☐ Rhino3D
- ☐ Trimble SketchUp
- ☐ Infrawork
- ☐ civil 3D
- ☐ None
- ☐ Other (specify): ………….

B- For GIS

- ☐ ArcGIS
- ☐ ESRI
- ☐ Qgis
- ☐ DeLorme
- ☐ Geomedia
- ☐ Ekshayal Smart GIS
- ☐ Nemetschek Solibri
- ☐ Rhino3D
- ☐ Trimble SketchUp

Other

(specify): ………….

*4. How many years of **experience have you worked** with **Building Information Modelling** (BIM) and Geographic information system (GIS):*

A- For BIM

☐ 0 - 5 ☐ 6 – 10 ☐ 11 - 15 ☐ >15 How ☐

B- For GIS

☐ 0 - 5 ☐ 6 – 10 ☐ 11 - 15 ☐ >15 How ☐

5- *Please **review** the workflows process description (attached in the PowerPoint slides) then (ticking the relevant box) and **comment** on the following: (scale 1-6, where 1=Strongly disagree and =strongly agree)*

Questions for Figure 9-1: Undertake Strategic Definition

	Questions	**1**	**2**	**3**	**4**	**5**	**6**	**Comments**
1	Do you believe that the workflow provides a guide to enhance the BIM-GIS enabled collaboration adequately?							
2	Would you recommend adding or removing any of the activities? Which ones and why?							
3	Do you think these workflows are effective in engaging the right people at the right time to achieve project objectives? Why?							
4	based on your experience, do you find such a workflow useful? Why?							
5	In your opinion, what are the benefits of a structured process for collaboration process?							
6	Would you use such a workflow in the future? Why?							
7	Would you recommend implementing such a workflow in the future? Why?							
8	In which ways do you think that the workflow can be improved?							

Questions for Figure 9-2: Develop Employers Information Requirements

	Questions	1	2	3	4	5	6	Comments
1	Do you believe that the workflow provides a guide to enhance the BIM-GIS enabled collaboration adequately?							
2	Would you recommend adding or removing any of the activities? Which ones and why?							
3	Do you think these workflows are effective in engaging the right people at the right time to achieve project objectives? Why?							
4	based on your experience, do you find such a workflow useful? Why?							
5	In your opinion, what are the benefits of a structured process for collaboration process?							
6	Would you use such a workflow in the future? Why?							
7	Would you recommend implementing such a workflow in the future? Why?							
8	In which ways do you think that the workflow can be improved?							

Questions for Figure 9-3:Team Appointment, Project Objectives, and Site Information

	Questions	1	2	3	4	5	6	Comments
1	Do you believe that the workflow provides a guide to enhance the BIM-GIS enabled collaboration adequately?							
2	Would you recommend adding or removing any of the activities? Which ones and why?							
3	Do you think these workflows are effective in engaging the right people at the right time to achieve project objectives? Why?							
4	based on your experience, do you find such a workflow useful? Why?							
5	In your opinion, what are the benefits of a structured process for collaboration process?							
6	Would you use such a workflow in the future? Why?							
7	Would you recommend implementing such a workflow in the future? Why?							
8	In which ways do you think that the workflow can be improved?							

Questions for Figure 9-4: BIM Execution Plan

	Questions	1	2	3	4	5	6	Comments
1	Do you believe that the workflow provides a guide to enhance the BIM-GIS enabled collaboration adequately?							
2	Would you recommend adding or removing any of the activities? Which ones and why?							
3	Do you think these workflows are effective in engaging the right people at the right time to achieve project objectives? Why?							
4	based on your experience, do you find such a workflow useful? Why?							
5	In your opinion, what are the benefits of a structured process for collaboration process?							
6	Would you use such a workflow in the future? Why?							
7	Would you recommend implementing such a workflow in the future? Why?							
8	In which ways do you think that the workflow can be improved?							

Questions for Figure 9-5: Prepare Feasibility Study

	Questions	1	2	3	4	5	6	Comments
1	Do you believe that the workflow provides a guide to enhance the BIM-GIS enabled collaboration adequately?							
2	Would you recommend adding or removing any of the activities? Which ones and why?							
3	Do you think these workflows are effective in engaging the right people at the right time to achieve project objectives? Why?							
4	based on your experience, do you find such a workflow useful? Why?							
5	In your opinion, what are the benefits of a structured process for collaboration process?							
6	Would you use such a workflow in the future? Why?							
7	Would you recommend implementing such a workflow in the future? Why?							
8	In which ways do you think that the workflow can be improved?							

Questions for Figure 9-6: Develop Possible Route Options

	Questions	1	2	3	4	5	6	Comments
1	Do you believe that the workflow provides a guide to enhance the BIM-GIS enabled collaboration adequately?							
2	Would you recommend adding or removing any of the activities? Which ones and why?							
3	Do you think these workflows are effective in engaging the right people at the right time to achieve project objectives? Why?							
4	based on your experience, do you find such a workflow useful? Why?							
5	In your opinion, what are the benefits of a structured process for collaboration process?							
6	Would you use such a workflow in the future? Why?							
7	Would you recommend implementing such a workflow in the future? Why?							
8	In which ways do you think that the workflow can be improved?							

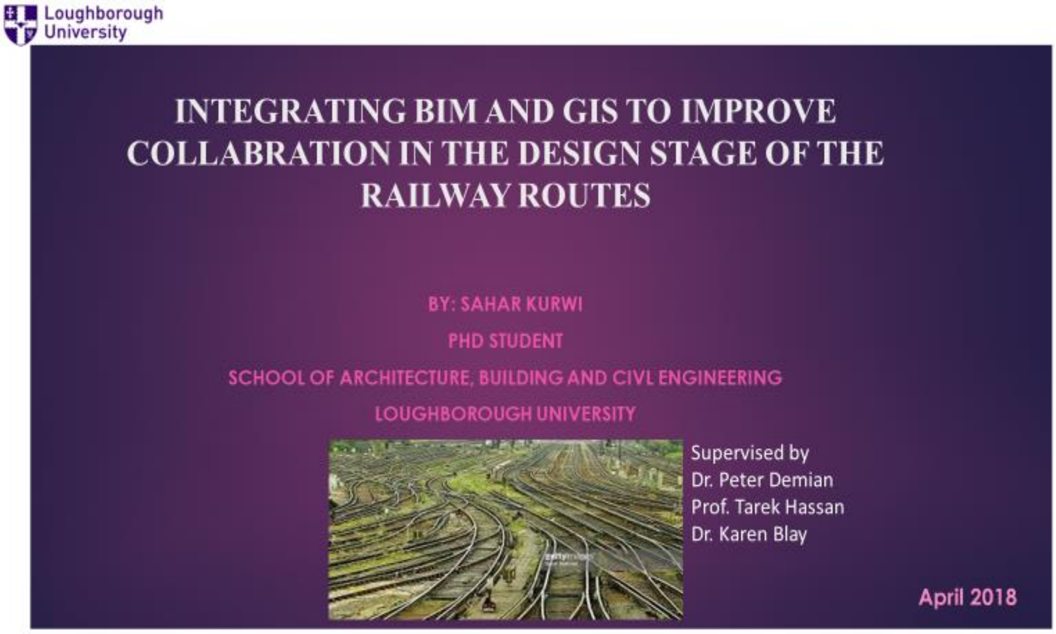
Questions for Figure 9-7: Assess Possible Route Options

	Questions	1	2	3	4	5	6	Comments
1	Do you believe that the workflow provides a guide to enhance the BIM-GIS enabled collaboration adequately?							
2	Would you recommend adding or removing any of the activities? Which ones and why?							
3	Do you think these workflows are effective in engaging the right people at the right time to achieve project objectives? Why?							
4	based on your experience, do you find such a workflow useful? Why?							
5	In your opinion, what are the benefits of a structured process for collaboration process?							
6	Would you use such a workflow in the future? Why?							
7	Would you recommend implementing such a workflow in the future? Why?							
8	In which ways do you think that the workflow can be improved?							

Questions for Figure 9-8: Develop Railway Track Model

	Questions	1	2	3	4	5	6	Comments
1	Do you believe that the workflow provides a guide to enhance the BIM-GIS enabled collaboration adequately?							
2	Would you recommend adding or removing any of the activities? Which ones and why?							
3	Do you think these workflows are effective in engaging the right people at the right time to achieve project objectives? Why?							
4	based on your experience, do you find such a workflow useful? Why?							
5	In your opinion, what are the benefits of a structured process for collaboration process?							
6	Would you use such a workflow in the future? Why?							
7	Would you recommend implementing such a workflow in the future? Why?							
8	In which ways do you think that the workflow can be improved?							

Validation Presentation Handout

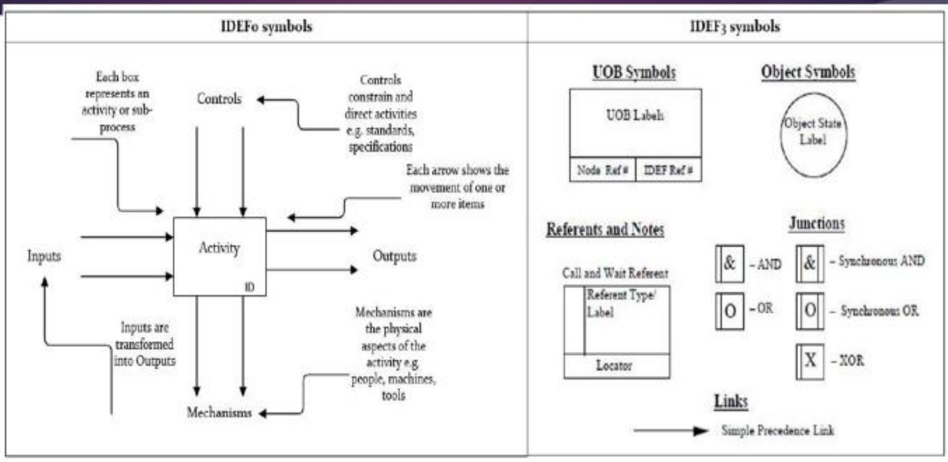


Loughborough University

Problem Definition

Loughborough University

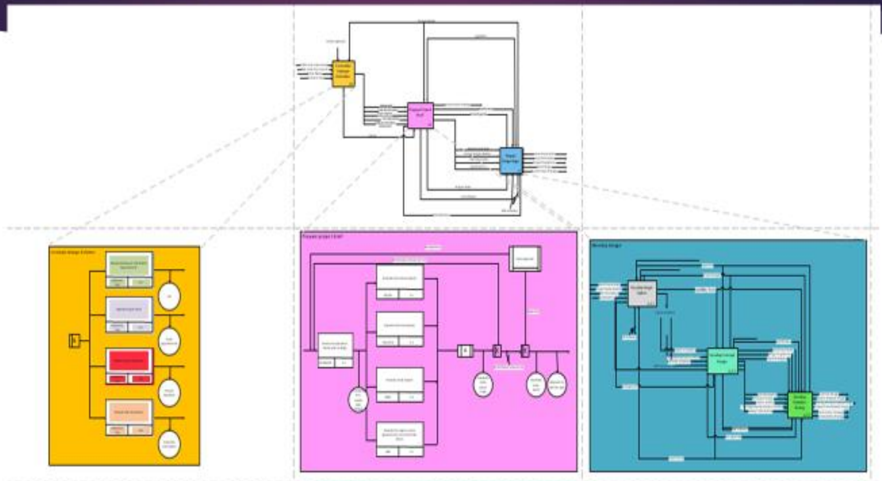
The Frameworks



Loughborough University

Loughborough University

The Frameworks



Loughborough University

Viewpoint for Projects

- ➢ Document and information management solution to share, control and collaborate the documents with dispersed project teams through a cloud-based.
- ➢ It is used to present the IDEF workflows as it is user friendly.

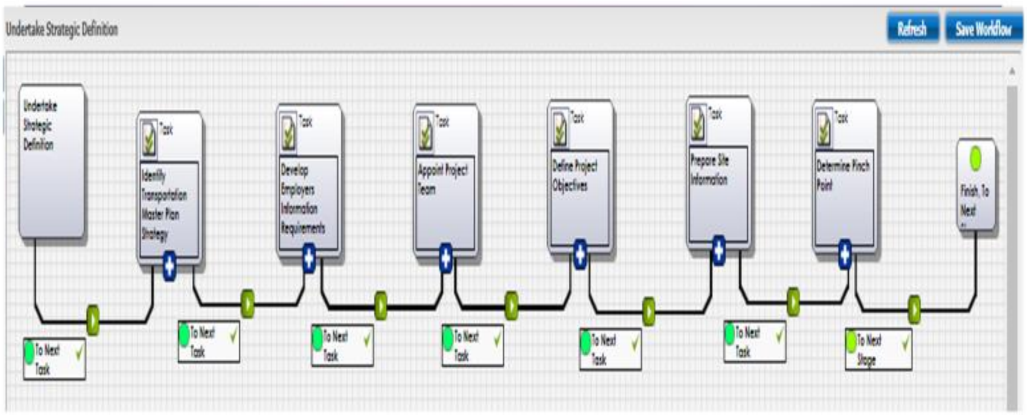


Figure 1: Undertake Strategic Definition

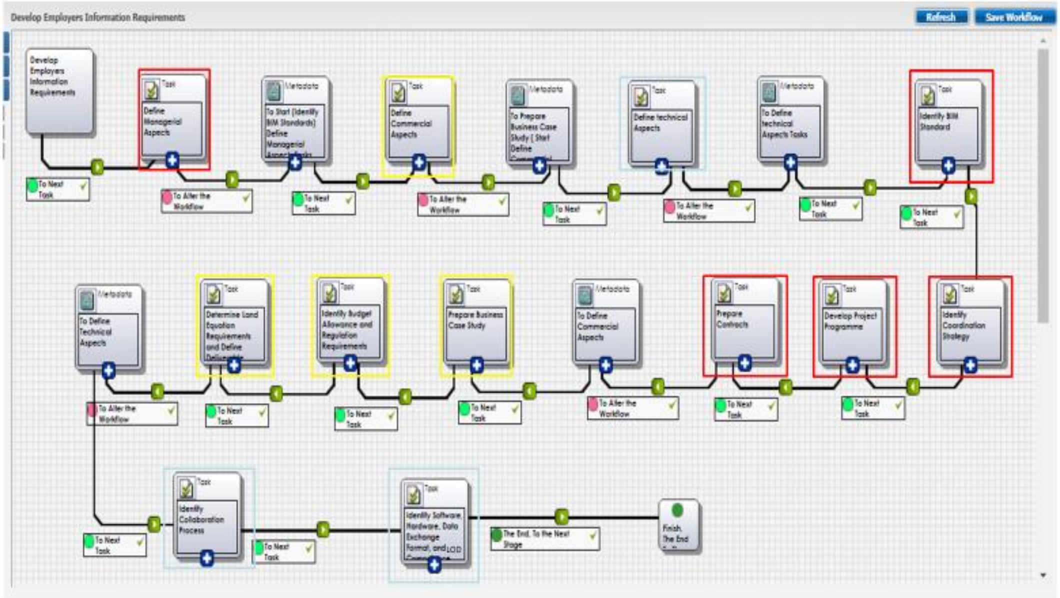


Figure 2: Develop Employers Information Requirements

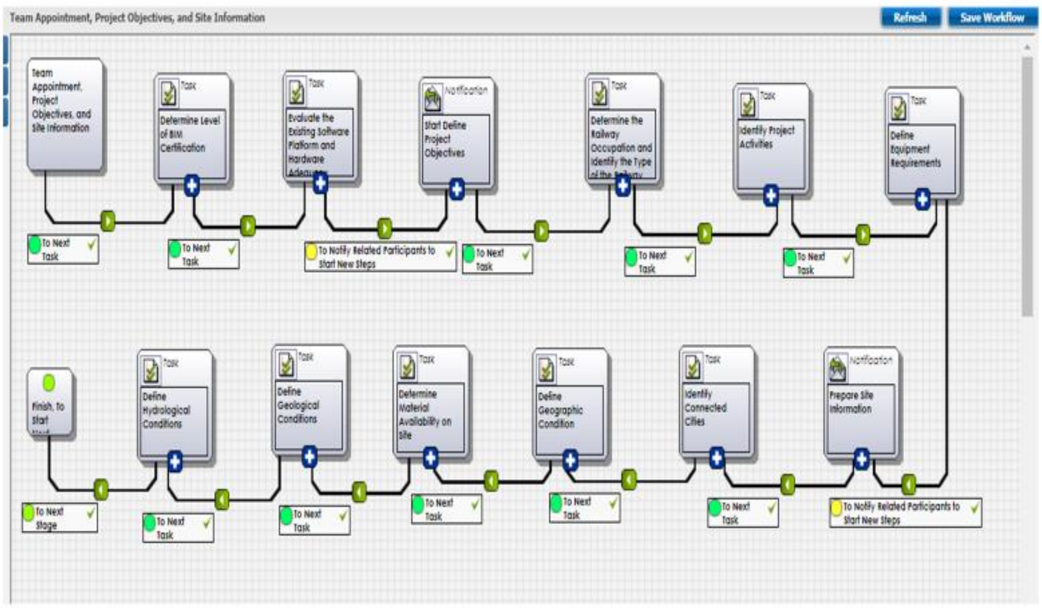


Figure 3:Team Appointment, Project Objectives, and Site Information

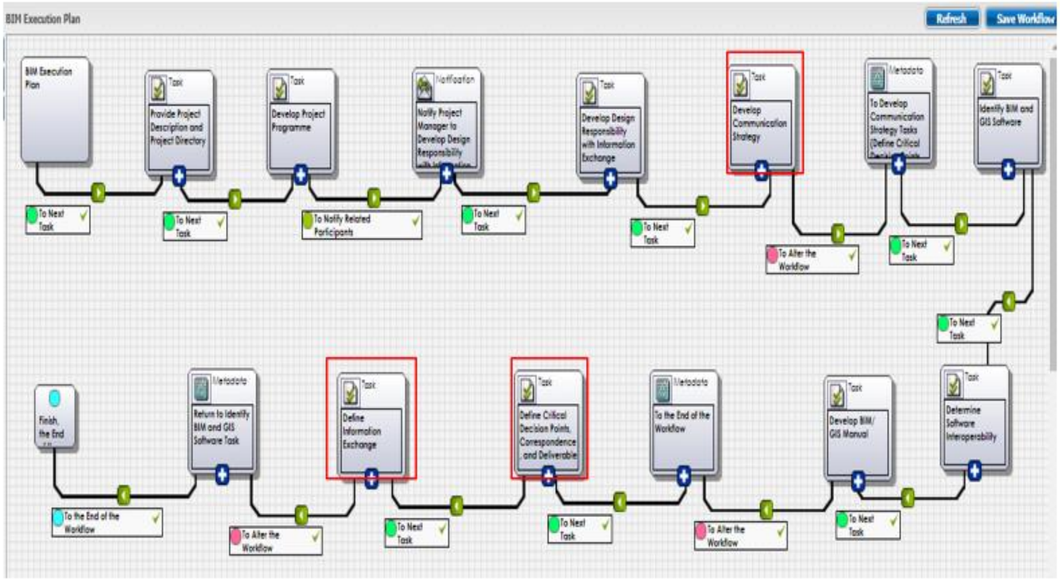


Figure 4: BIM Execution Plan

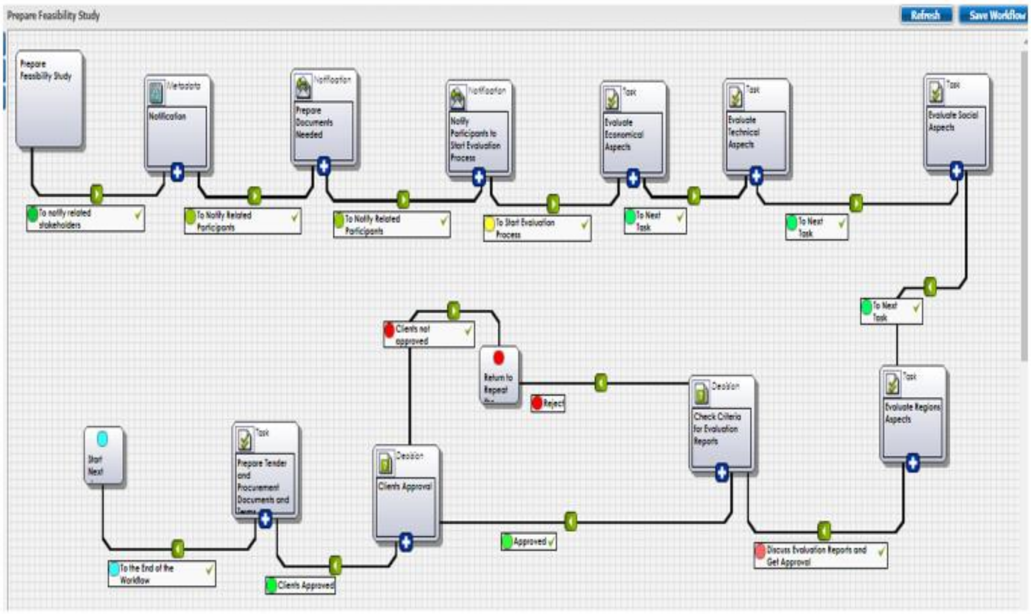


Figure 5: Prepare Feasibility Study

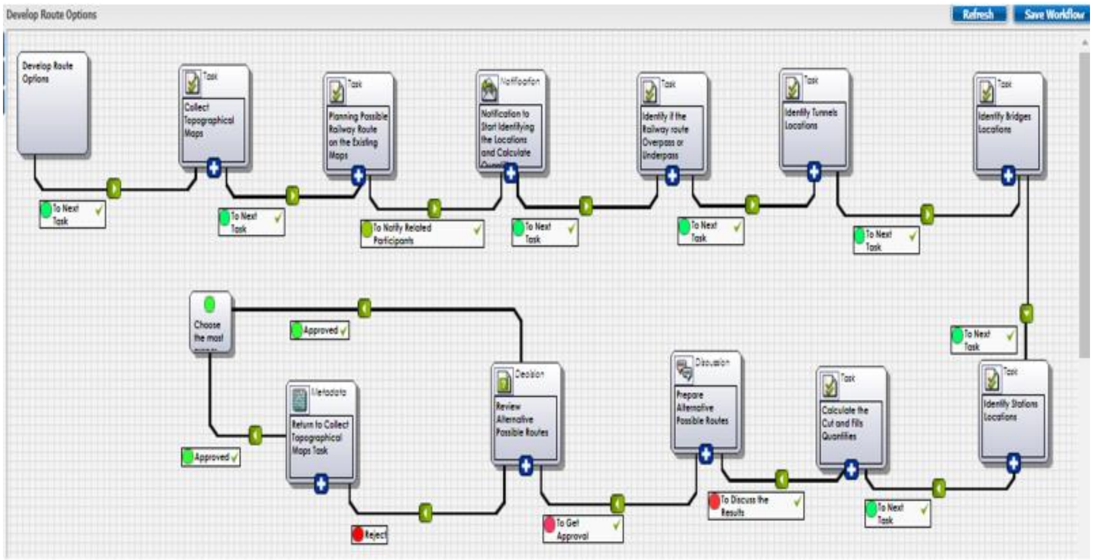


Figure 6: Develop Possible Route Options

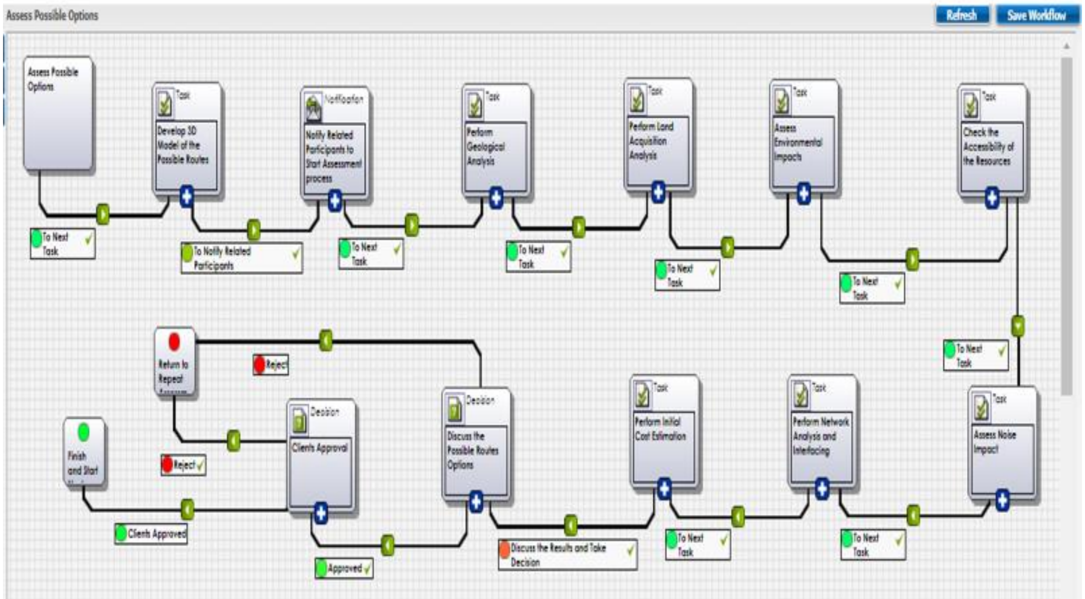


Figure 7: Assess Possible Route Options

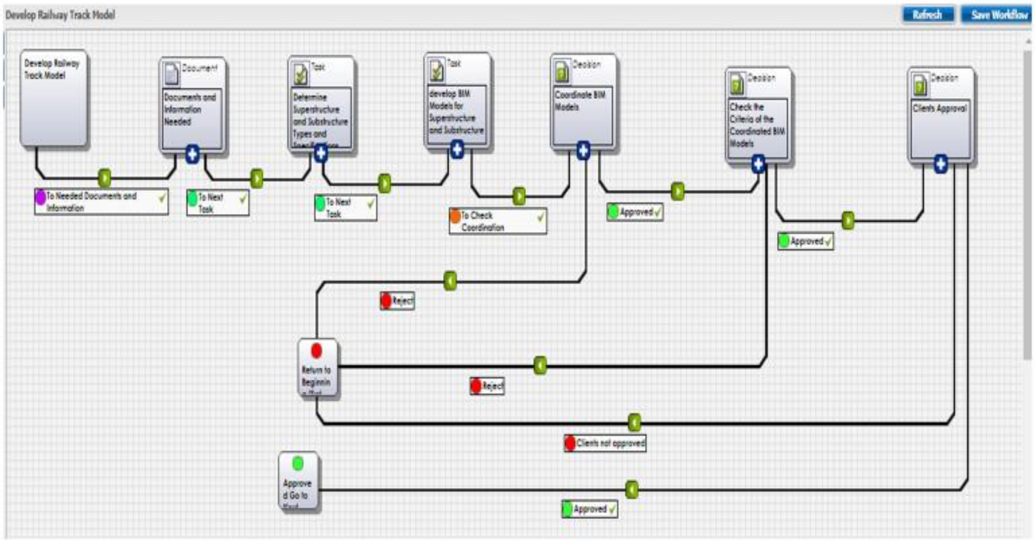


Figure 8: Develop Railway Track Model

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*Please **review** the workflows process description and **comment** on the following:*

1- Do you believe that the workflow provides a guide to enhance the BIM-GIS enabled collaboration adequately?

2- Would you recommend adding or removing any of the activities? Which ones and why?

3- Do you think these workflows are effective in engaging the right people at the right time to achieve project objectives? Why?

4- based on your experience, do you find such a workflow useful? Why?

5- In your opinion, what are the benefits of a structured process for collaboration process?

6- Would you use such a workflow in the future? Why?

7- Would you recommend implementing such a workflow in the future? Why?

8- In which ways do you think that the workflow can be improved?

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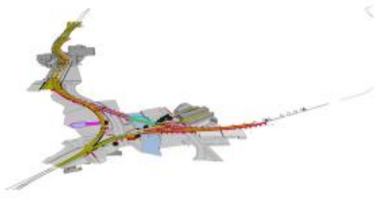
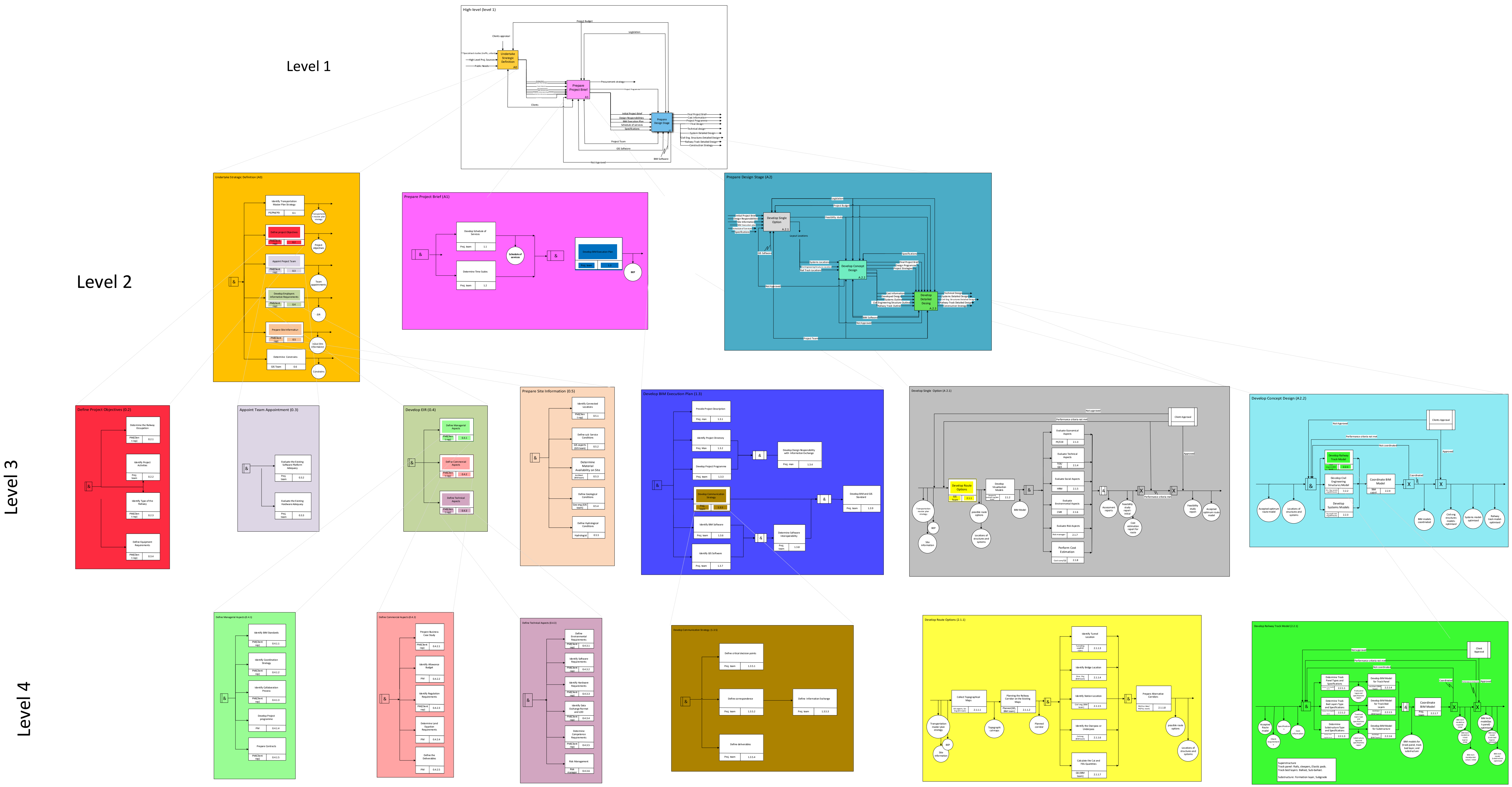
Thank you



Appendix F: The Research Outputs



Level 1
Level 2
Level 3
Level 4