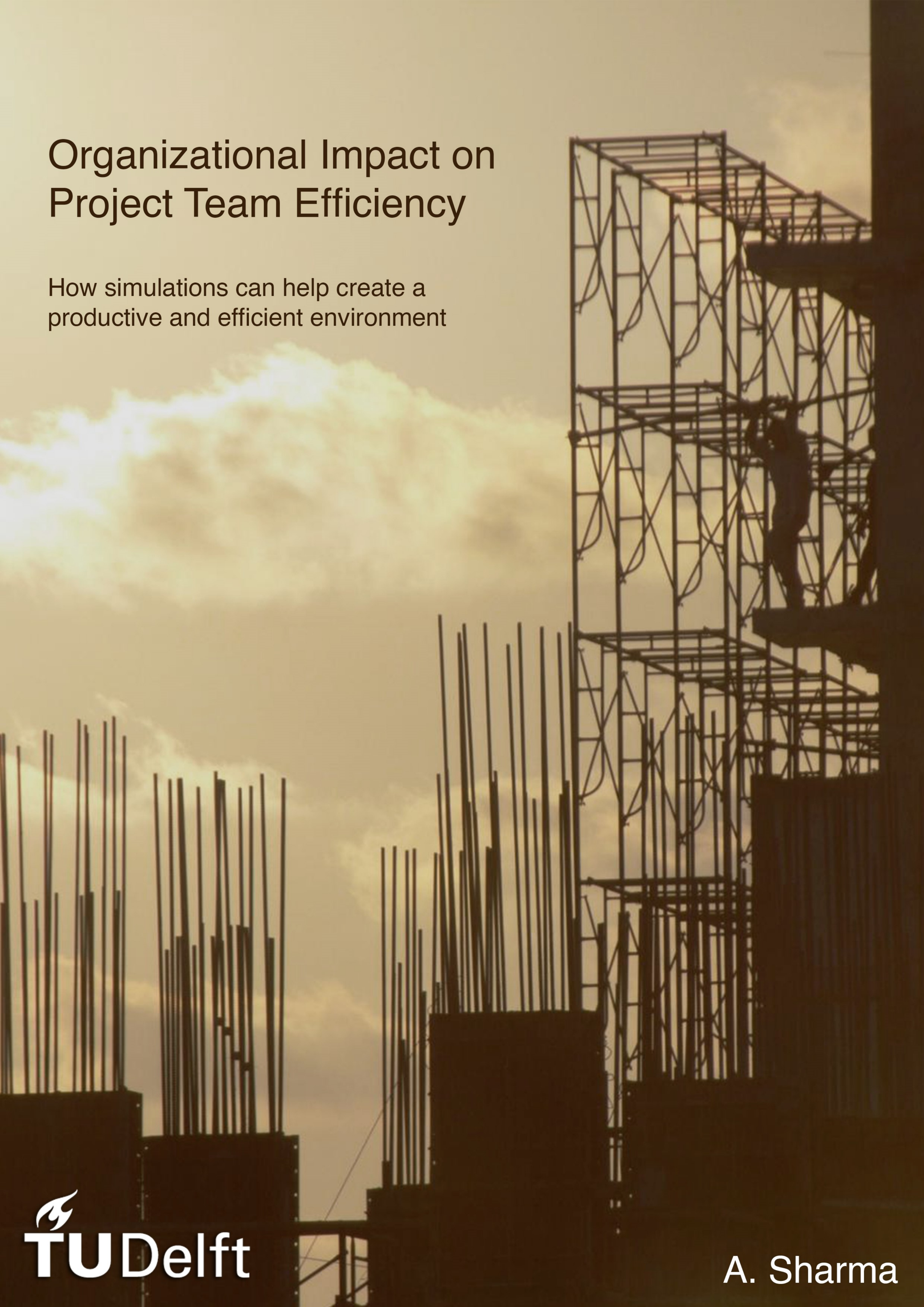

Organizational Impact on Project Team Efficiency

How simulations can help create a productive and efficient environment

TU Delft

A. Sharma

Thesis report

Organizational Impact on Project Team Efficiency

How simulations can help create a productive and efficient environment

By

Ascharya Sharma

to obtain the degree in Master of Science

at Delft University of Technology

Student number: 5002095

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Making projects more predictable

Preface

The past year has been incredibly challenging for me in both professional and personal life however those challenges were but an opportunity to grow both mentally and emotionally. Looking back at the journey I embarked on, I feel nostalgic and gratified for the support of so many people who made my academic and research life fulfilling and complete.

First, I would like to express my sincerest gratitude to my parents – My emotional and mental support, without whom, this entire journey would not have been possible. Their guidance and tremendous support have constantly helped me to identify myself as a person for whom I will forever be grateful.

Next, I would like to express my deepest appreciation to my esteemed research committee for their constant motivation, opinions, and guidance due to whom this research could materialize. I have been fortunate to have the opportunity to research under the guidance of some of the most brilliant minds of this generation. I would also like to express my sincerest appreciation to Mr. Andre and AMPS delft without whom I would not have been in a position to reach my research objectives. I started this research with the main objective of learning something completely new and different from my field of study. I would like to thank you for making agent-based modeling a fun-learning, hands-on experience for me. I enjoyed working under your guidance.

Last but certainly not least, my heartfelt appreciation goes to all my friends in the Netherlands, India, and the United States, who made this journey fun and easy.

With this, I present to you all, the results of the research that I proudly carried out at the Delft University of Technology (TU Delft). I wish you an enjoyable read.

Ascharya Sharma

18th March 2022

Delft, The Netherlands

Executive Summary

Studies confirm that communication and information exchange plays an integral role in the success of a project and points out several sources from where the communication issues are typically observed. Studies confirm increasing complexity, team composition, and organization structure to be some of the variables that affect the communication observed in a workplace. These communicational issues form team-based inefficiencies which directly affect the time, cost, and quality of the end project.

Typical project management practices advocate the Critical Path Method (CPM) to devise the schedules for projects. However, this approach fails to take into account the aspects such as how team members interact with each other, the impact of information asymmetries, the time it takes for the decisions to be made by the management, efforts required for coordination, and the culture of a company, etc. These aspects indirectly contribute to the project duration in the form of indirect work classified as coordination, decision wait, and rework. These aspects when not taken into account also impact the procured schedules and plans making them less realistic. Therefore, it is deemed necessary that an approach should be explored that supplements the traditional way of planning and enables the users to take into account the indirect work in addition to the primary production work.

This study uses Agent-based modeling as a tool to explore areas through which the efficiency of a team can be improved. Team efficiency in this study is a measure of the time it takes for a project team to complete the work. Studies show that the construction industry, in particular, is highly prone to schedule delays. Studies claim that even modest improvement in work-based efficiency in construction can add significant revenue and value to the industry. This forms the main motivation to take project duration or time as the main indicator of team efficiency in this study.

Agent-based modeling in this study is used to explore how team composition and organizational structure in the context of communication affect team efficiency. Both team composition and organizational structure have an inherent dilemma concerning communication. Team-based on heterogeneous composition is identified to perform better in terms of innovation and creativity however some studies point out conflict enabling states that are triggered in such teams due to differences in perspectives, and objectives. Similarly, the organizational structure is mainly based on the architecture of the team. The team can have multiple decision layers bounded by hierarchy and company culture. Centralization in structures enforces more coordination at the expense of time lost in communication transactions in vertical hierarchies meanwhile decentralized systems have faster decision making at the expense of reduced quality of the project. Motivated by these dilemmas, this study explores the Agent-based perspective of team composition and organization structure in the context of communication on team efficiency.

Agent-based modeling is a potent tool that can take into account how the interaction in a project environment occurs. Agents can be defined as singular or aggregated entities with distinct characteristics owing to which they behave in a specific environment. Agent-based modeling is capable of mimicking how the micro-level behavior of agents impacts the emergent behavior of the system. Therefore, in this research, the Agent-based perspective is presented to explore the relationship between variables. The emphasis of the research is on ABM as a tool and its adaptation in the construction industry.

Based on the stated gap, the following research questions and sub-questions are formed:

> ***"**How can ABM be used to analyze the effects of team composition and organization structures on project team's efficiency while taking into account the effects of communication?"*

To successfully answer the main research question, the following sub-questions have to be Answered:

(1) What is team efficiency and how can it be measured?

(2) What are the effects of team composition, organization structure, and communication on team efficiency and how can they be modeled?

(3) Varying team composition and organization structure, what are their effects on team efficiency and communication?

This study uses a real-life case study to reach its research objectives. The study models the MEP and finishing phase of a residential building – Hazratganj Mini which is a part of a project portfolio being developed as an integrated township in India. The project team of Hazratganj mini which comprises both, the client's and contractor's team is the main element of interest in this research. The project team is characterized by shared responsibilities of team members over multiple projects which makes this case study interesting from the point of view of research. The project team operates mainly on the premises of the in-house expertise of the company but with the support of a labor crew provided by a contractor. This team is further subjected to structural changes to reflect the impact of organizational changes on team efficiency.

This study uses multivariable sensitivity analysis to explore the effect of six pragmatic variables on team composition. These variables are team experience, centralization, formalization, matrix strength, information exchange probability, and noise. The results of sensitivity analysis are further subjected to statistical analysis to determine the correlation between these variables and team efficiency. It is found that Team experience has a positive correlation with team efficiency and also has the highest impact on efficiency among the chosen variables. Centralization shows a strong and negative correlation with team efficiency and lastly matrix strength shows a positive correlation suggesting the matrix-based team formation for improved efficiency. Formalization, information exchange probability, and noise showed a weak or no correlation with team efficiency.

The organizational structure of the project team is varied as per the client-contractor relationship inspired by the EPC contract. Keeping the volume of the work constant, the structural changes produced insights into how the variation of decision layers and strategic interests may influence the interactions and duration. The introduction of EPC-inspired structures increased the duration of the project by almost a month (3%) which can be attributed to an almost 18.4% increase in coordination work and a 100% increase in decision-wait compared to the original case.

Based upon the identified observations, it is recommended to retain highly experienced professionals in the work team while also training relatively newer employees to promote faster communication and better collaboration since experience is most strongly correlated to team efficiency based on the chosen factors and performed analysis. The second main recommendation is concerned with the hierarchical or organizational structure of the project team. The project teams should be made decentralized with the delegation of the decisions based on risk-frequency type. Decentralized systems in addition to matrix team formation can be viewed as an empowering structure that has the potency to produce more integrated and faster results, with better management of information. This recommendation is stemmed from the ability of decentralized and matrix systems to facilitate faster communication and hence decisions within teams. Finally, the adoption of communication tools such as information and communication technology (ICT) and Project Management Information system (PMIS) is also recommended to support communication between employees. Another major recommendation from the study points to the adoption of Agent-based modeling as a tool for decision-support. Agent-based modeling enables organizational learning which enables teams to adopt and strategize as per the need of projects.

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Overview of Acronyms

ABM: Agent-based modeling

CPM: Critical path method

HRM: Human resource management

ODD: Overview, design concepts, and design

R&D: Research and Development

AIMD: Aircraft Intermediate Maintenance Division

NPS: Naval Postgraduate School

FTE: Full–time equivalents

PBL: Project-based learning

EPC: Engineering Procurement and Construction

MEP: Mechanical Electrical and Plumbing

CMD: Chief Managing Director

PM: Project Manager

SL: Team leader

ST: Team member

ICT: Information and Communication Technology

BIM: Building Information Modeling

PMIS: Project Management Information Systems

PART I

1

Introduction

86% of employees and executives attributed lack of collaboration and ineffective communication as the main cause of workplace failures (salesforce, 2014). These communication and collaboration problems are typically observed to persist within project teams due to the factors such as increasing complexity of tasks (Moenkemeyer et al., n.d.), team composition (Marx et al., 2021), and organization structure (Jin & Levitt, 1996) resulting in team-based inefficiencies. These inefficiencies are then translated onto the project level, affecting the budget, time, and quality of the result (Scott-Young & Samson, 2008). According to a study published by Project Management Institute (2013), one in five organizational projects in the United States was unable to meet either their project deadlines or allocated budget due to poor communication.

So far, traditional approaches have been used to execute work processes in the construction industry (Jin & Levitt, 1996). Traditional project management practices advocate the Critical Path Method (CPM) for making project schedules. The CPM method is primarily based on the sequential precedence of activities which determines the major milestones, critical events, and most importantly anticipated finish time of a task (Jin & Levitt, 1996). A modified version of CPM is still used in various industries like construction, aerospace, software development, and research (Weaver, 2006). However, this method seriously fails to acknowledge the role of organizational factors such as communication transactions happening across the vertical and horizontal tiers of a company, the time consumed in decision-wait, how actors interact with each other (formally or informally), and also the impact of company's culture (Hsu et al., 2016a; Jin & Levitt, 1996). These aspects in turn affect the efficiency of a project team however rarely taken into account during the planning of a project. Hence, it is rendered necessary to pay close attention to aspects such as communication, information flow, and actor interaction – the organizational aspects, within project teams to enhance collaboration and promote better project team efficiency.

1.1 Organizational factors affecting Team efficiency

Many organizational factors can be identified which need deliberate attention for promoting team efficiency.

Team composition is identified as one of such factors (Marx et al., 2021). A team can be composed based on various differentiating variables such as diversity of disciplines, the experience of team members, and availability of team members (Hsu et al., 2016a). Although a diverse team can be quite efficient in terms of innovation and quality of the end product (Jackson, 1996), diversity has been identified to have a close relation to communication costs and frictions within organizations (Marx et al., 2021). Marx et al. (2021) suggest finding a balance between team diversity and homogeneity for improved functioning of teams as well as the organization.

So far, team composition and employee resourcing to a project-based organization are some of the responsibilities of the Human Resource Management (HRM) department (Raiden et al., 2004). The department ties human resources to the operational and strategic needs of the project as well as the company (Raiden et al., 2004). The companies tend to use plenty of typologies to foster teams which are also sometimes based on the personalities of individuals, for example, Belbin's team role model (DILL, 1982), Margerison and McCann's team management wheel (Raiden et al., 2004). These typologies are fairly easy to adopt, compare and apply in a company setting. However, these typologies fail to comprehensively acknowledge the social context in which the teams are required to operate. For example, how the knowledge/information is exchanged between individuals, the effects of the company's climate, norms, working culture, etc. These factors are highly influential regarding the communication within project teams and insufficient management may lead to information asymmetries (Huang et al., 2019) eventually impacting project team efficiency (Caniëls et al., 2019; Lai et al., 2018). Therefore, a composition is to be investigated that leads to the optimal flow of communication within project teams thereby improving team efficiency without compromising the quality of results. The tradeoff between the homogeneity and heterogeneity of the team has to be explored in conjunction with working norms to determine its effect on project team efficiency.

Another crucial aspect that affects team efficiency is the organization structure (Jin & Levitt, 1996). Ahmady et al. (2016) claim that an organizational structure is mainly composed of two elements; the hard elements which represent the tangible aspects of an organization such as individuals, or groups, and on the other hand, the softer elements, which define the relationship among these hard elements such as hierarchy, working norms. Scott-Young & Samson (2008) used the term *Autonomous project team structure* to define this factor. They defined autonomous team structures as the ones which *"work independently and outside the normal boundaries and chains of commands of the organization"*. However, in reality, not all teams are autonomous. Based on the hard elements of the organization such as the number of members, the number of decision layers, and also the soft elements such as centralized or decentralized decision-making culture, different organizational structures can be differentiated (Jin & Levitt, 1996). Highly centralized structures are assumed to have a higher quality of decisions at the expense of additional time that is spent on informational and communicational transactions. Jin & Levitt (1996) argue that a hierarchical structure increases the decision backlog on senior management which results in decision-wait and causes delays in the progress of work while decentralized structures have a decision being made at the point of need which saves additional time spent on communication and decision-wait but at the expense of reduced quality of a product. Therefore, the structure of the organization has to be further investigated as to how it affects the team efficiency? How adding more decision layers or changing the decision-making norms would impact the efficiency of the project team?

Both qualitative and quantitative methods can be used to explore the relation between team composition, organization structure, communication, and project team efficiency. Qualitative methods such as cross-case studies, interviews, and questionnaire surveys can also be used for this study. However, the qualitative methods pose a few limitations. First, every project is unique by its nature. Cross-case comparisons in particular might not be very helpful in comprehensively understanding the relations due to differing project conditions of cases. Interviews and Questionnaire surveys generate a high data dependence upon the individuals working on projects which might also add the subjectivity of the individuals in the obtained data. This makes the critical comparison between these factors a big challenge. Lastly, these qualitative methods are highly static in nature; the results produced from the qualitative analysis can be very limited in terms of predicting the emergent behavior of systems as a result of variations in the chosen factors. Quantitative methods can provide a clearer relation among chosen factors while also adding the element of dynamics to the evaluation. Quantitative methods can be used to study trends and make more robust comparisons between vaiables due to which a quantitative exploration is adopted in this research.

To address the inefficiencies of project teams created by team composition and organizational structure while also taking into account communication the approach of – Agent-Based Modeling (ABM) is proposed. Agent-based modeling is capable of taking the traditional approaches of project management into account while keeping in view the softer aspects such as team member interaction, organization structure, team composition, and the company's working culture.

1.2 Agent-based modeling as a remedy

Agent-based modeling can be defined as the process of simulating and analyzing complex socio-technical systems using virtual agents which represent undifferentiated project entities, for example, project teams, organizations, or even stakeholders to imitate the behaviors and interactions of individuals in the system (Crooks & Heppenstall, 2012a; Jin & Levitt, 1996; P. Zhang et al., 2019). Agent-based modeling generates results based on how these agents or undifferentiated entities interact with each other and also with the environment given their local knowledge and social situation to develop *what-if* scenarios (K. Kim & Kim, 2010b; Tah, 2005b; P. Zhang et al., 2019). These What-if scenarios enable the users to interpret and compare the emergent behavior of the system corresponding to different input variables (ePM, 2005). Due to the repetitive, distinct, and complex interactions between these social agents, different and unique system behaviors can be observed (Bonabeau, 2002a; Sawhney et al., 2003).

Till now, agent-based modeling is widely used in studying production-related problems in the process industry. ABM is being used to plan factories and to exert better process control (Negmeldin & Eltawil, 2015). Moreover, the modeling has also found its utility in addressing supply-chain problems (Xue et al., 2009), construction operations with traffic congestions (K. Kim & Kim, 2010b), construction dispute resolution (El-adaway & Kandil, 2010), construction management education (Rojas & Mukherjee, 2006) and also to optimize plans, resource utility, project cost, and duration (Abou Yassin et al., 2020).

As also mentioned before, different team compositions and organization structures have different impacts on communication and thus team efficiency. While a diverse team is claimed to have higher innovation, the team is also believed to have higher communication problems (Marx et al., 2021). Similarly, strictly hierarchical structures are claimed to have higher decision quality at the expense of time due to decision delays and communication (Jin & Levitt, 1996). These qualities make team composition and organization structure not just technical entities of a company but also social components which significantly impact the course and success of a project. Given the ability of agent-based modeling to analyze complex socio-technical situations (Lange et al., 2021) and predict the emergent environment (Crooks & Heppenstall, 2012a) of the project, the technique is thought to be useful to abridge the mentioned gaps. Agent-based modeling can be useful in predicting the non-linear behavior of agents and thus the system (Gilbert & Troitzsch, 2005) while developing a multi-variable model rather than an equation-based model (P. Zhang et al., 2019). Lastly, ABM can be a cost-effective method to test the impact of different management strategies, and variables on the emergent behavior of the system (K. Kim & Kim, 2010a; Tah, 2005a; P. Zhang et al., 2019).

1.3 Research Objectives, Research Questions, and Scope

1.3.1 Research Objectives

The primary objective of this research is to assess the utility of Agent-based modeling as a tool to evaluate and enhance the efficiency of project teams. The objective is to use ABM to model and analyze the varying effects of team composition and organization structure in the context of communication and evaluate its impact on team efficiency in the construction industry. The intention is to vary composition using team-based parameters such as collective experience, and team orientation (matrix or functional teams) while also independently varying organization structure inspired through formal contracts and observing its effects on team efficiency. Although team efficiency can be gauged on multiple facets, the main focus of this study will be on the duration of the project team to achieve the specific goal. Duration is chosen as the indicator of team efficiency because it is a quantitative measure that enables better and more convenient comparison and studies claim high hidden value potential of duration optimization in the construction industry.

1.3.2 Research Questions

Based on the problem statement established so far, the following research question is defined:

"How can ABM be used to analyze the effects of team composition and organization structures on project team's efficiency while taking into account the effects of communication?"

To successfully answer the main research question, the following sub-questions have to be Answered:

(1) What is team efficiency and how can it be measured?

(2) What are the effects of team composition, organization structure, and communication on team efficiency and how can they be modeled?

(3) What are the effects on team efficiency and communication when team composition and organization structures are varied?

1.3.3 Scope

Although agent-based modeling can be used to simulate a wide variety of situations, for this thesis the focus would be on the construction industry. As the intention is to evaluate the impact of team composition and organization structure, the construction industry can offer significant flexibility in choosing different phases or even the entire process of construction that can be modeled (Gabrieyel, n.d.). It should also be noted that the contract type will only be used as a motivation to vary team composition and organization structure but is not the main focus of the study. Since a team can be composed in innumerable ways, the idea is to motivate the composition based on client-contractor relation formed due to a contract type and mimic its effect on hierarchy and team composition while also influencing the communication observed in the project team. It should be noted that the intention of this research is not to comment upon the effectiveness of a particular contract type or delve into the depths of how contracting systems affect efficacy but just to use them as motivation.

The construction industry is usually governed by concrete goals for project teams and has a diversity of people that can be chosen for the job (Hsu et al., 2016a), which makes this industry even more lucrative considering the objectives of this study. The personality of individuals also plays an integral and significant part in making the teams effective (Varvel et al., 2004). This thesis however will focus only on the characteristic of the entire team rather than choosing to model the behavior of individual team members. Lastly, the study intends to use the Agent-based modeling software SimVision® which is owned by ePM for this thesis.

1.4 Thesis outline

This thesis is mainly outlined in three parts as shown in figure 1. Part I entails the theoretical chapters of the report covering the background and literature exploration done for this research. Part II includes conceptualization and parameterization of the agent-based model while also focusing on experimentations. Finally, the thesis is concluded with part III which focuses on the interpretation and evaluation of results and synthesizing them into practical and scientific recommendations.

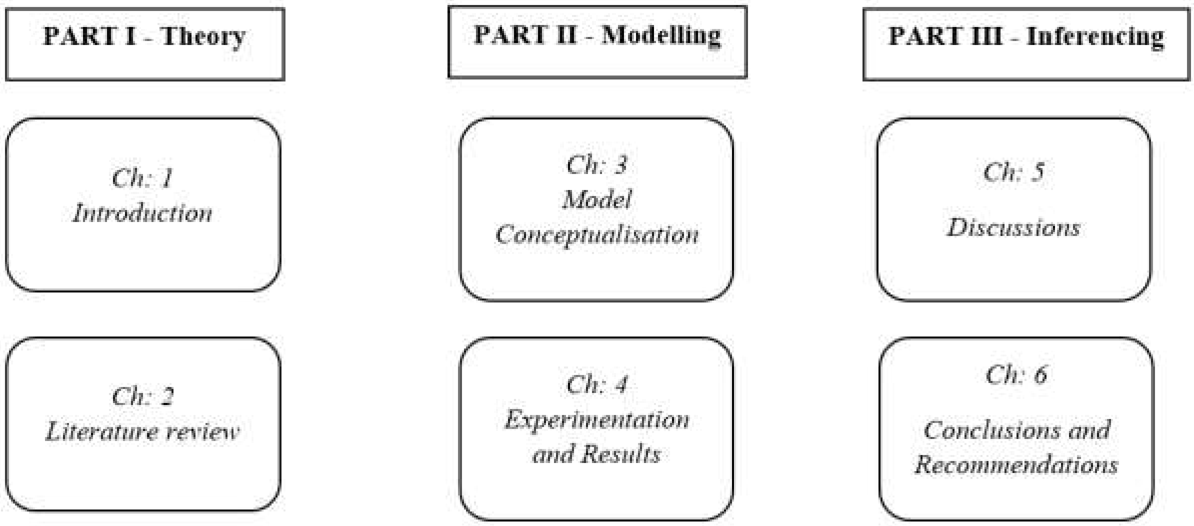


Figure 1: Structure of report

Having defined the structure of this report, it is also crucial to identify the roles of these chapters in addressing the formed research questions. Sub-question 1 mainly aims to theoretically identify the meaning of team efficiency and also the methods of its measurement. Therefore, the literature review performed in chapter 2 caters to descriptively answering sub-question 1. Literature study also theoretically motivates the construction of the agent-based model for this research by exploring previously developed models in various studies hence also partly answering sub-question 2. This garnered information is then utilized in chapter 3 for the construction of an agent-based model. This study uses Object, Design concepts, and Details (ODD) protocols to comprehensively document the concepts and functioning of the developed agent-based model which can be found in Appendix J. The model is then subjected to experimentation in chapter 4 which is followed by synthesizing the meaning of results in chapters 5 and 6, thus answering subquestions 2 and 3.

2

Literature review

The purpose of this chapter is to strengthen the current theoretical understanding of team efficiency which further supports the construction of the model that is developed in the process of this research. This is achieved by performing explorative desk research on all the relevant topics and concepts. The explorative research is performed by mainly referring to the academic studies and articles coming from different management and scientific journals and also engineering reports. This research also refers to articles of leading engineering companies and consultancies to take pragmatic views into account concerning the topic being explored.

This chapter entails the literature review done to build the knowledge base for this research. The chapter can be broadly segregated into 3 parts: (1) Defining the team efficiency and how it can be measured, (2) Exploring factors that influence team efficiency – specifically Organization structure and team composition and how they can be modeled, and, lastly (3) evaluating the utility of ABM as a tool. This chapter is also concluded with a short synthesis of the chapter highlighting the main insights from the review.

2.1 Team efficiency

2.1.1 Definition

Before defining team efficiency, it is rendered necessary to define what is meant by a team. Y. Zhang et al. (2021) define a team as a group of people having complementary skillsets who work towards a common objective and hold themselves mutually accountable for the outcomes. *Project* teams on the other hand can be defined as a temporary and dynamic group of members with diverse yet complementary skills, originating from different functional departments throughout a project (Buvik & Rolfsen, 2015; Cohen, 1997; Pavez et al., 2021). Project teams are often required to execute tasks in flexible, innovative, and faster ways owing to the organizational demands of the emerging marketplace (Liu & Cross, 2016) which requires these teams to be efficient (Lisbona et al., 2020).

The efficiency of a team can be interpreted and gauged in multiple ways; Piccoli et al. (2004) defined team efficiency as the ability of the team members to streamline their outcomes with the goals of the team while also focusing on the impact it has on the employees. Kim et al. (1999) give the perspective of team efficiency from an R&D viewpoint and describe it as the ability of the team to optimally use resources within constraints (Y. Kim et al., 1999; Liu & Cross, 2016). However, one of the most commonly acknowledged and used definitions of a team's efficiency is the ability of a team to meet the allocated budget and schedules of a project (Liu & Cross, 2016; McComb et al., 2007; Ryan & O'Connor, 2009; Weiss et al., 2011).

2.1.2 Efficiency indicator used for this study

Due to the criticality of project teams in the emerging marketplace, their role draws them significant attention in organizational research (Liu & Cross, 2016). The literature points out several academic studies that tend to define project teams' success and efficiency however, the agent-based perspective on the topic is fairly limited. A comprehensive study done by Khodabandelu & Park (2021) which enlists and analyses 182 journal articles related to the application of agent-based modeling in the construction industry could only point to a handful of articles based on team efficiency. Hsu et al., (2016a) conducted one of the most direct studies related to the topic of team member selection and its effects on team efficiency which they measured through earned profits. Other studies attempted to look at other performance-based indicators of the project teams such as productivity, effectiveness, innovation, and performance each of which mostly attempted to use budget and time as the main indicator for their chosen dependent variable. This study intends to explore the project team's efficiency from the perspective of duration or the time expended by a project team to achieve their goals.

As evident from figure 2, nearly 50% of all the projects worldwide between the years 2011 and 2018, irrespective of their industry were prone to schedule delays (Al-Wadei, 2020). This figure is, even more, overwhelming for the construction industry. An independent report from McKinsey and Company (2015) reports at least 77% of Megaprojects are to be delayed by at least 40%. Construction delays are considered to be a global phenomenon (Anastasopoulos et al., 2012; Arditi et al., 2017; Arditi & Pattanakitchamroon, 2006; Changali et al., 2015; Gonzalez, 2017; Lucko et al., 2021; Sambasivan & Soon, 2007). For example, 70 percent of construction projects in Saudi Arabia suffered time delays (Assaf & Al-Hejji, 2006) while in Australia, 7 out of 8 projects (approx. 88%) were delayed (Chan & Kumaraswamy, 1997).

Figure 2: Year Vs. percentage delay (Source: Al-Wadei, 2020)

A cross-industry comparison also reveals the construction industry as one of the bottom-most contenders in terms of workplace and labor productivity (Barbosa, Mischke, et al., 2017; Barbosa, Woetzel, et al., 2017; Changali et al., 2015), which can be simply defined as the ratio of input and output in work processes (Dozzi & AbouRizk, 1993). It is estimated that improving the current efficiency and thereby productivity of construction work processes (currently 1%) even equivalent to global economic growth (currently 2.8%) is likely to add a value of $1.63 trillion to the industry (Barbosa, Woetzel, et al., 2017). This forms the main motivation to investigate how time variables can be estimated and even optimized from the standpoint of Agent-based modeling. Even with the exponential growth of technology in recent years, it remains equivocal as to why projects suffer huge delays? And certainly, the literature offers several dimensions to explore the reasons from both microscopic and macroscopic lenses; Organizational theory is used to explore how the decision-making and control structure of the modern-day organizations be modified to achieve increased efficiency and performance in the objective seeking (Al-Fadhali & Zainal, 2017), Agency theory and contracts, on the other hand, are being explored and tested to minimize information asymmetries and to streamline the objectives of principle and agents to reduce conflicts and thereby improve the efficiency (Al-Fadhali & Zainal, 2017; Ceric, 2014). Even concepts of resource-based theories are also being explored to gain efficiency through asset and resource advantages (Al-Fadhali & Zainal, 2017).

2.1.3 How can team efficiency be modeled for this study?

This sub-section explores the literature citing agent-based models whose purpose somewhat aligns with the objectives of this study. The studies are primarily based on SimVision® which also provides an understanding of how the modeling software can be initialized and used for achieving the research objectives. This sub-section intends to motivate the model development process by theoretically highlighting the conceptualization and implementation of previously built models.

Employing organizational modeling and simulation to reduce F/A – 18 E/F F414 engine maintenance time

Slack & Hagan (2006) used SimVision® to model the effects of organizational changes on the maintenance throughput time of aircraft engine F414. Aircraft Intermediate Maintenance Division (AIMD) collaborated with Naval Postgraduate School (NPS) to identify what organizational changes can be made to decrease the maintenance cycle of the engine F414 which powered F/A-18 E/F aircraft. AIMD successfully adopted other process improvement methods such as lean and six-sigma beforehand to improve the processes. The efforts to optimize organizational components were the next attempt to further their successes with process improvement. To reach the research objectives, Slack & Hagan (2006) collected data through interviews to establish the organizational model. The model was then adjusted to reach the accuracy in the predictions of the model till the margin between the predicted time and the actual time of maintenance was within 3%. Once the model could accurately reproduce the reality, the organizational changes were made in the form of parallel activities, combining positions, creating and adding new positions, and also altering the duration and frequency of meetings. These interventions were then compared to the baseline (original mode) based on total process duration, position backlog, cost, and also functional risk. Task duration, the main focus of the research was found to be highly and positively affected by paralleling the tasks.

Similar to the objectives of this research, the study conducted by Slack & Hagan, (2006) also intended to reduce process duration. The study perfectly describes and articulates the methodology of constructing their model however the dimensions explored to mediate with organizational elements are fairly limited. Few of the intervention strategies did focus on combining positions and adding extra Full-Time Equivalents (FTEs) to some positions but this did not significantly affect the spatial arrangement of the organizational structure which highly impacts the decision-making velocity across the hierarchy. In this research, however, motivation can be taken from the study conducted by Slack & Hagan (2006) to experiment with increasing the number of FTEs and check its effects on duration. But in addition to that, this study also explores the effects of dramatically changing the organizational structures of the project team and checking its impact on project duration owing to different contract-induced structures.

The study conducted by Slack & Hagan (2006) also attempted to look at the centralization parameter affecting the process duration. However, this study in addition to the centralization parameter also explores the robustness of factors such as formalization, matrix strength, team experience, information exchange probability, and noise over the duration of the project. These factors impact the composition and working culture of teams which may have a significant impact on the duration of the project.

Predictive simulation as a decision support system to manage AEC Global Teamwork

Ioannidou et al., (2009) argue that the management of time and human resources gives competitive advantages through improved productivity, increased product quality, reduced waste, and most importantly enhanced team member well-being. To substantiate their argument, Ioannidou et al. (2009) used the predictive simulation tool - SimVision® to model organizational components to improve team process and performance.

Ioannidou et al. (2009) conducted this study in the Project-based learning (PBL) course offered at Standford University which intended to promote interdisciplinary learning in the AEC industry by the means of a virtual project which encompassed activities ranging from architectural designs, development of technical plans to the management of schedules and cost. Ioannidou et al. (2009) performed this study on a group in which they also played a role of a participant.

Based on the outline of the course, Ioannidou et al. (2009) defined the major milestones of the project in SimVision®. A work-breakdown structure was then prepared to identify distinct activities which could be attributed to each team member. Due to the academic nature of the project, the organizational structure of the project team was predominantly flat as shown in figure 3. The activities and positions in the created model were populated by the means of data collected during and after the course was completed by the means of surveying the participants.

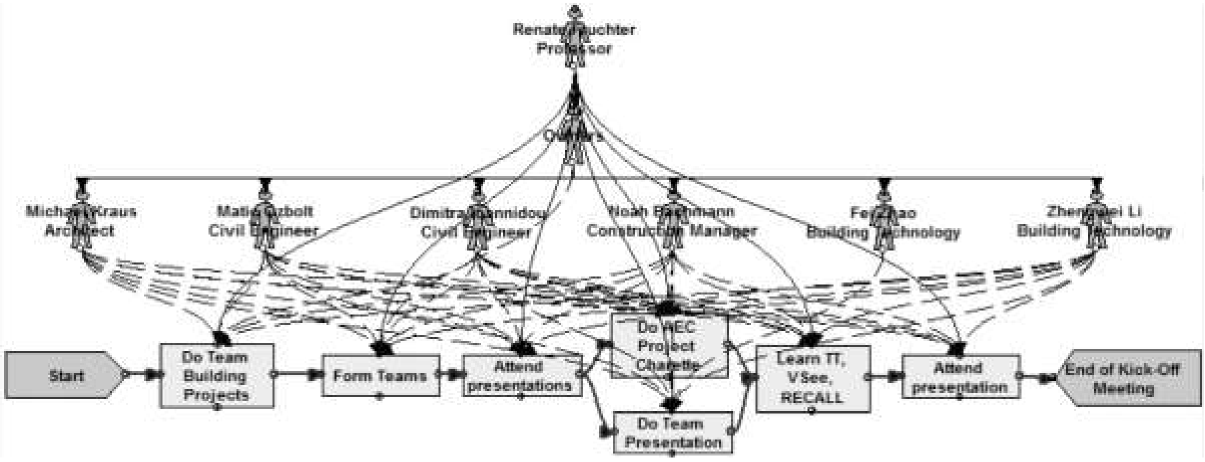


Figure 3: Predictive simulation as a decision support system to manage AEC Global Teamwork (Source: Ioannidou et al., 2009)

Similar to the objectives of this research, the study conducted by Ioannidou et al. (2009) also aimed to explore the organizational effects of a project team by reflecting on the impact of meetings, centralization, and formalization on project duration and positions-backlog. Ioannidou et al. (2009) associated additional time in project completion by the means of position backlogs and additional coordination work that had to be done by the team in the initial phases of the PBL course.

In this study, the split of duration is also explored from the means of implicit work that is generated due to the nature of work. Coordination time, rework, and decision-wait in addition to the primary production time are taken as the basis for cross-scenario comparisons. Taking the motivation from the current study, it will be also interesting to argue these additional times from the perspective of position backlogs.

2.2 Factors influencing Team efficiency

In the previous section, team efficiency was explored based on its meaning and from an ABM perspective. To further extend this exploration, this section identifies different factors that affect team efficiency. This section intends to enlist all the modellable factors that may influence team efficiency and choose two of the most prominent factors which will act as independent variables in this research.

Based on the adopted definition of team efficiency, various factors can be identified that influence the duration of a process or a project. Castka et al. (2001) explored the factors that affected the efficiency of the team and differentiated high-performing teams from the rest. Castka et al. (2001) reviewed various theories and concepts from the late 1990s and synthesized them to produce two main types of factors: System factors and Human factors which are shown in figure 4:

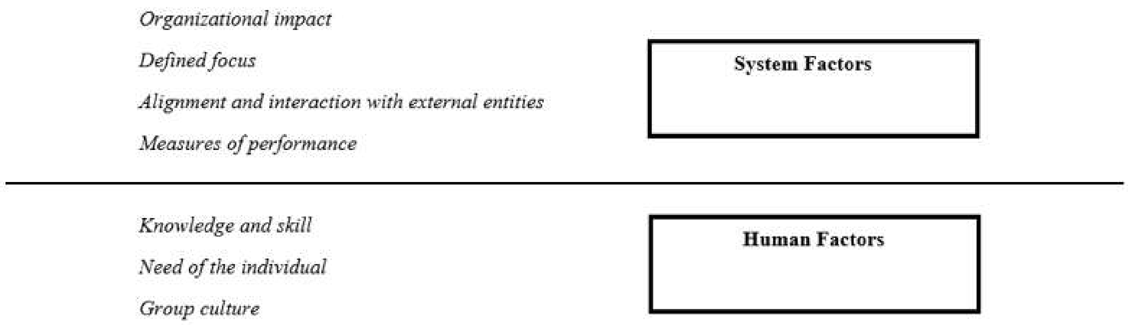


Figure 4: System and Human Factors (Source: Castka, 2001)

Organizational impact refers overall properties and characteristics of an organization in terms of its culture, team formation (including group size, composition, and purpose of the team), methods used to gauge team performance, and reward systems. Defined focus refers to the clarity of goals while alignment and interaction with external entities refer to the system thinking of a project team. Castka et al. (2001) argue that the team member must think of their team as a part of a bigger system and form relations based on that.

Human factors such as knowledge and skills define the requirement of all the needed expertise in a particular subject. Castka et al. (2001) mention that the needs of the individual members have to be aligned with the needs of the group. Castka et al. (2001) mention that people will only agree to the team if it satisfies their own needs first. Lastly, group culture refers to the shared vision, learnings, trust consensus, and empowerment among team participants.

Scott-Young & Samson (2008) further explored the connection between the success of the project and team management. Scott-Young & Samson (2008) claims that efficient project management is one of the main objectives of multiple capital projects. However, the studies which determine the effects of team factors on project success (time, cost, and operability) are fairly limited. Therefore, they hypothesized and tested a five-dimensional model enlisting team factors that directly affected the project success of 56 capital projects newly finished by 15 Fortune 500 companies. Their five-dimensional model can be seen in figure 5.

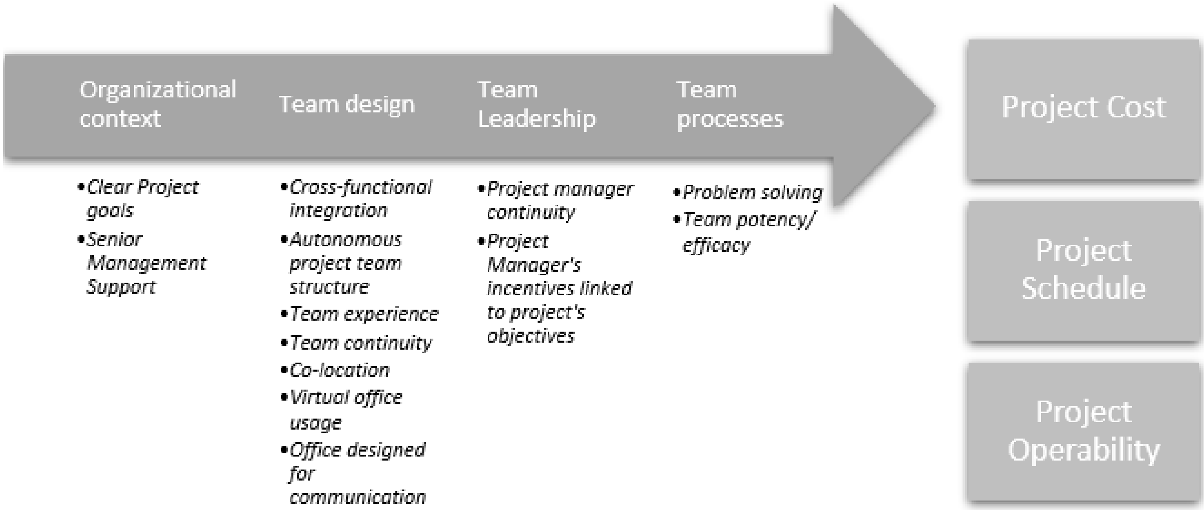


Figure 5: Five-dimensional model (Source: Scott-young & Samson, 2008)

Goals and objectives	Clear realistic objectives
	Strong business case/sound basis for project
Performance monitoring	Effective monitoring/control
	Planned close down/review/acceptance of possible failure
Decision-maker(s)	Support from senior management
	Competent project manager
	Strong/detailed plan kept up to date
	Realistic schedule
	Good leaders
	Correct choice/past experience of project management methodology/tools
Transformations	Skilled/suitably qualified/sufficient staff/team
Communication	Good communication/feedback
Environment	Political stability
	Environmental influences
	Past experience (learning from)
	Organisational adaptation/culture/structure
Boundaries	Project size/level of complexity/number of people involved/duration
Resources	Adequate budget
	Sufficient/well allocated resources
	Training provision
	Proven/familiar technology
	Good performance by suppliers/contractors/ consultants
Continuity	Risks addressed/assessed/managed
	User/client involvement
	Different viewpoints (appreciating)
	Project sponsor/champion
	Effective change management

Figure 6: Critical success factors (Source: Fortune & White, 2006)

Fortune & White (2006) also attempted to enlist "critical success factors" which influence projects. They claim that identifying critical success factors is the most approachable way to deal with human and organizational aspects of the project. They however point out that there exist several studies which present these critical factors but the consensus on these factors is fairly limited. In their study, Fortune & White (2006) reviewed 63 publications and their reviews to compile a list of success determinants referred to as critical success factors as shown in Figure 6. Although the critical success factors determined by Fortune & White (2006) are a general compilation of internal and external factors, several factors can be identified that directly impact the performance of efficiency of teams such as suitably skilled staff communication feedback, experience, the boundaries (project size, complexity, number of people involved).

Changali et al. (2015) bring the industry perspective on the topic by enlisting factors that account for poor efficiency in the construction sector as shown in figure 7:

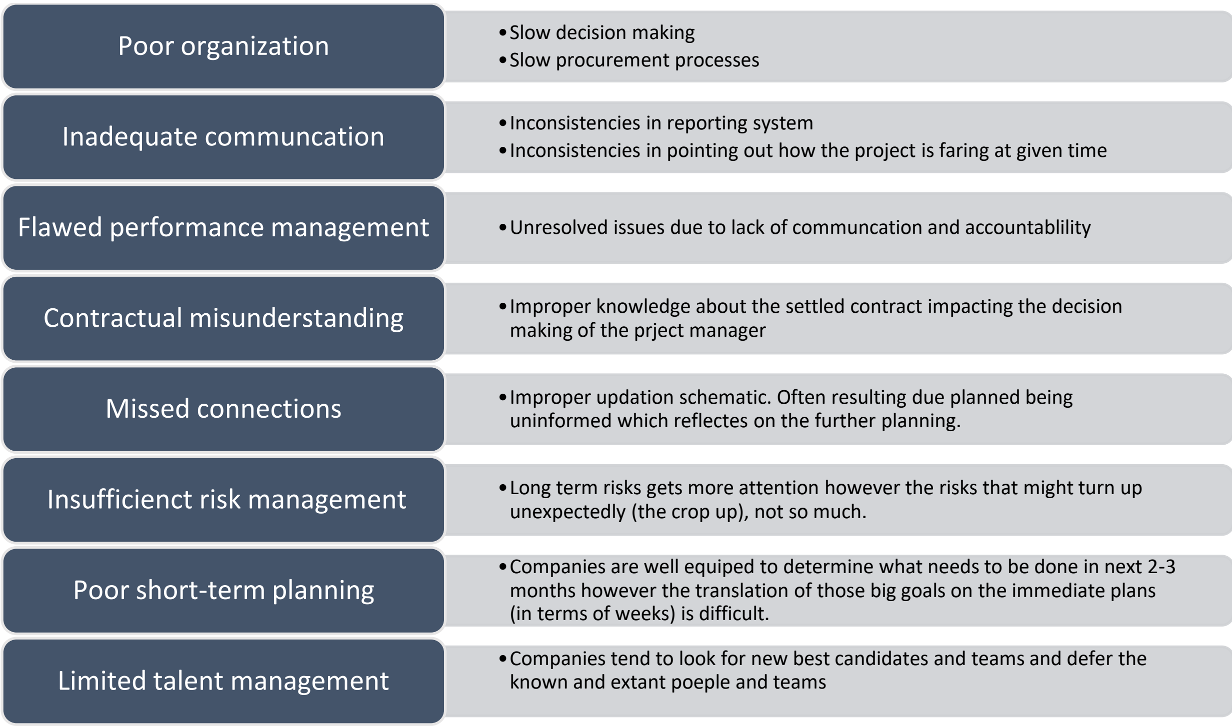


Figure 7: Factors contributing to poor efficiency in the construction industry (Source: Changali, 2015)

The factors identified after literature exploration done in regards to team performance, project performance, and project success, it was found that there exists an abundant overlap between the team-related factors that affect the efficiency and eventually the performance. Fortune & White (2006) also identified ample overlap between the critical success factors they identified from their literature exploration. Although it will be interesting to explore the effects of all the factors from an ABM perspective, however, the scope of this research limits this exploration to a few team-related characteristics.

According to a study conducted by Deloitte, a survey of leaders from over 7000+ companies originating from 130 different countries identified "*How to redesign organization structure?*" as the most prominent issue (Bersin, 2016). Bersin (2016) mentions that due to the digitization of the world, the companies are moving from a strict hierarchical structure to a flatter organizational orientation which Deloitte refers to as a *Network of teams.* Tollman et al. (2016) also claims that according to a survey conducted by Boston Consultancy Group almost 80% of the companies underwent an organizational redesign and more than half of them were unsuccessful. But a question arises why does the organizational structure of a company matter so much? Tran & Tian (2013) argues that the centrality of organization structure revolves around process efficiency and effectiveness however the topic remains one of the most cited, yet least understood. Denicol et al. (2021) further supports this claim and brings a perspective on megaproject construction and organization structure ambiguity. Denicol et al. (2021) cite a megaproject as one which costs over the US $1 Billion in a public or a private sector and is believed to provide long-lasting assets thus making large impacts on society. Denicol et al. (2021) claim that a megaproject is usually an undertaking of multiple stakeholders and the relationship between them produces complex organizational challenges which are often untapped and underexplored. Klessova et al. (2020) further express this gap in research and development (R&D) based on inter-firm projects.

The studies cited above explored the concept of organizational structure from a broader lens citing the connections between different stakeholders, firms, and teams while stressing the untapped potential that lies in the effective management of these connections. BCG's smart design approach proposes three steps for efficiently and successfully redesigning organizational structures which suggest focusing on team architecture as well as on the behaviors that identify with organizational goals (Tollman et al., 2016). Tollman et al. (2016) suggest focusing on the internal hierarchies of structures in regards to *Who reports to Whom.* They suggest defining the organizational geometry (indicating a span of control and number of layers) while also establishing distinct roles and responsibilities. Tollman et al. (2016) then stress the importance of identifying individual talents to fill those roles in such a way that shared responsibilities cooperate. They argue that the work in organizations can be interdependent which requires composition and policies which are conducive to cooperation and results. Higgs et al. (2005) support this claim by establishing a link between the composition of a team and its performance. Hsu et al. (2016) also established a connection between team composition (determined through team member selection) and team efficiency.

As mentioned before, even though several factors can be identified that impact team efficiency, organization structure, and team composition are among the factors that are most pressing considering the inclination of industries. Therefore, this study explores the effect of these variables on team efficiency. These factors are further explored in detail in the next sub-section.

2.2.1 Team composition and communication

This section explores the communicational aspects of a team in light of its composition. Additionally, this section also discusses factors that motivate the modeling of team composition and communication.

One of the initial innovators in the field of team composition can be traced back to the mid-1910s' when Earnest Shackleton with his exemplary display of leadership managed to rescue his crew from recurring harsh disasters during their polar expedition (Koehn, 2011). Some interesting and relevant lessons that can be drawn from their expedition would be dynamic spontaneity and careful team composition. Koehn (2011) in his article stressed the importance of continuously changing and adapting the goals according to the changing environment and urgencies which is hereby referred to as dynamic spontaneity. The second front which is stressed is that of team composition – Choosing the right person for the right job in the context of the entire team and goals in hand.

Research has shown the impact of team composition on team effectiveness and team performance (Belbin, 2004; Higgs et al., 2005; Hsu et al., 2016b; Pisani, 2012; Zarzu et al., 2013). Team composition not only evaluates what an individual member contributes but also how the aggregated characteristics of team members translate into team performance (Zarzu et al., 2013). However, the best orientation or composition is still a topic of debate in the scientific community (Lim & Klein, 2006). Generally, it is accepted that homogeneous teams are much more efficient when it comes to extracting the available knowledge and concepts; The homogeneity in the team helps to focus more on the subject topic which helps to improve the quality (Hsu et al., 2016b). On the other hand, diversity in teams is highly associated with creative problem solving and innovation (X. Zhang et al., 2021). It often helps to make a complex system more robust (Hsu et al., 2016b). However, heterogeneity is also linked with increased communication problems (Marx et al., 2021) and high levels of conflicts (Higgs et al., 2005). Higgs et al. (2005) mention four types of communicational problems in heterogeneous and diverse teams; Dissent over goals, preconceived opinions, semantic differences, and misunderstanding in non-verbal communication, which makes it essential to evaluate the type of team to be used for certain tasks. Higgs et al. (2005) also state that the heterogeneous and diverse teams surely have some benefits on non-routine tasks due to the creative potential however for routine tasks, the benefits are *uncertain.* They mention that the disadvantages due to increased communicational risks, conflicts, and reduced group cohesion might prove to be more disastrous than beneficial which forms the main motivation for studying team composition in the given study.

2.2.2.1 How can team composition and communication be modeled in this study?

Since the scope of this research is limited to modeling only the team characteristics, the individual-based variables influencing team composition are not modeled in this study. SimVision® however, enables the model of team composition and communicational aspects of a team with the help of six pragmatic factors; Team experience, Centralisation, and Formalisation. Matrix strength, Information exchange probability, and Noise (ePM, 2005).

Team experience defines how much the members of a team are acquainted with the activities being performed (ePM, 2005). Team experience also impacts the need for communication among team members. High team experience implies that the team members are well-acquainted with the kind of activities being performed which reduces the need for team members to communicate while low team experience implies that the activities undertaken by the team members are relatively novel to them which will produce more communication in-between them (ePM, 2005).

The degree of centralization is not a direct measure of team composition however is a vital factor that determines the communication within a team. Centralization is the representation of the decision-making system of a team (ePM, 2005). High centralization implies that the decisions are generally taken by the senior management which implies a high vertical communication flow whereas low centralization implies that the decisions are taken by the team members responsible for activities that reduce the need for communication.

Formalization represents the communication culture of a team by representing how formal or informal the exchanges occur within the teams. The high formalization will reduce the need for the team members to engage and rely on other informal communications and vice-versa.

Matrix strength is representative of both team composition and communication. Matrix strength determines how a team member is placed within a team. High matrix strength is representative of a team that is project-based (comprising of several skillsets) and is supervised by a project manager whereas, on the other hand, the low matrix strength is representative of skill-based functional teams, supervised by the functional head (ePM, 2005). The team characterized by high matrix strength is assumed to be less reliant on the informal meetings and more dependable on the informal exchanges within the team. Teams with low matrix strength on the other hand are assumed to be more dependent on formal meetings and less on informal information exchanges (ePM, 2005).

And lastly, information exchange probability is a pragmatic and quantitative factor that acts as the variable representing the volume of communication exchanged between positions connected with the communication links (ePM, 2005).

The motivation to model team composition and communicational factors in SimVision® comes from research conducted by Kik (2010). Kik (2010) conducted a study to quantify organizational risks in managerial decision-making. In the process of gauging the impact of different pragmatic factors on the developed agent-based model, Kik (2010) collected data and performed a robustness test to assess the impact of information exchange probability, Noise probability, Functional error probability, and project error probability on the final duration of the project. The idea is to follow a similar methodology in this research to determine the outcome space by varying the input of factors representing team composition and communication and then conducting a directed search – To use some kind of optimization method to identify the most critical inputs for the factor (Kwakkel, 2011), to gauge the effectiveness.

2.2.2 Organization structure

The organizational structure which in this study is a measure of hierarchy has also been found to be extensively linked with team efficiency (Greer et al., 2018). Chen & Brockett (2014) uses the term formation control to describe the degree and ways of hierarchy. They define formation control as a way in which the interconnected agents interact and communicate with one another in a centralized or decentralized manner for a shared goal. They claim the factor to be one of the most studied topics in multi-agent systems. However, Greer et al. (2018) further argue that the topic has a plethora of diverging and conflicting findings when it comes to its impact on team efficiency. Functionalist's point of view claims that the hierarchy supports team efficiency by enabling better coordination and team member interaction (Greer et al., 2018; Woolley et al., 2008) while on the other hand, studies show that hierarchy also hurts team efficiency by triggering conflict-enabling states due to incompatibilities, differences in perspectives and interests (Greer et al., 2018). Therefore, organization structure was deemed to be an interesting variable for the study since agent-based modeling does take into account how interactions among team members affect the team. The study will contribute to the agent-based perspective of hierarchy in the construction sector and in conjunction with team composition, which is thought to be an interesting area of study.

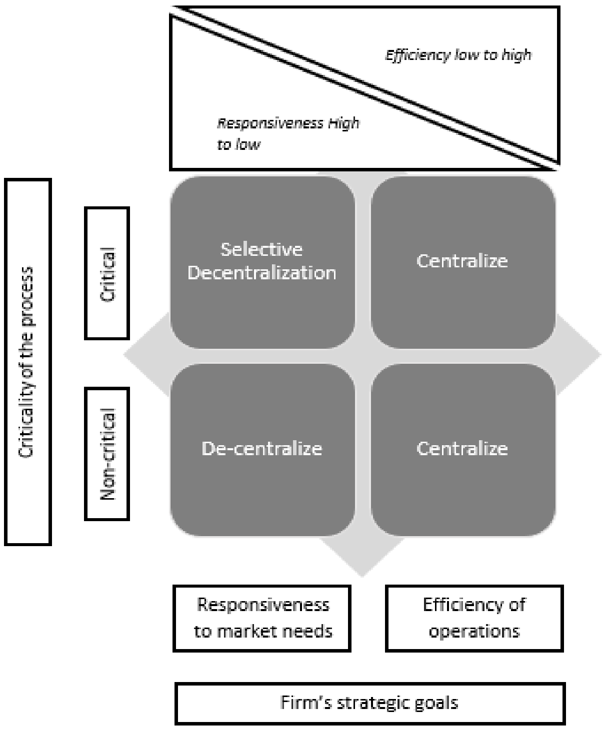


Figure 8: Centralization model (Source: Choudhary, 2020)

The power and decision-making capabilities of a team are largely determined by the organizational structure and policies of the company (Jin & Levitt, 1996). The decision-making in a company can be either centralized; where the decision making is in the hand of a few people, higher in the hierarchy (Kokemuller, 2019), or decentralized; in which the power of decision making is distributed across various levels of management (Choudhary, 2020). Choudhary (2020) points out the inherent dilemma that is often faced while setting the organization of a company. On one hand, centralization allows organization-wide consistency in terms of standardization, control to regulate work quality, clarity in terms of roles and responsibilities (Chain of command) and also it saves costs by ensuring there is no duplication of efforts and resources being utilized optimally. On the other hand, decentralized systems have flexibility which ensures adaptation according to local demands, motivates employees to develop a sense of loyalty and ownership for their work, increases the pace of decision making, and lastly, promotes better innovation within project teams.

Choudhary (2020) points out that no one-size-fits-all but instead the organizational structure of each process has to be determined separately which might also result in centralized and decentralized teams coexisting in the same company. Choudhary (2020) also suggests a simple model recommending how the organization structures should be designed, which can be seen in Figure 8. SimVision® offers the possibility of gauging the effect of hierarchy through its centralization parameter and also through the layers of hierarchy built by attaching reporting links between team members/positions that are formed while modeling. The reporting links identify members between whom the information is exchanged on a regular and hierarchical basis and who are responsible for taking decisions. SimVision® is highly capable of determining the consequences of organizational designs resulting from team architecture which makes organization structure to be one of the focuses of this study.

2.2.2.1 How can organization design be modeled?

One of the objectives of this research is to mimic the existing settings of the activities and project team on SimVision® and vary the organization structure to review its results on the duration. A project team can be varied in innumerable ways; From adding more layers to the hierarchy to lowering them, from changing the number of people reporting to their seniors for decisions to be made to making the people the point-of-decision themselves. To bring more structure to the organizational changes implemented in this study, client-contractor collaboration is explored.

Collaboration based on different contract types results in various reporting systems in project teams which impacts the hierarchies, information and communication observed in the project teams (Cusimano, 2011; J. Han et al., 2019; Mishra et al., 2015; Moree, 2013; Suprapto et al., 2016). Since a contract type includes elements like remuneration scheme, risk allocation, and incentives (Suprapto et al., 2015) which is outside the scope of this thesis, the term client-contractor collaboration will be referred to denote the organizational relationship between both entities.

Literature has broadly classified the client-contractor relationships into two types: (1) Tradition relations and (2) Partnering relations (Du et al., 2016; Suprapto et al., 2015; Xu et al., 2005; Xue et al., 2010). A Traditional relationship can be defined as the one in which the project owner is responsible for project definition defining its scope and thereby selecting contractor(s) based on competitive bidding to actualize the project (Korvinus, 2017). The responsibility of procuring the project thereafter lies with the contractor (Korvinus, 2017). To demonstrate the traditional relations as per the definition cited by Korvinus (2017), EPC contracting structure is proposed. EPC stands for Engineering, Procurement, and Construction contracts where the contractor is responsible for engineering services, procurement of material and equipment, and construction (Seng, 2012). A typical relational chart is shown in Figure 9.

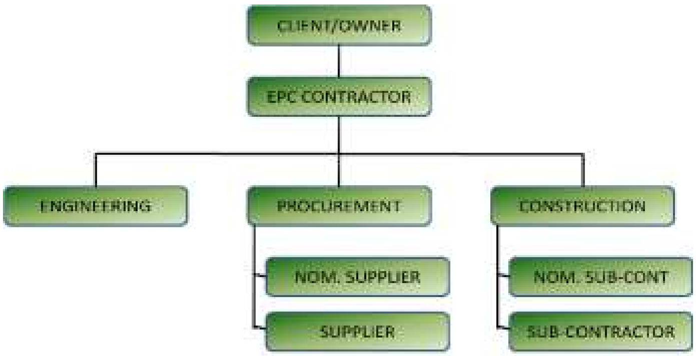


Figure 9: EPC Source: Seng (2012)

Partnering relations on the other hand are formed to promote a collective attitude among clients and contractors (Korvinus, 2017). Lin & Darnall (2015) defined partnering with the help of strategic alliances which they cite as a voluntary collaboration between organizations to facilitate product exchange, sharing, mutual development of technology, or the provision of services to achieve common goals. The core aspect of strategic alliancing is equality among parties; Cooperation is promoted through trust, understanding, and mutual pain and gain (Walsh, 2015). Since the intention is to use contracts only as a motivation to compose organization structures and also keeping in view the time required for modeling individual contracts, only EPC is further developed as a comparative case scenario in this research to determine the impact of organizational structural change.

2.3 Utility of Agent-based modeling

This section aims to evaluate the aptness of using agent-based modeling for the formed objectives. This section discusses the relevance and applicability of ABM in different domains. By evaluating the advantages and disadvantages of using ABM.

Agent-based modeling has found extensive application and utility in different domains. Agent-based modeling can be very well used to simulate the emergent behavior of a system (Bonabeau, 2002b; Crooks & Heppenstall, 2012b; Hsu et al., 2016b; Jin & Levitt, 1996). As explained before, the model is characterized by agents, which are individually capable of acting as intelligent entities. Although the actors may hold certain individual opinions towards a subject, the emergent decision can be radically different. A common example of this can be seen in Group-think situations. In group-think situations, the individuals tend to behave as per the dominant opinion of the group even though they individually may hold different opinions (Bonabeau, 2002b; Crooks & Heppenstall, 2012b; Hsu et al., 2016b; Jin & Levitt, 1996). ABM is highly useful in evaluating such socio-technical behaviors (Lange et al., 2021).

The agent-based model can also be useful to describe some natural occurrences within the project environment. This can be true since the model created acts more or less analogous to the reality of the project environment. Crooks & Heppenstall (2012) mention the abilities of ABM in a dynamic social environment which are created using agents having autonomy, heterogeneity, and their activity which is dependent on their goals, perceptions, rationality, communication, mobility, and learning. They claim that these attributes when modeled in ABM help to include multiple dimensions of the project environment and predict the emergent behavior of a system. However, when abstract parameters are used to describe the actors, the model may also result in an unrepresentative reality (Bonabeau, 2002b; Crooks & Heppenstall, 2012b).

Agent-based models are also highly flexible. This means that the variables in the model created can be fairly easily manipulated and adapted to new settings (Bonabeau, 2002b; Crooks & Heppenstall, 2012b; Jin & Levitt, 1996). ABM enables testing of various *What-if* scenarios in a safe environment to quantitatively determine the impacts of different variables on the outcome of interest (Bonabeau, 2002b; Crooks & Heppenstall, 2012b; Jin & Levitt, 1996). This ability makes Agent-based modeling a sustainable and safe source of project planning.

Lastly, Agent-based modeling is highly useful for quantitatively determining the behavior and culture of organizations (Koohborfardhaghighi & Altmann, 2017; Kooy, 2012). The modeling expert from AMPS delft claims that most organizations know about the existence of indirect work (rework, coordination, and decision-wait) in the projects. However, its extent and impacts are often unknown. Agent-based modeling acts as the learning tool which represents these indirect works quantitatively and acts as a decision support tool for the companies. However, despite having several advantages, agent-based modeling also has some limitations.

There is no generally acceptable level of abstraction when it comes to the level of detail and modeling of the information, in general. The process of modeling is more an art than just a science (Bonabeau, 2002b; Crooks & Heppenstall, 2012b; Jin & Levitt, 1996). Since the modeling of every single activity or even every single agent can be a highly complex and intricate process, the modeling involves the aggregation of these entities (Bonabeau, 2002b; Crooks & Heppenstall, 2012b; Jin & Levitt, 1996). The level of detail has to be adjusted as per the requirement of the user which makes modeling more than just a science.

Additionally, Agent-based modeling attempts to model humans or groups of humans, which cannot be replicated accurately. Humans exhibit non-linear behavior and the reasons for this can be attributed to more than just a few variables. The replication can only be to an extent of the decision-making which is assumed and based on the rationality of humans (Bonabeau, 2002b; Crooks & Heppenstall, 2012b). This induces a certain level of inaccuracy in the models.

Another limitation can be the computational time required for generating the results. The computational efficacy of ABM can be low since a large number of actors have to interact within the environment with the set constraints. This can be even more pronounced if iterations are involved in the process (Crooks & Heppenstall, 2012b).

2.4 Synthesis

The literature review performed in this research intends to build the required knowledge base to comprehensively evaluate the relationship between team composition, organization structure, communication, and team efficiency. In addition to exploring scientific journals and consultancy reports of leading firms, this chapter also looks into studies that used SimVision® for the construction of Agent-based modeling to gain a better understanding of the construction of Agent-based model for this research.

Section 2.1 begins by exploring the literature involving team efficiency. Section 2.1 first cites studies that employed different definitions for the term and then defines the meaning of team efficiency for this research. From more interpersonal variables such as the ability of team members to align their efforts with the common goals of the team (Piccoli et al., 2004) to more collaborative variables such as cost, time, and quality attributed to the final product (Liu & Cross, 2016; McComb et al., 2007; Ryan & O'Connor, 2009; Weiss et al., 2011), efficiency has a multitude of dimensions on which it has been evaluated. However, considering the notorious reputation of the construction industry concerning time delays (Al-Wadei, 2020; Anastasopoulos et al., 2012; Arditi et al., 2017; Arditi & Pattanakitchamroon, 2006; Changali et al., 2015; Gonzalez, 2017; Lucko et al., 2021; Sambasivan & Soon, 2007) and on the other hand, the potential for adding enormous value to the industry by modestly increasing the team-based efficiency (Barbosa, Woetzel, et al., 2017), this study focuses on time or project duration as the main indicator of team efficiency. Section 2.1 concludes by investigating two studies that used

SimVision® for exploring team efficiency in the engine maintenance cycle of F/A – 18 E/F F414 (Slack & Hagan, 2006) and the team efficiency of a global team involved in a project-based learning academic course (Ioannidou et al., 2009).

Section 2.2 further extends the knowledge by exploring different factors that affect team efficiency. The literature cites multiple social, organizational, human, and context-based factors that affect the efficiency of a team (Castka et al., 2001; Changali et al., 2015; Fortune & White, 2006; Scott-Young & Samson, 2008). However, among these factors, two independent studies conducted by Deloitte and Boston Consultancy Group (BCG) stressed the need for an organizational redesign for team efficiency as the most prominent concern among companies therefore this study gauges the impact of team composition and organization structure on team efficiency in the context of communication (Bersin, 2016; Tollman et al., 2016).

Team composition has been identified as one of the main factors that affect the efficiency of the team (Castka et al., 2001; Hsu et al., 2016a; Pisani, 2012; Zarzu et al., 2013). On one hand, heterogeneous teams are claimed to be effective in exploring innovative and creative solutions however, on the other hand, such teams are also claimed for having communicational frictions (Higgs et al., 2005; Marx et al., 2021). Homogeneous teams in contrast are claimed to have better potential in exploring a particular topic with limited communicational frictions (Hsu et al., 2016a). This forms the composition of the teams as a topic of debate in the scientific community. To address this, a tool is required that is apt for gauging socio-technical situations more objectively and quantitatively for which ABM is proposed, and hence team composition is taken as one of the independent variables for this research.

The organizational structure of a project team has a similar dilemma. While a strict hierarchy brings control and structure to the work processes, it can also trigger conflict enabling states among team members due to differences in perspectives, and goals which are counterproductive for team efficiency (Greer et al., 2018; Jin & Levitt, 1996; Woolley et al., 2008). Studies also point out the direct effect of having a multilayer hierarchy on communicational time and the quality of the project. This forms the main motivation for considering organization structure as one of the independent variables for the study.

Section 2.2 concludes by proposing ways in which both team composition and organization structure of a project team can be modeled. It explores the utility of sensitivity analysis/ robustness test (Kik, 2010) in conjunction with statistical analysis to explore and compare the factors that affect team composition. It also highlights the usage of contracts and their effects on decision layers and the organizational structure (Cusimano, 2011; J. Han et al., 2019; Mishra et al., 2015; Moree, 2013; Suprapto et al., 2016) of the project team to motivate organizational changes for the modeling process.

Lastly, this chapter concludes by highlighting the utility of agent-based modeling for reaching the research objectives of this study. Section 2.3 cites areas in which agent-based modeling flourishes as a technique while also drawing the boundaries implicated by its limitations. The ability of Agent-based modeling to quantitatively evaluate complex socio-technical situations (Bonabeau, 2002b; Crooks & Heppenstall, 2012b; Hsu et al., 2016b; Jin & Levitt, 1996) in addition to its flexibility in terms of evaluating and comparing different *what-if* scenarios (Bonabeau, 2002a; Jin & Levitt, 1996) makes this tool apt for reaching the research objectives of this study.

PART II

3

Model Conceptualisation

Part I of the research gives an academic understanding of how team composition and organizational structure affect the team's efficiency while taking into account communication. However, to have a more holistic and comprehensive view of the dependencies between these variables a quantitative comparison is also deemed necessary. Therefore, the research also focuses on taking a model-based approach to quantitatively strengthen the relationship between these variables.

For the conceptualization of the agent-based model, a modeling plan (Appendix-C) is devised and implemented. The modeling plan is developed to guide a sequential and logical construction of the agent-based model by focusing on the main research questions, the purpose of the model, and the key elements that characterize and derive this model. However more in-depth documentation of the underlying concepts that support the functioning of SimVision® and thereby the agent-based model is documented using Overview, Design concept, and Details (ODD) protocols (Grimm et al., 2006, 2010) (Appendix J). It should be noted that the modeling plan only supports the sequential construction of the Agent-based model by focusing on aspects that SimVision® is capable of modeling. Whereas the ODD protocols focus on exploring the underlying concepts that support the functioning of Agent-based modeling software (SimVision® in this study) and stressing its choice for the research. ODD is widely acknowledged and adopted as a methodology to document Agent-based models due to its effectiveness against ambiguities and its potency to make the substance of research more easily documentable, understandable, and reproducible for any further research (Hsu et al., 2016a; Taillandier et al., 2015; Zhuo & Han, 2020).

The ambition of this chapter however is to establish and conceptualize an agent-based model and set a solid foundation for the experimentation performed in the next chapter. This chapter begins by introducing the case study used in this research. The case study highlights the main context under which the agent-based model is constructed. Following the case study, the conceptualization and parameterization of the agent-based model follow. The resultant model intends to closely mimic the environment of the case used for this research and finally to test the authenticity of the developed model, the model is subjected to verification and validation.

3.1 The case-study

3.1.1 About the Company

The case study used in this research has been requested and retrieved from one of the biggest public real estate companies in India, Omaxe Limited. Founded in the year 1989, the company has successfully delivered a plethora of residential, commercial, and township-related projects all around India and has been awarded numerous accolades and recognitions for its efforts and vision of delivering quality and outstanding real estate spaces.

Motivated by its mission, "*To push the boundaries and make happy spaces for customers*", the company is mainly guided by its five main pillars – Customer Satisfaction, Creating value for stakeholders, Professionalism, Transparency, and Quality. The company is known for delivering large-scale integrated township projects which encompass multiple residential-commercial units designed for the versatile demographic of India. Table 1 gives a glimpse of the successful project delivered by Omaxe.

S.no	Project type	Name of Project	Location
1.	Integrated Township	New Chandigarh	Chandigarh, Punjab
2.	Integrated Township	Omaxe City	Indore, Madhya Pradesh
3.	Integrated Township	World street Faridabad	Faridabad
4.	Commercial Mall	Omaxe Connaught place	Greater Noida
5.	Residential	Omaxe Heights	Lucknow
6.	Residential	Omaxe Royal Residency	Ludhiana
7.	Luxury Residential	The Forest Spa Noida	Noida

Table 1: Township projects by Omaxe

Omaxe has its footmark across 30 cities in India in which the company has already delivered more than 87.7 million sq. ft. of built space (Commonfloor, n.d.). Currently, Omaxe is working on 46 real-estate projects which include 18 aggregated township projects, 15 housing projects, 11 commercial-complex projects, and 2 Hi-tech townships. Among the 18 township projects, the focus of this research is on a residential-commercial building being constructed as a part of a township project in Lucknow, India.

3.1.2 The case overview

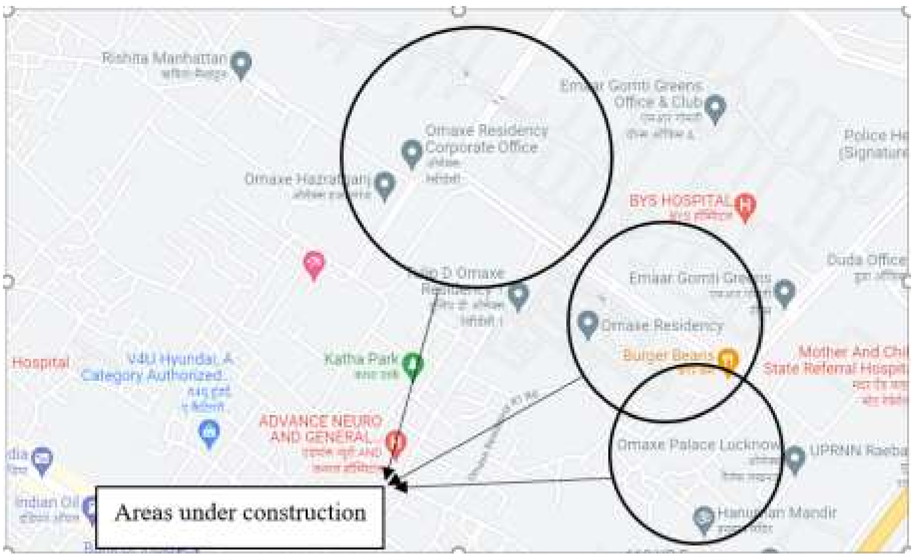


Figure 10: Township location - Uttarpradesh, India

Omaxe intends to build a high-quality integrated township in the city of Lucknow, Uttarpradesh. The company aims to transform the area of Gomti Nagar into a versatile modern space that can accommodate residential complexes, commercial centers, office spaces, etc. while also preserving the royal heritage of Lucknow (Omaxe, n.d.). Gomti Nagar is one of the fastest developing areas in Lucknow and has a high investment potential that the company seeks to explore.

Thus, the company intends to build multiple residential-commercial complexes and add value to the existing infrastructure of the city. The township being constructed has 9 residential-commercial projects out of which the focus of this research is limited to the *MEP and Finishing Phase of a 7-story complex, Hazratganj Mini (Also known as Omaxe Hazratganj Phase II)*. Hazratganj Mini is a medium-sized residential-commercial project (USD 1.36 Million) that intends to accommodate studio apartments, commercial shops, and office spaces ranging from 270 to 800 sq. ft. in space size. The building is currently in its last phase of development (MEP and Finishing Phase) which makes this project lucrative from the perspective of modeling.

This study establishes the baseline model (replicating the existing environment of the company) using three distinct models – Model 1, 2, and 3. Model 1 is characterized by planned dates of activities while model 2 is characterized by actual dates of activities. Using Model 2 as a reference, the project settings are introduced in Model 1 such that the activity and total duration of Model 1 become equal to durations in Model 2. This newly balanced model is the baseline which is designated as Model 3. Evidently, the construction of these models heavily relies on the project data. Carrying out this research in parallel to the execution of MEP and finishing phase enables accurate identification of actual dates and more reliable data in terms of team settings which forms the core of any agent-based model. Moreover, the validation of an extant project is relatively easier and more accurate due to the ease of data and fact recollection from the project sources.

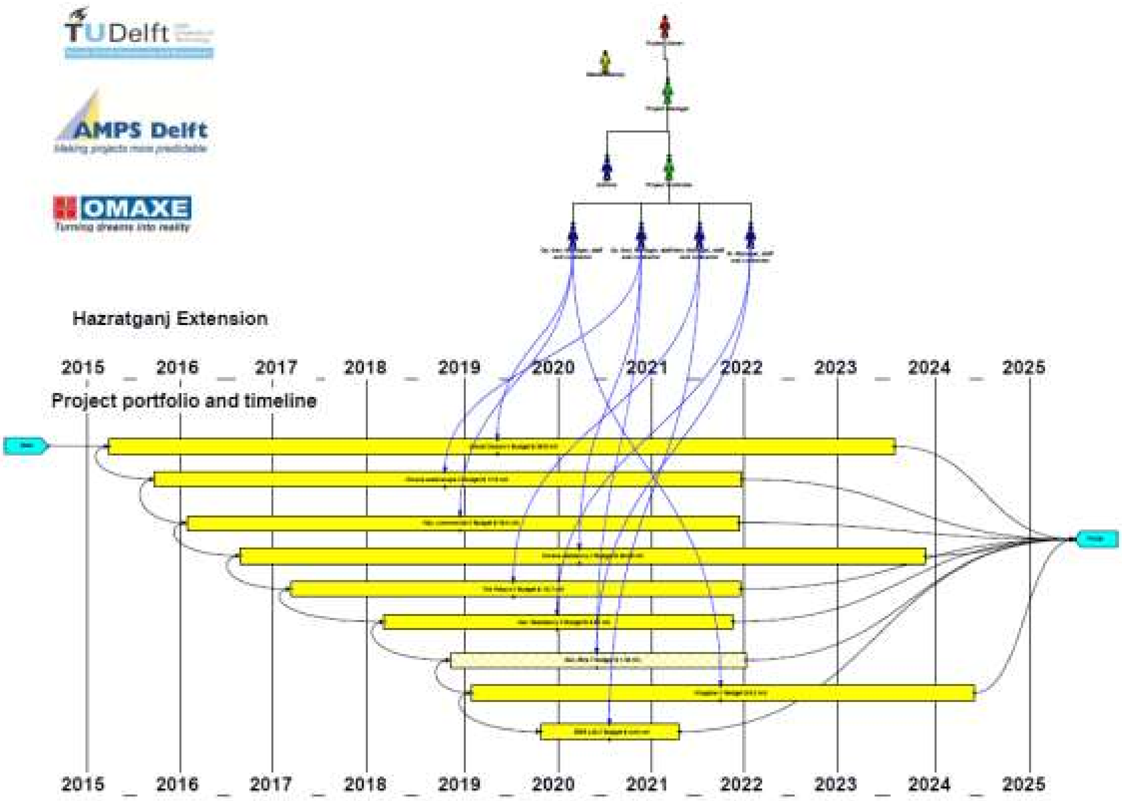


Figure 11: Project portfolio

A higher resolution of the image can be referred to in appendix G.1.

A personal motivation to choose this project also comes from the fact that project team members had shared responsibilities. Since Omaxe intended to construct an integrated township, the project team members had simultaneous engagements which segregated their time over multiple projects. This aspect brings uniqueness to the chosen case and an agent-based perspective is thought to be useful in determining how the project teams performed in an integrated project owing to their shared responsibilities.

The construction of this integrated township shortly began after the acquisition of Government permits. The project was initiated with the construction of a USD 35 Million commercial-residential project - Grand Omaxe in the year 2015. From the year 2015 to 2017, Omaxe added five more projects to the portfolio of the integrated township with an aggregated budget of approximately USD 107 Million. It was only in the year 2018 that the construction of Hazratganj Mini commenced. The initial plans of Hazratganj mini predicted the delivery of the project by August 2021. However, due to the strategic interests of Omaxe to have cost optimization across the portfolio, the building was finally delivered in January 2022; implying a 5-month delay. Omaxe added two more projects in the Integrated township after the construction of Hazratganj Mini. A SimVision® schematic below represents the timeline of the project portfolio and the teams responsible for their realization.

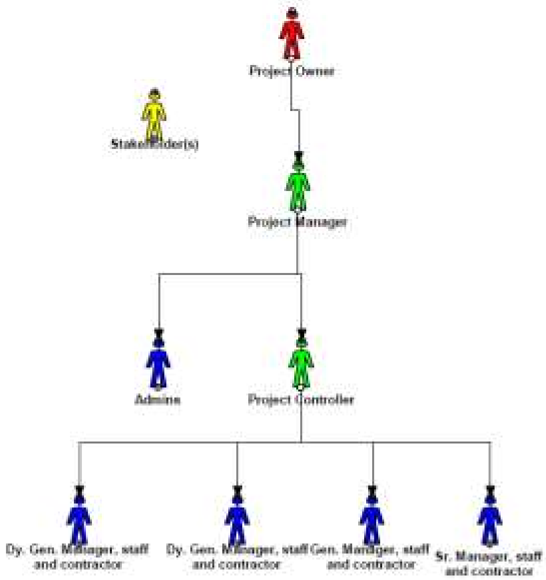


Figure 12: Organization structure (Portfolio)

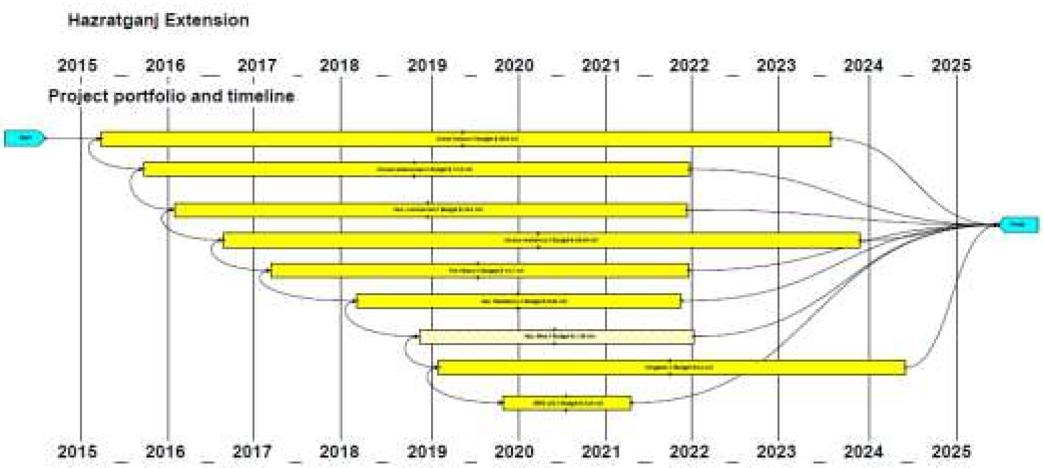


Figure 13: Project timeline

The person-like icons at the top of Figures 11 and 12 represent the positions and their spatial location which is meant to display the intrinsic hierarchy and reporting system between these positions. Yellow-rectangular figures (Figures 11 and 13) on the other hand represent the projects within the integrated township of Hazratganj extension. The blue arrows connecting positions with the sub-projects represent the delegation of project teams within the integrated township project. The images above highlight two main characteristics of this township project: First, the shared responsibilities of the project teams over multiple projects, and second, the parallel execution of all the projects in the township. Although the aggregated positions above show only one more project (Hazratganj residency) in addition to Hazratganj mini being built by the team of senior manager, however, a closer look at the team members and sub-project teams reveal an even higher overlap of responsibilities, which will be explained in the upcoming section.

3.2 The Agent-based model

Having defined the background of the case study used in the previous section, this section aims to elaborate on the process and substance of the agent-based model constructed in this research. The literature cites, the construction of an agent-based model revolves around three main elements: (1) The agents, (2) the environment, and (3) Agent-environment interactions (Abou Yassin et al., 2020; Crooks & Heppenstall, 2012a; Hsu et al., 2016a; Khodabandelu & Park, 2021). This section aims to sequentially explain the development of these elements in the context of three models; Model 1, Model 2, and Model 3 and thereby presenting the final baseline. The intention of developing these three models is to promote a systematic and orderly approach to the construction of the baseline. Although the process of constructing these models and thereby the baseline is highly iterative in nature, these three models act as milestones in the modeling process and represent the main data and findings in regards to Hazratganj Mini.

3.2.1 Model 1

The process of constructing the baseline model begins with the development of Model 1 where the main elements of the agent-based model (agents, environment, and agent-environment interaction) are first defined. This model aims to represent how the project was intended to be performed and thus acts as the starting point in the modeling. The key characteristics that differentiate Model 1 from the remaining two models are the definition of its environment and also the default nature of system settings. Model 1 acts as the representation of the project in terms of *planned activities.* To elaborate, the project schedule is always governed by a set of activities and their planned dates of completion. However, in reality, the course of execution of these activities may take longer or shorter than anticipated. This means that for every activity, there remain two sets of start and finish dates; *the planned dates and actual dates.* Since Model 1 acts as the starting point, this model represents the activities defined according to their planned dates.

Another factor that differentiates Model 1 from the rest of the models is the default nature of its system settings which include team experience, centralization, formalization, matrix strength, probabilities, etc (Appendix J). In the following sub-sections, the chronological development of the model is explained.

3.2.1.1 System Settings

Program	Value	Units
Name	Program	
Description		
Start Date	01/Apr/2021	
Trials	1000	
Seed	0	
WBS Separator	.	
WBS	0.0	
Calendar	Edit...	
Team Experience	Medium	
Centralization	Medium	
Formalization	Medium	
Matrix Strength	Medium	
Info Exchange Prob.	0	
Noise Prob.	0	
Functional Error Prob.	0	
Project Error Prob.	0	
Behavior File	Default	
Revisions	Edit...	
Escalators	Edit...	
Hyperlinks	Edit...	

Project	Value	Units
Name	Hazrat	
Description	MEP an	
Priority	Medium	
Work Day	8	☐
Work Week	5	☐
Team Experience	Medium	☑
Centralization	Medium	☑
Formalization	Medium	☑
Matrix Strength	Medium	☑
Info Exchange Prob.	0	☑
Noise Prob.	0	☑
Functional Error Prob.	0	☑
Project Error Prob.	0	☑
Fixed Cost	0	
Fixed Revenue	0	
Cost Rate	0	Days
Revenue Rate	0	Days
Actual Cost	0	
Actual Revenue	0	
WBS		
Chart Color		
Categories	Edit	
Business Drivers	Edit	
Revisions	Edit	
Escalators	Edit	☑
Hyperlinks	Edit	

Table 2: (a) Program setting tab, (b) Project setting tab (Model 1)

Before laying the elements of the model in SimVision®, it is essential to define some basic properties of the model through system settings. These settings enable to define the company's working culture which includes how the decisions are made (centralization), how the communication and information flow among team members occur (Information exchange probability, formalization), and if the team members are co-located (Matrix strength), etc. These basic properties can either be left to default or changed as per the requirements of the case.

The system settings can be introduced on two levels; The program level (Table 2a) and the project level (Table 2b). SimVision® allows to model a portfolio of projects and the program settings define system settings for all the projects in the portfolio. Since the objective of this study is limited to modeling only one project, the program settings are adjusted according to it. Project settings on the other hand allow adjusting the properties of the model catering only to one specific project.

As explained before, one of the key characteristics of Model 1 is in its default nature of system settings, therefore, the parameters such as Team experience, centralization, formalization, and matrix strength are kept to Medium (the default value) and the probabilities including information exchange, noise, functional error, and project error are kept to zero in both, program and project setting tabs. The checked sign following the parameters (Table 2b) shows that the properties are locked and are not altered from their default value.

Another crucial aspect of modeling that is defined in these settings tabs is the start date of the project and the number of Monte Carlo simulation runs. The start date determines the starting point in the simulated time-space in SimVision®. As Model 1 corresponds to the planned dates of the activities, the start date mentioned in the program settings tab (Table 2a) is 1st Apr. 2021 corresponds to the planned start date of the MEP and the finishing phase of Hazratganj Mini.

SimVision® is a probabilistic tool that takes multiple variables, associate probabilities with them, and work on the principle of Monte Carlo runs. SimVision® enables the users to define the number of iterative runs required for a program and the software displays the results by taking the average of the values produced from the iterative runs, impacting the accuracy of the results (ePM, 2005). The default number of runs corresponds to 25 however, to achieve better accuracy in terms of final results without compromising much of the computational time, the number of runs is changed to 50 (for the iterative process). However, to check the accuracy of the final results of the completed model a test with 1000 runs is also performed. Higher runs provide a better saturation of results

In addition to this, the project setting also enables to define work period of the project team. As evident in Table 2b, the tab enables to input the number of working days in a week and also the number of hours the project team works in a day. Although the company has 6-working days a week culture, considering the number of non-activity days due to holidays over the span of MEP and the finishing phase of the project, the number of average working days is calculated to be 5 per week with 8 hours of activity every day.

Having defined the basic settings, the next steps involve the establishment of ABM elements.

3.2.1.2 The agents

Supervisor	Connected From	Connected To
1	Project Controller	Construction head HAZ. MINI
2	Project Controller	Finishing head
3	Project Controller	MEP head
4	Construction head HAZ. MINI	Construction Manager HAZ. MINI
5	Construction Manager HAZ. MINI	Construction supervisors HAZ. MINI
6	MEP head	MEP Manager
7	MEP Manager	MEP supervisors
8	Project Owner	Project Manager
9	Project Manager	Project Controller
10	Project Manager	Admins
11	Finishing Foreman	Finishing crew (Contractor)
12	Construction foreman (Haz. Mini)	Construction crew HAZ. MINI
13	MEP foremen	MEP crew (Contractor)
14	MEP supervisors	MEP foremen
15	Construction supervisors HAZ. MINI	Construction foreman (Haz. Mini)
16	Finishing head	Finishing Manager
17	Finishing Manager	Finishing Supervisors
18	Finishing Foreman	Facade crew (Contractor)
19	Finishing Supervisors	Finishing (Jr. engineer)
20	Finishing (Jr. engineer)	Finishing Foreman

Table 3: Supervision links (Model 1)

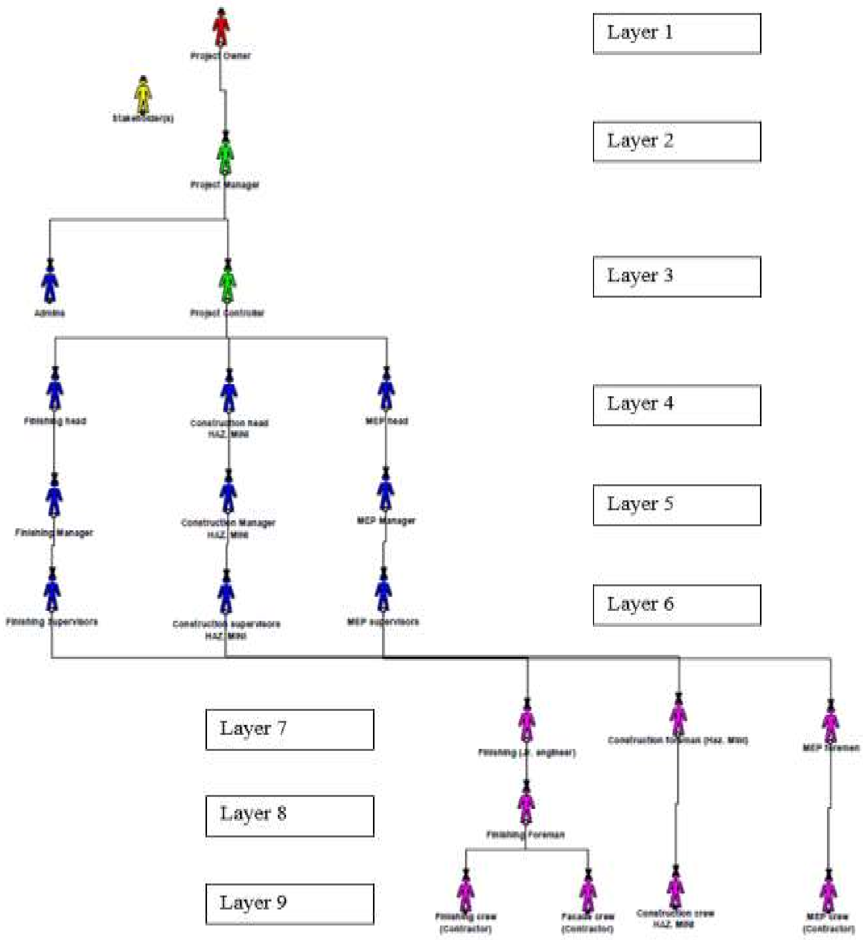
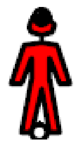


Figure 14: Organization structure (Model 1)

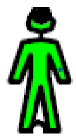
As also explained in chapter 2, agents are individual and distinct entities that interact with one another and are influenced by the external environment. The agents in this model represent the organizational structure of the project team working on Hazratganj Mini. With the use of the official organization chart of a project team working on the integrated township project and also with the consultation of the Assistant manager from Omaxe, the reporting system and hierarchy of the project team are determined and tabularized as shown in Table 3. The table presents the supervision and reporting links existing between supervisors (connected from) and subordinates (connected to) represented through aggregated agents - *positions* (Appendix J). Based on the identified links, the organizational structure of the project team is modeled. The modeled structure displays the positions working on Hazratganj Mini which are grouped through 9 layers of hierarchy as shown in Figure 14.

To facilitate better representation and understanding of the project team, the color schematic is used to differentiate between positions as follows:

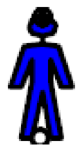
Project owner: The owner of the project forms the first entity in the organizational structure of the project team and is represented through a red-shaped position. As explained before, the integrated township project is being built by Omaxe using in-house expertise, the owner here represents the Chief Managing Director (CMD) of the company. The CMD acts as the main client in the model and also is responsible for making crucial decisions.



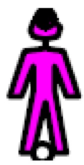
Senior Management: The senior management of the project team is represented using a green-shaped position in this model. The senior management is comprised mainly of the project manager and the project controller who are responsible for overlooking the main construction execution. Looking at the organization structure, it can be seen that the discipline heads (finishing head, construction head, and MEP head) directly report to the project controller. This is because the project controller is responsible for overlooking the construction that is happening across multiple projects in the portfolio. The project controller takes the regular decisions and enforces the profit optimization strategies. The project manager on the other hand is mainly responsible for strategizing and taking the most crucial decisions.



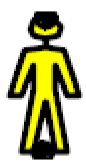
Construction team: The construction team represents the positions responsible for the actual execution of the activities in Hazratganj Mini. The team is represented using a blue-shaped position and comprises the bulk of the entities in the structure of the project team. The construction team comprises several distinct positions which are differentiated based on their roles in the project team, for example, the discipline heads, discipline managers, discipline supervisors, and admins. All these positions have varying degrees of responsibility towards Hazratganj mini. The construction team is responsible for carrying out the day-to-day activities observed in the execution of this project.



Contractor's team: The contractor's team is represented using a pink-shaped position. Although the planning and supervision of all the projects in the portfolio of Hazratganj Extension are done by the in-house team of Omaxe, the realization of the projects however is carried out through an externally sourced contractor which provides the workforce for the execution. The contractor's team comprises a junior engineer, foremen, and the working crew.



External stakeholder(s): External stakeholders are represented using a yellow-shaped position. Although the stakeholders are not directly involved in everyday works carried out in the portfolio of projects, they are crucial entities who are involved in the decision-making process. Due to their indirect role in the project, they are not a part of the hierarchical structure that is formed in the model but are represented as a separate and unattached entity. The external stakeholders in this model mainly represent the local politicians and other board members of Omaxe.



Position	Value	Units
Name	Proje	
Description		
Role	SL	
Application Experience	High	
FTE	0.25	
Salary	0	curr/FTE/hr
Work Day	8	☑
Work Week	5	☑
Chart Color		
Skill Set	Edit...	
Staffing	Edit...	
Categories	Edit...	☐
Escalators	Edit...	☑
Product	Edit...	
Hyperlinks	Edit...	

Table 4:Position setting tab

Having defined the structure of the organization on the canvas of SimVision®, state variables are attributed to each of these positions which gives them the characteristics to behave and interact differently. Table 4 shows the properties tab which enables the introduction of these characteristics in the positions. The positions in SimVision® can be characterized by their roles; Project manager (PM), Team lead (SL), Team member (ST), and application experience (High, Medium, or Low). These are the pragmatic factors that determine how efficiently a position performs its task and how the decisions are taken. Full-time equivalent (FTE) on the other hand determines how much time a position devotes to a particular project (Appendix J).

Position	Name	Description	Role	Application Experience	FTE	Salary	Work Day		Work Week
1	Project Controller		SL	High	0.25	0	8	☑	5
2	Finishing head		SL	High	0.3	0	8	☑	5
3	Finishing Supervisors		SL	Medium	2	0	8	☑	5
4	Finishing crew (Contractor)		ST	Medium	20	0	8	☑	5
5	Construction head HAZ. MINI		SL	High	0.5	0	8	☑	5
6	Construction Manager HAZ. MINI		SL	High	0.5	0	8	☑	5
7	Construction supervisors HAZ. MINI		SL	Medium	1	0	8	☑	5
8	Construction crew HAZ. MINI		ST	Medium	7	0	8	☑	5
9	MEP head		SL	High	0.2	0	8	☑	5
10	MEP Manager		SL	High	0.2	0	8	☑	5
11	MEP supervisors		SL	Medium	1	0	8	☑	5
12	MEP crew (Contractor)		ST	Medium	11	0	8	☑	5
13	Project Manager		PM	High	0.25	0	8	☑	5
14	Project Owner		SL	High	0.25	0	8	☑	5
15	Stakeholder(s)		SL	Medium	2	0	8	☑	5
16	Admins		SL	High	2.5	0	8	☑	5
17	Finishing Foreman		ST	Medium	1	0	8	☑	5
18	Construction foreman (Haz. Mini)		ST	Medium	1	0	8	☑	5
19	MEP foremen		ST	Medium	1	0	8	☑	5
20	Finishing Manager		SL	High	0.5	0	8	☑	5
21	Facade crew (Contractor)		ST	Medium	5	0	8	☑	5
22	Finishing (Jr. engineer)		ST	Medium	1	0	8	☑	5

Table 5: Position properties (Model 1)

Table 5 represents state variables allocated to different positions. These allocations are mainly based on assumptions and experimentations in conjunction with the concrete facts obtained from the consultations with the Assistant manager working on Hazratganj Mini. The assumptions are as follows:

Assumption 1: *In the organization structure, only the Project manager assumes the role of PM, all the discipline heads, managers, and supervisors assume the role of SL and the members of the contractor's team assume the role of ST.*

Roles attributed to the positions play a crucial role in determining the proportions of indirect work especially rework and coordination. If the exception is generated and the responsible decision-maker is attributed to the role of PM, the decisions are usually quickly taken in the favour of reworking (ePM 2005). On the other hand, if the responsible person is attributed with ST, the decisions are usually delayed increasing the coordination work and they also tend to ignore some errors (ePM, 2005).

Having stressed the impact of roles on the duration of the project and also on the proportions of indirect work, it becomes significant that they are to be rightfully attributed. As the guidelines given by ePM (2005) advise, the role of PM is generally attributed to the project manager and SL to the discipline leads. However, considering the multi-layer hierarchy in the project team combined with the traditional client-contractor relationship, all the members of the construction team (blue-shaped positions) are attributed with SL. This shows that the members of the construction team will have a certain degree of freedom in taking decisions when it comes to handling the exception generated by the contractor's team while also maintaining the chain of command within the team.

This assumption gives space for varying the roles and assessing their impact on the duration. These experimentations are further performed in Model 3.

Assumption 2*: All the team members from layer 1 to layer 5 have a high application experience. The remaining team members have a medium experience.*

Application experience determines the processing speed of the positions owing to their experience in performing similar kinds of works (ePM, 2005). Due to the impact on the processing speed, application experience usually has a dramatic impact on the duration of the project (ePM, 2005). Not all the members of the project team will have a similar level of experience. This leaves a space for experimentation with the model. Therefore, initially, the application experience as supposed in assumption 2 is taken for Model 1 and is further experimented with within model 3.

Assumption 3*: All the team members allocate equal time to multiple projects for which they hold responsibility.*

The full-time equivalents for the positions are calculated through the organization chart of Omaxe and also through consultations with the assistant manager. The organization chart explicitly states the projects for which a position holds responsibility. Here it is assumed that the positions will allocate equal time to all their projects which might not be the case in reality. Considering the strategic needs of the company, the positions might allocate more of their time on the projects that are more rewarding which impacts not only the speed of delivering the product but also the quality. This forms the underlying principle for calculating FTEs for the project. However, this assumption also gives space for experimentation which is performed in model 3.

3.2.1.3 Environment

The environment refers to the activities and processes that are to be performed by the agents. The schedule in SimVision® is generally represented with the help of at least one task representing a process or an event and two milestones, representing the start and finish of the project. The schedule can be further populated according to the main activities and tasks involved in the project being modeled.

To successfully model the environment, an appropriate level of abstraction has to be chosen that not only represents the essence of the model but also does so with a limited number of tasks (Appendix J). After a careful analysis of the project schedule provided by Omaxe, 11 main clustered activities are identified that appropriately represent the MEP and finishing phase of Hazratganj Mini. To club the activities together, a pivot table is prepared as shown below:

Row Labels	Start Date	Finish Date
⊞ Additional Service structures	Thu 15-04-21	Tue 29-06-21
⊞ Appartment Façade	Sat 15-05-21	Fri 30-07-21
⊞ Appartment Finishing	Thu 01-04-21	Mon 30-08-21
⊞ Appartment MEP	Thu 01-04-21	Mon 16-08-21
⊞ External Finishing	Wed 16-06-21	Mon 16-08-21
⊞ External MEP	Thu 15-04-21	Sat 14-08-21
⊞ Retail Façade	Thu 15-04-21	Mon 31-05-21
⊞ Retail Finishing	Mon 12-04-21	Thu 19-08-21
⊞ Retail MEP	Thu 01-04-21	Sat 14-08-21
⊞ Commissioning and completion	Mon 02-08-21	Wed 11-08-21
⊞ Legal Handover	Thu 05-08-21	Tue 31-08-21
Grand Total		

Table 6: Pivot Table - Activity Aggregation

The clustered activities mentioned in table 6 represent the aggregate of singular activities that are to be performed to fulfill the requirements of the clustered activities. Table 6 forms the basis for modeling the environment in SimVision® as depicted in figure 15

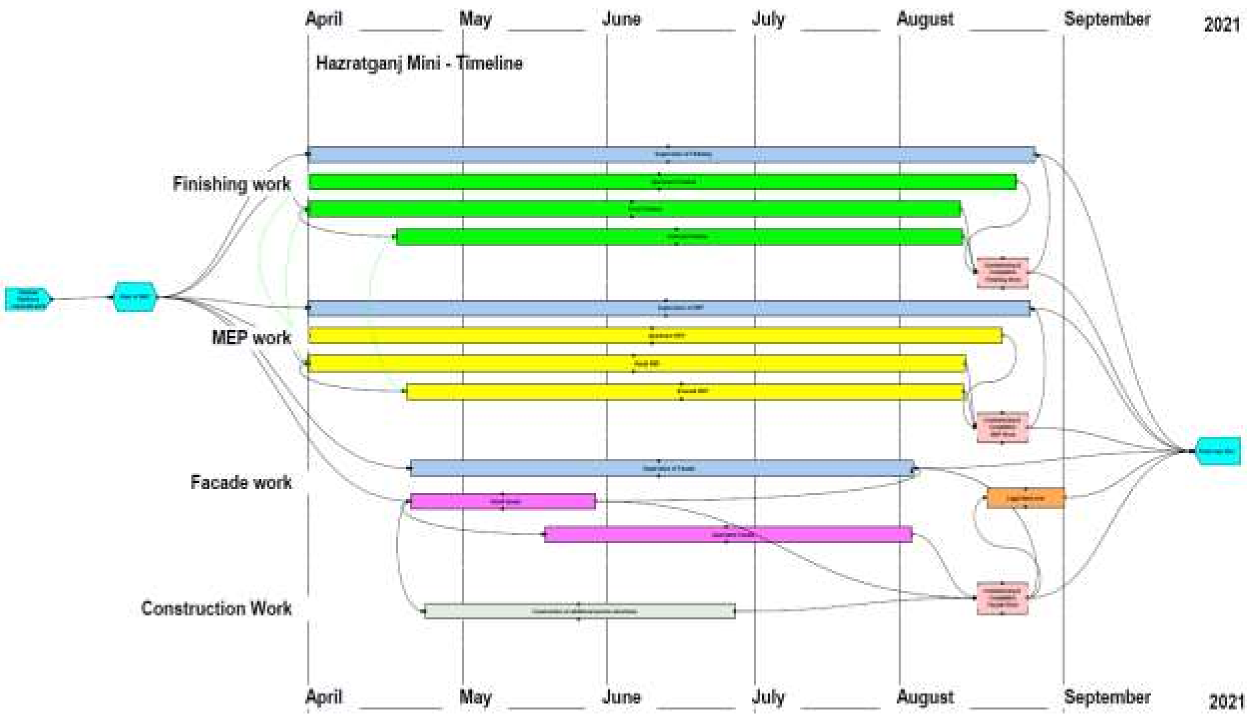


Figure 15: Activity successor-predecessor relationships

The higher resolution of the image can be found in Appendix G.3

The modeling of activities starts with identifying the major milestones of the project. For the phase under study, three main milestones are deemed necessary which are (1) Finished reinforced concrete work (2) Start of MEP phase, and (3) Finish Hazratganj Mini.

The finished reinforced concrete work represents the completion of all the construction-related work of Hazratganj Mini. This is a predecessor milestone to the beginning of the last phase of the Hazratganj mini. The next milestone i.e., the start of MEP indicates the beginning of this last phase. This milestone involves the activities related to finishes, MEP, construction of additional structures, and legal affairs related to Hazratganj Mini. Finally, the last milestone which is the Finish of Hazratganj represents the completion of the structure.

Having defined the major milestones of the project, the milestones are further populated with the activities. The milestones are linked with the aggregated activities using predecessor and successor relations thus defining the skeleton of the entire project as shown in Figure 15.

SimVision® allows defining the precedence of activities in the model using successor links. SimVision® offers three types of successor links (1) Finish-Start (2) Start-Start and (3) Finish-finish. The activities linked with the Finish-Start link indicate that the proceeding activity cannot start until the preceding activity is finished. Likewise, the Start-Start link indicates that two activities start at the same time and lastly, the Finish-Finish link indicates that the two activities finish at the same time irrespective of their starting time.

However, in reality, not all activities are executed in this systematic manner. The activities may start at sporadic times in comparison to each other and might also end at different times. To enable this flexibility in modeling, the successor link also enables to vary the start date of activities in relation to each other with the use of Lags. Lags can be introduced in the links to delay the start or finish date of the activity depending upon the type of link used. The default value of lag is set to zero but it can be changed to a positive whole number as per the requirement. Table 7 represents the successor links used in Model 1 with their properties.

Successor	Type	Lag	Units	Connected From	Connected To
1	Finish-Start	0	Days	Finished Reinforce concrete work	Start of MEP
2	Finish-Start	0	Days	Start of MEP	Supervision of Finishing
3	Finish-Start	0	Days	Start of MEP	Apartment Finishes
4	Finish-Start	0	Days	Start of MEP	Supervision of MEP
5	Finish-Start	0	Days	Start of MEP	Apartment MEP
6	Finish-Start	13	Days	Start of MEP	Supervision of Facade
7	Finish-Start	13	Days	Start of MEP	Retail facade
8	Finish-Start	0	Days	Construction of additional service structures	Comissioning & Completion Facade Work
9	Start-Start	7	Days	Apartment Finishes	Retail Finishes
10	Start-Start	48	Days	Retail Finishes	External Finishes
11	Finish-Finish	0	Days	Comissioning & Completion Finishing Work	Supervision of Finishing
12	Finish-Start	0	Days	Supervision of Finishing	Finish Haz Mini
13	Finish-Start	0	Days	Retail Finishes	Comissioning & Completion Finishing Work
14	Finish-Start	0	Days	External Finishes	Comissioning & Completion Finishing Work
15	Start-Start	0	Days	Apartment MEP	Retail MEP
16	Start-Start	11	Days	Retail MEP	External MEP
17	Finish-Finish	0	Days	Comissioning & Completion MEP Work	Supervision of MEP
18	Finish-Start	0	Days	Apartment MEP	Comissioning & Completion MEP Work
19	Finish-Start	0	Days	Retail MEP	Comissioning & Completion MEP Work
20	Finish-Start	0	Days	External MEP	Comissioning & Completion MEP Work
21	Finish-Start	0	Days	Supervision of MEP	Finish Haz Mini
22	Start-Start	26	Days	Retail facade	Apartment Facade
23	Finish-Finish	0	Days	Retail facade	Supervision of Facade
24	Finish-Finish	0	Days	Comissioning & Completion Facade Work	Supervision of Facade
25	Finish-Start	0	Days	Retail facade	Comissioning & Completion Facade Work
26	Finish-Start	0	Days	Supervision of Facade	Finish Haz Mini
27	Start-Start	0	Days	Retail facade	Construction of additional service structures
28	Finish-Start	5	Days	Apartment Facade	Comissioning & Completion Facade Work
29	Finish-Start	0	Days	Legal Hand over	Finish Haz Mini
30	Finish-Start	0	Days	Comissioning & Completion Finishing Work	Finish Haz Mini
31	Finish-Start	0	Days	Comissioning & Completion MEP Work	Finish Haz Mini
32	Finish-Start	0	Days	Comissioning & Completion Facade Work	Finish Haz Mini
33	Finish-Start	0	Days	Comissioning & Completion Facade Work	Legal Hand over
34	Finish-Start	0	Days	Apartment Finishes	Comissioning & Completion Finishing Work

Table 7: Successor link type

Task	Name	Description	Priority	Work Type	Work Value	Units	Assignment	Skills	Requirement Complexity	Solution Complexity	Uncertainty
1	Supervision of Finishing		Medium	Supervisory	1	FTEs		Generic	Medium	Medium	Medium
2	Apartment Finishes		Medium	Work Volume	884	Days		Generic	Medium	Medium	Medium
3	Retail Finishes		Medium	Work Volume	564	Days		Generic	Medium	Medium	Medium
4	External Finishes		Medium	Work Volume	256	Days		Generic	Medium	Medium	Medium
5	Supervision of MEP		Medium	Supervisory	1	FTEs		Generic	Medium	Medium	Medium
6	Apartment MEP		Medium	Work Volume	490	Days		Generic	Medium	Medium	Medium
7	Retail MEP		Medium	Work Volume	291	Days		Generic	Medium	Medium	Medium
8	External MEP		Medium	Work Volume	261	Days		Generic	Medium	Medium	Medium
9	Supervision of Facade		Medium	Supervisory	1	FTEs		Generic	Medium	Medium	Medium
10	Retail facade		Medium	Work Volume	64	Days		Generic	Medium	Medium	Medium
11	Apartment Facade		Medium	Work Volume	115	Days		Generic	Medium	Medium	Medium
12	Construction of additional service struct		Medium	Work Volume	278	Days		Generic	Medium	Medium	Medium
13	Comissioning & Completion Finishing Wo		Medium	Max Duration	5	Days		Generic	Medium	Medium	Medium
14	Comissioning & Completion MEP Work		Medium	Max Duration	5	Days		Generic	Medium	Medium	Medium
15	Comissioning & Completion Facade Wor		Medium	Work Duration	5	Days		Generic	Medium	Medium	Medium
16	Legal Hand over		Medium	Work Duration	15	Days		Generic	Medium	Medium	Medium

Table 8: Task/activity properties

Having defined the main activities and milestones of the model, the proceeding step is to characterize these tasks. As evident from Table 8 the activities are characterized by four kinds of work types – Work volume, work duration, Max duration, and supervisory.

Work volumes are used for the activities where the amount of work is fixed and its duration is inversely proportional to the number of members (positions and FTEs) working on it. Therefore, in the table above, all the activities where physical and manual work is performed on-site by the project team members are allocated with this work type. The work-volume calculator in SimVision® makes it possible to calculate the work volumes of all the activities taking into account the (in)efficiencies of the working crew. This tool requires the input of start and finish dates of activity, number of FTEs working on it, number of days in a week during which the work is done, number of hours spent each day in the job, and lastly their allocation percentage. The allocation percentage indicates the (in)efficiencies of the working crew. (In)efficiencies or allocation being a pragmatic factor is difficult to quantify. Therefore, its value is calculated through experimentation which is further discussed in detail in the next section.

Supervisory work type is allocated to the tasks which correspond to the supervision activities. As evident in Figure 15, the activities are bundled together depending upon their disciplines. For example, the finishing of apartments, finishing of retail, and external finishes share a common spatial location named Finishing activities. These bundled spaces are supervised by the discipline supervisors by the activity represented on the top of these bundles and are represented with blue boxes. These activities do not have any duration since the supervision of the activities will last till all the activities in the bundle are completed. For example, the supervision of finishes will last till the finishing of the apartment, finishing of retail and external finishes are completed. Therefore, the supervisory activities are characterized by Full-Time Equivalents (FTEs) which shows the FTE resource requirements of the supervisory task.

Both work duration and max duration are used for the tasks where the duration of the task is independent of the FTEs allocated to it. However, the main differentiating factor between them is their susceptibility and influence to indirect works. Work duration is influenced by rework and coordination work and on the other hand, the Max duration, as the name suggests is the maximum duration a task is likely to take which includes rework and coordination work. To show the versatility that SimVision® offers to model the duration of tasks, a combination of both Max duration and work duration is used in the last four activities. As visible in Figure 15 the commissioning and completion activities are divided according to the disciplines in contrast to the Pivot table visual (Table 6) which shows it as a single activity. This is done for the convenient allocation of supervisors to the commissioning and completion activities however it is made sure that the duration of activities remains parallel and more or less the same to each other. These activities are chosen to be characterized with work duration and max duration due to their low dependency upon the number of team members working on them. Completion and commissioning activities entail the testing of finished products, finalizing the remaining documents of the project, and commissioning while the legal handover activities represent the acquisition of no-objection certificates from relevant government bodies which is likely to take their own defined legal time.

Having defined the work type and work values of the activities, the proceeding step is to introduce task-specific characteristics such as priority, requirement complexity, solution complexity, and uncertainty. Since the main premises of Model 1 resides in the default nature of its system settings, the task-specific activities are kept to their default value which is medium. This also forms the basis of a major assumption made in Model 1.

Assumption 4*: All the activities defined have similar priority and equal proportions of complexity and uncertainty corresponding to their durations.*

Omaxe is a profit-seeking organization that will prioritize tasks according to the value it will generate and the effects it will have on its income. As Hazratganj Mini is one among several projects being executed in the project portfolio, it is very much possible that the project team focuses and prioritizes activities that are in other projects of the portfolio and even treats the activities in the Hazratganj mini-project differently. Similarly, the complexity and uncertainty are also subject to the nature of activities. MEP and finishing work for example might have higher complexity than façade works. This gives the space for further experimentation which is performed in Model 3.

3.2.1.4 Agent-Environment interaction

Having defined the agents represented by the organization structure of the project team and environment represented by tasks and activities of MEP and finishing phase, this section defines "*how the elements of ABM interact*".

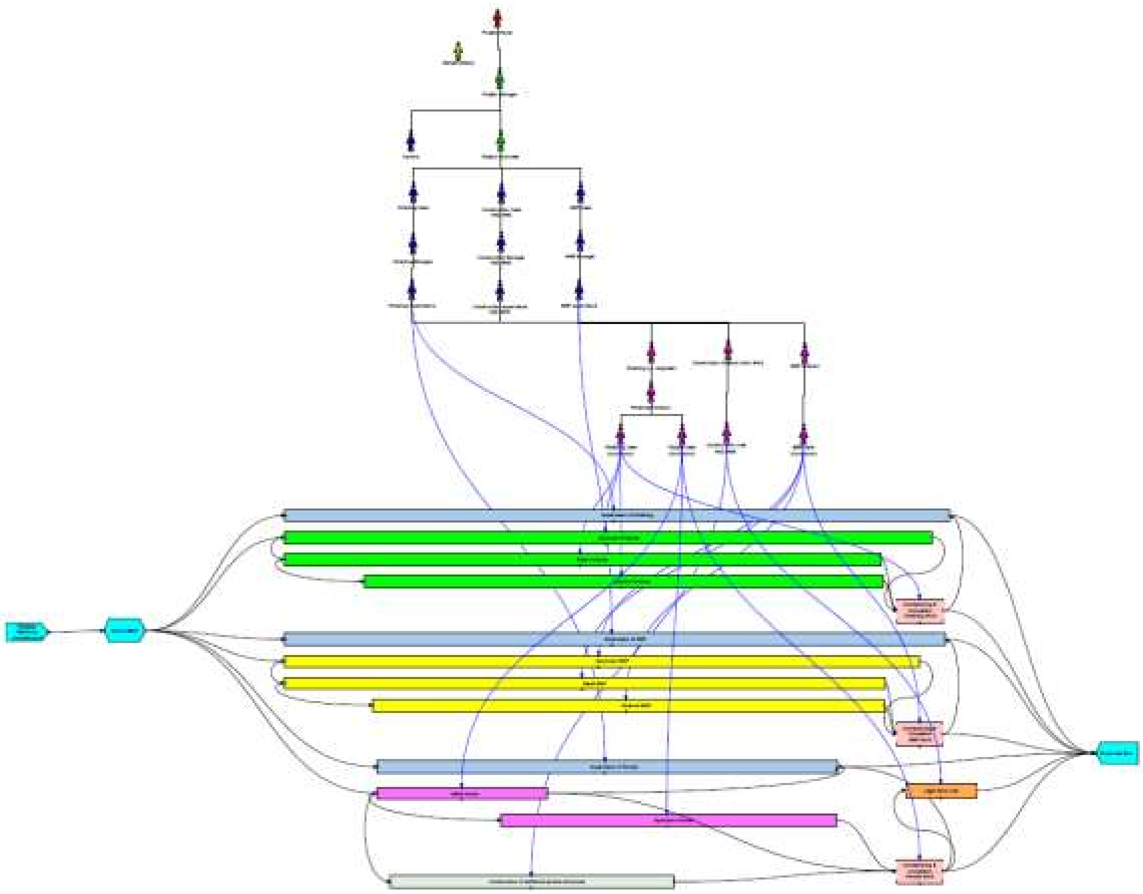


Figure 16: Agent- Environment interaction (a)

Figure 16 provides an overview of how the agents interact with their environment. Relevant positions from the project team are designated to appropriate tasks using task assignment links (blue arrows) which appropriates the positions with the primary responsibility of executing the task.

SimVision® has two kinds of task assignment links – primary task assignment link and secondary task assignment link. A task can only have one primary assignment however in the contrast, a position may have multiple primary task assignments indicating multiple responsibilities within the project. The main difference between primary task assignment and secondary task assignment is that of handling exceptions. Whenever an exception or error is encountered in an activity, the position linked with the primary task assignment is the one that handles it. Depending upon other factors, the position either reports the error to the supervisor, applies a quick fix, or ignores it.

Task assignment links also determine the amount of time a position will spend to execute a task. Using the allocation strength, the actual time spent by the position which includes the (in)efficiencies in the work process is determined. Having calculated the work-volumes of the task owing to FTEs, start and finish dates of activities, working days in a week, and working hours, the allocation is adjusted such that the finish date of the activity in SimVision® matches the finish date of the activity in schedules. Table 9 represents the allocation of primary task assignments existing between relevant positions and tasks. In addition to task assignment links, the elements of the Agent-based model in SimVision® also interact through meetings, rework links, and communication links.

Primary Assignment	Allocation	Connected From	Connected To
1	45	Finishing crew (Contractor)	Apartment Finishes
2	30	Finishing crew (Contractor)	Retail Finishes
3	30.5	Finishing crew (Contractor)	External Finishes
4	47.5	MEP crew (Contractor)	Apartment MEP
5	28	MEP crew (Contractor)	Retail MEP
6	27.5	MEP crew (Contractor)	External MEP
7	75	Construction crew HAZ. MINI	Construction of additional service structures
8	80	Finishing Supervisors	Supervision of Finishing
9	100	Finishing Supervisors	Supervision of Facade
10	100	MEP supervisors	Supervision of MEP
11	45	Facade crew (Contractor)	Retail facade
12	46	Facade crew (Contractor)	Apartment Facade
13	50	MEP crew (Contractor)	Comissioning & Completion MEP Work
14	50	Facade crew (Contractor)	Comissioning & Completion Facade Work
15	35	Finishing crew (Contractor)	Comissioning & Completion Finishing Work
16	100	Construction crew HAZ. MINI	Legal Hand over

Table 9: Position allocations

Meetings

SimVision® allows simulating the effect of meetings in terms of communication and information exchange. These meetings although reducing the number of errors being made by the positions however can result in consuming too much time, especially for the positions who are heavily occupied in project ePM (2005).

Figure 17 shows the organizational structure of the project team alongside the meetings that the positions attend. The meetings in SimVision® are depicted using pink-quadrilateral boxes. SimVision® allows to populate these meetings with participants connected through grey arrows as shown in the figure and also enables to characterize the meetings based on their priority, duration, repetitions, and start and finish times.

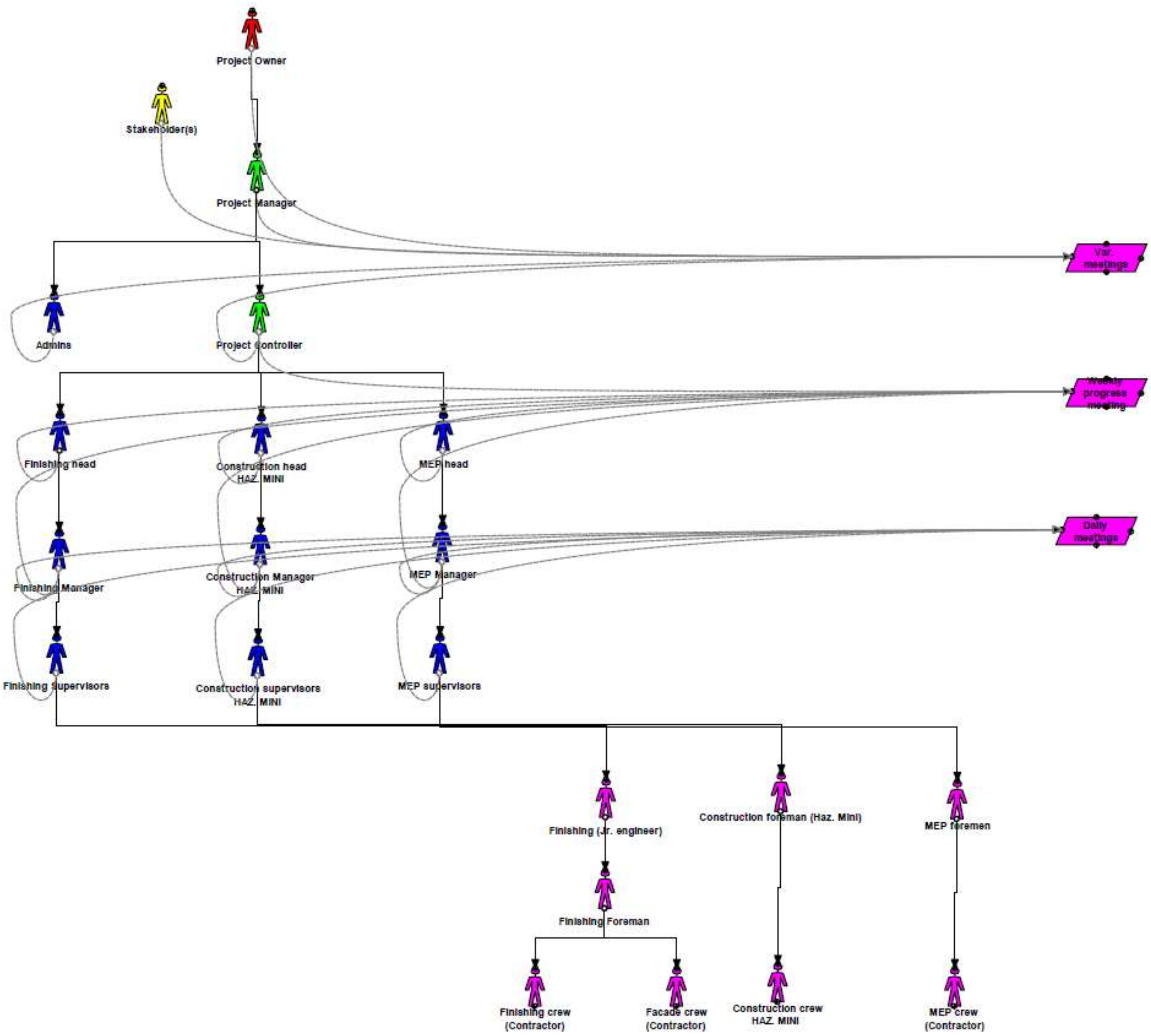


Figure 17: Hazratganj Mini Meetings (Model 1)

Table 10 depicts the properties of the meetings defined for Model 1 and Appendix J.1 tabularizes the meeting participants. The data on the meetings is collected through the semi-structured interviews conducted with the assistant manager. Based on the interviews, three major meetings are identified that relate to Hazratganj mini. A daily meeting where the debrief of daily updates and problems encountered are shared among the supervisors and discipline heads. Weekly meetings that entail the updates to the project controller from the managers and finally various meetings abbreviated as <Var. meetings> which include all the other infrequent meetings such as stakeholder meetings, change control meetings, etc. It should be noted that just like tasks and activities in the previous section, team meetings are also characterized by some assumptions. The main assumption is about bundling infrequent meetings into various meetings and defining their frequency and duration.

Name	Description	Priority	Duration	Units	Repeating	Meet Every	Units	Start Time
Weekly progress meeting		Medium	1	Hours	Yes	1	Weeks	04:00 PM
Var. meetings		Medium	2	Hours	Yes	1	Months	11:00 AM
Daily meetings		Medium	35	Minutes	Yes	1	Days	08:00 PM

Table 10: Meeting properties (Model 1)

***Assumption 5**: Various meetings on average are likely to occur once every month for two hours.*

Since various meetings include every other meeting but the daily and weekly meetings, some of the meetings may likely take longer or shorter in duration and also happen more or less frequently challenging the assumed values. This leaves space for further experimentation with these variables which is performed in Model 3.

Another assumption made in regards to the meetings is the priority of the meetings and also the participants. Owing to the default properties of Model 1, the priority of all the meetings is kept to the default value which is medium. Depending upon the urgency and requirements of meetings, the priorities will differ and so will their participants.

Assumption 6: *All the meetings are treated with equal urgency*

Positions will show a higher willingness to participate in the meetings which are more urgent to the needs of the project and on the other hand will tend to ignore the less important ones in favor of their primary work. This also renders space for the experimentation which is explored in Model 3.

Rework links

Rework links are used to indicate the interaction of tasks, more specifically a dependent and driver task in the project environment. Rework mainly displays how a dependent task will be affected if the driver task fails. The failure of the driver task will generate rework for the dependent task. The rework links are red dashed lines that are connected from the driver activity to the dependent activity as shown in figure 18. A higher resolution of the figure can be found in Appendix G.3.

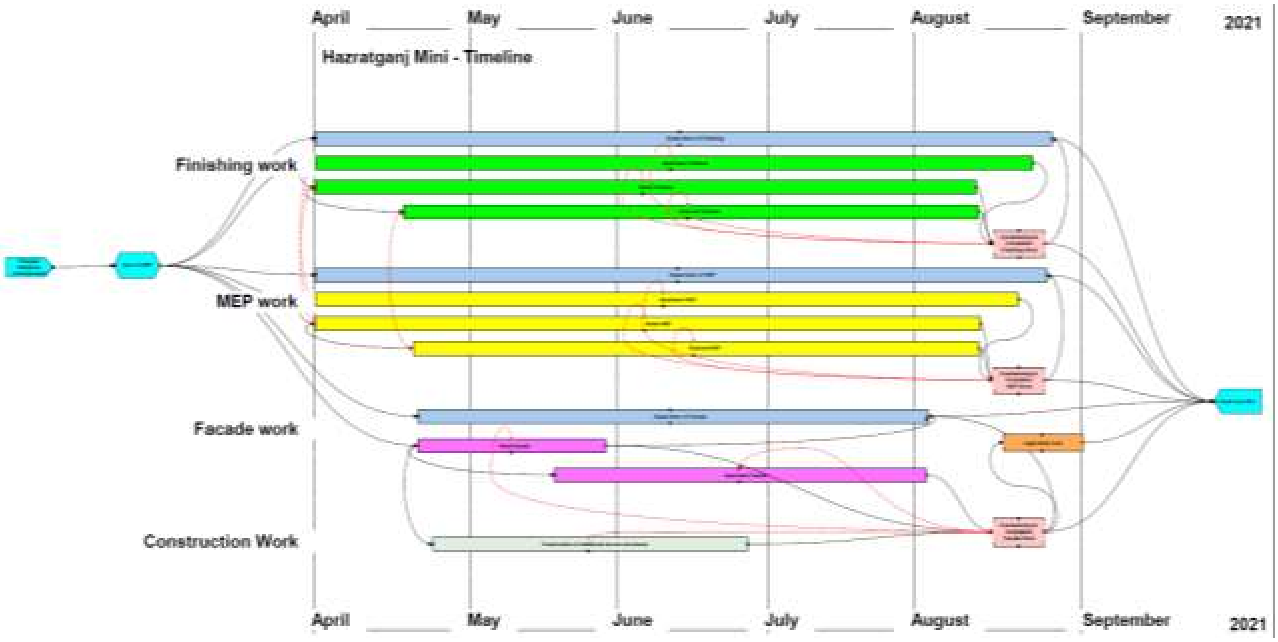


Figure 18: Rework links (Model 1)

These rework links are established based on logical reasoning, experimentation, and facts collected from the interviews. The MEP and finishing phase show considerable interdependence. Changes in MEP also produce rework in finishes due to disruptive works. For example, leaking pipes, unlinked wires, or inefficient ventilation may require rework which will also have an impact on the finishes of the units where the work is being performed. Therefore, Model 1 shows corresponding Finishing and MEP activities connected with the rework links.

Likewise, the rework links are also established between commissioning and completion activities and finishing, MEP, and façade related activities. This is due to the fact final testing is an intrinsic part of commissioning and completion which oftentimes results in small fault findings which produce rework.

The degree of rework produced among different activities will vary according to the nature and scale of the activities. For example, the amount of rework produced in Finishes activities due to disruptions caused by MEP will be higher than the minor finishing problems identified during the testing phase of commissioning and completion. To incorporate this variation of degrees, SimVision® allows to vary the strength of rework links as per the requirements.

Rework	Strength	Units	Connected From	Connected To
1	0.5	Days	Apartment MEP	Apartment Finishes
2	0.5	Days	Retail MEP	Retail Finishes
3	0.5	Days	External MEP	External Finishes
4	0.5	Days	Apartment Finishes	Comissioning & Completion Finishing Work
5	0.5	Days	Retail Finishes	Comissioning & Completion Finishing Work
6	0.5	Days	External Finishes	Comissioning & Completion Finishing Work
7	0.5	Days	Apartment MEP	Comissioning & Completion MEP Work
8	0.5	Days	Retail MEP	Comissioning & Completion MEP Work
9	0.5	Days	External MEP	Comissioning & Completion MEP Work
10	0.5	Days	Retail facade	Comissioning & Completion Facade Work
11	0.5	Days	Comissioning & Completion Facade Work	Apartment Facade
12	0.5	Days	Construction of additional service structures	Comissioning & Completion Facade Work

Table 11: Rework link settings (Model 1)

Table 11 depicts the activities connected through rework links and also the strength of these links. The strength of rework links can be established in various units and degrees. However, in Model 1, a strength of 0.5 per day is assumed for all the activities. This implies that whenever a driver task has an exception, the dependent task requires 0.5 days of rework.

Communication links

Communication links are used to indicate the added interactions that need to happen among team members wherever an interface between teams is formed. Communication links stress the additional information exchange that occurs between different positions who are performing the tasks parallel to each other and where the tasks show interdependencies. The communication links are green dashed lines that are connected between activities having interfaces as shown in figure 19. A higher resolution of the figure can be found in Appendix G.3.

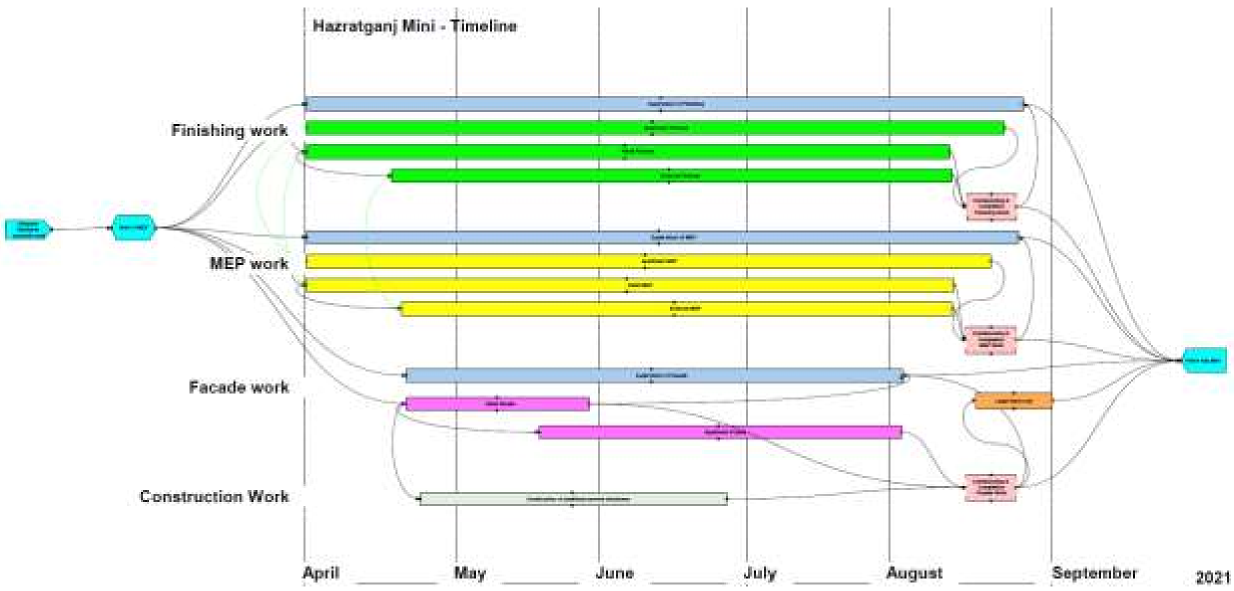


Figure 19: Communication links

As the timeline above depicts, the tasks show a high degree and need for interface management due to tasks being executed parallelly. This engenders a need for interface management where the activities are collocated. Therefore, the corresponding Finishing and MEP activities are connected using communication links.

It should be noted that the communication links are only required between activities that do require that additional communication exchange to manage the interface (ePM, 2005). Due to this reason, the amount of communication happening between different teams does not show a high variance among themselves and the communication is highly dependent on the culture of the project team. Therefore, SimVision® allows establishing the strength of communication links in a global way using information exchange probability, unlike the rework strength which has a higher degree of variance among activities. Table 12 below shows the activities connected through communication links.

Communication	Connected From	Connected To
1	Apartment Finishes	Apartment MEP
2	Retail Finishes	Retail MEP
3	External Finishes	External MEP

Table 12: Communication links settings

Having defined all the elements of Model 1, the next step is to run the model. The results display the Gantt chart representing the duration of activities. These activities are arranged according to the Work-breakdown structure which depicts the relevant activities together. Also, SimVision® offers insights based on the breakdown of works in Primary production work, rework, coordination and decision-wait.

The entire model 1 and the results obtained are depicted in the following pages.

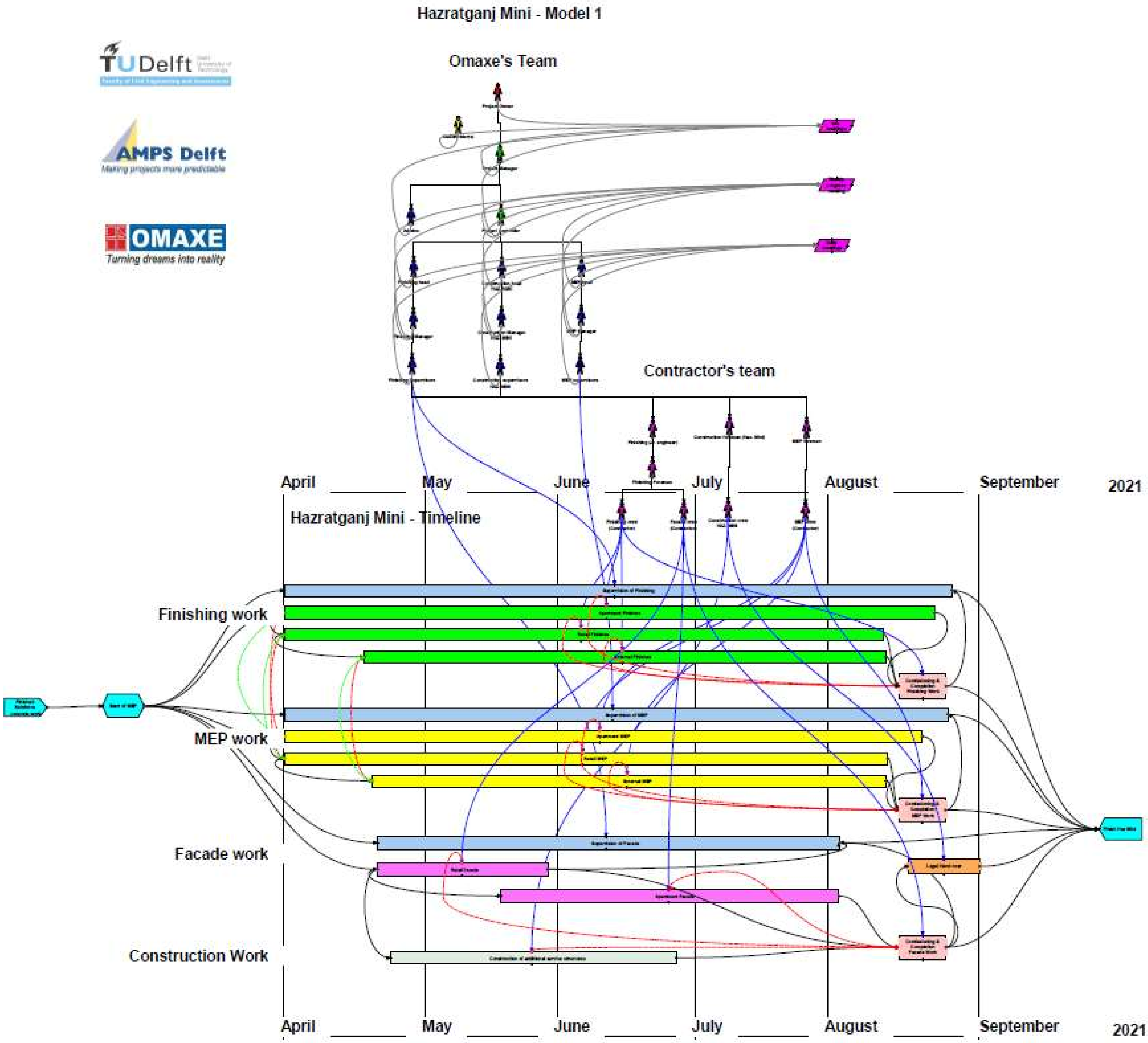


Figure 20: Model 1

Task	Duration (days)	Start	Finish
Milestone	**Sim. Date**	**Planned Date**	**CPM Date**
Meeting	*Duration*	*Start Date*	*Meeting Risk*
Start	**01-Apr-2021**	**01-Apr-2021**	
Hazratganj Mini	155.1	01-Apr-2021	03-Sep-2021
Finished Reinforce concret	**01-Apr-2021**	**01-Apr-2021**	
Weekly progress meeting	*1.00 hours*	*02-Apr-2021*	*0.30*
Var. meetings	*2.00 hours*	*01-Apr-2021*	*0.31*
Daily meetings	*35.00 minutes*	*02-Apr-2021*	*0.44*
Start of MEP	**01-Apr-2021**	**01-Apr-2021**	
Finish Haz Mini	**03-Sep-2021**	**31-Aug-2021**	
Apartment Finishes	137.1	01-Apr-2021	16-Aug-2021
Supervision of Finishing	147.1	01-Apr-2021	26-Aug-2021
Retail Finishes	129.1	12-Apr-2021	19-Aug-2021
Construction of additional servi	70.1	19-Apr-2021	28-Jun-2021
External Finishes	60.1	17-Jun-2021	16-Aug-2021
Comissioning & Completion Fi	7.0	19-Aug-2021	26-Aug-2021
Apartment MEP	134.2	01-Apr-2021	13-Aug-2021
Retail MEP	134.3	01-Apr-2021	13-Aug-2021
Supervision of MEP	144.1	01-Apr-2021	23-Aug-2021
External MEP	122.0	16-Apr-2021	16-Aug-2021
Comissioning & Completion M	7.0	16-Aug-2021	23-Aug-2021
Retail facade	39.2	19-Apr-2021	28-May-2021
Supervision of Facade	116.1	19-Apr-2021	13-Aug-2021
Apartment Facade	67.1	24-May-2021	30-Jul-2021
Comissioning & Completion F	7.0	06-Aug-2021	13-Aug-2021
Legal Hand over	21.0	13-Aug-2021	03-Sep-2021
Finish	**03-Sep-2021**	**31-Aug-2021**	
Program Gantt: Program			

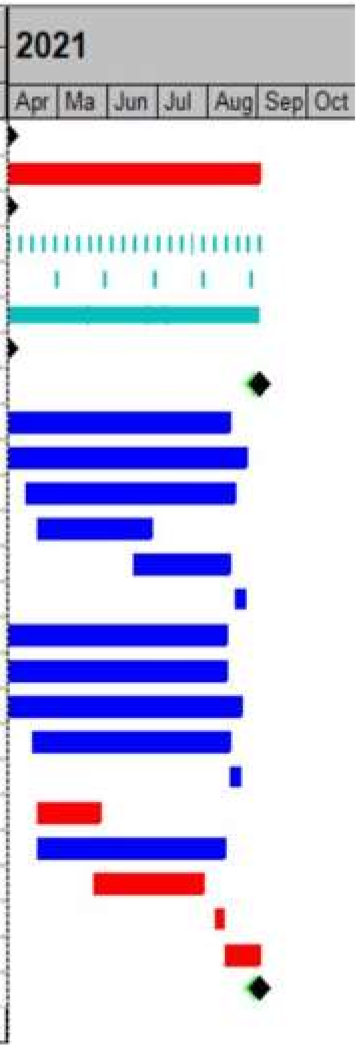


Table 13: SimVision Gantt Chart

Table 13 represents the Gantt chart for the activities modeled for this research. The first column (Task/Milestone/Meeting) represents the name of the task/activity. Simulated duration as the name suggests represents the duration of the tasks in days. Planned and CPM dates refer to the start and simulated finish dates of the activities respectively. The graphical representation on the right side of the figure above shows the duration of these activities. The Red lines represent the critical activities while the blue activities are characterized by some float (additional time for completion even if they get delayed). Green diamonds shapes on the right side of the graphical presentation refer to the user-defined or planned milestones and they are placed corresponding to their planned date. On the other hand, black diamonds refer to the simulated milestones which are a result of simulated activity duration and successor links defined in the model. As evident above, the simulated milestones (Black diamonds) more or less overlap the planned milestones (Green diamonds) which confirms the accuracy of the built model. The validity of this model is further explained in the Validation section of this chapter.

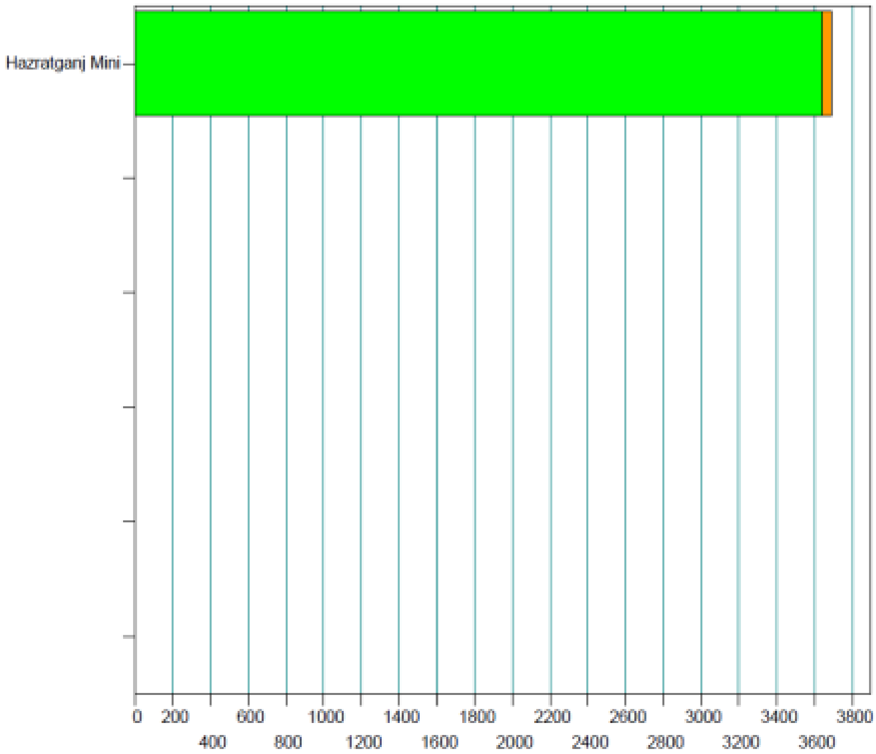


Figure 21: Work breakdown (Model 1)

Graph 21 above represents the breakdown of works. The green block is indicative of primary production work. As evident from the image above, the graph shows an almost negligible amount of indirect work (Rework, coordination, and decision work). This is due to the default characteristics of this model. This result is indicative of an ideal scenario where all the activities are performed and completed as per the plans. However, in reality, the course of action and execution may differ from plans. Therefore, the next model which is Model 2 is indicative of how the activities are executed.

3.2.2 Model 2

The main factor that differentiates Model 2 from the remaining models is the usage of *actual dates* instead of planned dates for populating the durations of activities while keeping default system settings. SimVision® allows the comparison of two different models contrasting the durations of their activities. The intention is to use Model 2 as a reference to model 1 while performing the balancing exercise explained in the next section.

Table 14 shows the comparison between the planned and actual dates of the activities obtained in consultation with the assistant manager working on the project. The table below gives two main

	Planned durations			Actual dates		
Activity	Duration (Days)	Start (DD-MM-YYYY)	Finish (DD-MM-YYYY)	Duration (Days)	Start (DD-MM-YYYY)	Finish (DD-MM-YYYY)
Apartment Finishes	129	01-04-2021	30-08-2021	238	29-03-2021	30-12-2021
Retail Finishes	117	01-04-2021	16-08-2021	213	02-04-2021	06-12-2021
External Finishes	116	01-04-2021	14-08-2021	168	28-05-2021	10-12-2021
Apartment MEP	111	11-04-2021	19-08-2021	231	16-03-2021	10-12-2021
Retail MEP	64	15-04-2021	29-06-2021	210	29-03-2021	28-11-2021
External MEP	104	15-04-2021	14-08-2021	147	10-06-2021	28-11-2021
Apartment Facade	39	15-04-2021	30-05-2021	74	15-09-2021	09-12-2021
Retail Facade	66	15-05-2021	30-07-2021	74	15-09-2021	09-12-2021
Construction of additional service structure	52	16-06-2021	15-08-2021	149	10-06-2021	30-11-2021
Commissioningand completion	9	01-08-2021	11-08-2021		Yet to Start	-
Legal Handover	23	05-08-2021	31-08-2021		Yet to Start	-

Table 14: Date comparison table

indications for the construction of Model 2. Firstly, some of the activities started before their planned dates. These include Apartment finishes, Apartment MEP, and Retail MEP. This suggests that the start dates of the milestones (Finished Reinforced Concrete and Start of MEP) and also the start date in the program settings of SimVision® are to be adjusted according to the earliest start time among these activities which is for Apartment MEP, starting on 16th March 2021.

Secondly, two activities; commissioning & completion and Legal handover at the time of consultation interview were yet to start. This implies that Model 2 is to be constructed taking into account the logical precedence of activities while keeping the durations almost identical to the planned dates.

Having identified the actual dates of the activities, the proceeding step is to construct model 2. The construction of Model 2 is derived from Model 1, keeping all the elements of the model such as activities, organization structure, links, durations, settings, etc., the same. The first change made in regards to Model 2 is to shift the start dates of milestones and program settings to 16th March 2021. In doing so, the model starts the simulation taking 16th March as the start point. The second change corresponds to changing the work type and values of activities to match the actual dates. Since Model 2 is intended to be used as a reference and the duration corresponding to activities is deterministic in nature, the work type is changed to Max duration. These activities are further attributed to work values equivalent to the working days (5 days a week) between their start and finish dates

Task	Name	Description	Priority	Work Type	Work Value	Units
1	Supervision of Finishing		Medium	Supervisory	1	FTEs
2	Apartment Finishes		Medium	Max Duration	198	Days
3	Retail Finishes		Medium	Max Duration	176	Days
4	External Finishes		Medium	Max Duration	140	Days
5	Supervision of MEP		Medium	Supervisory	1	FTEs
6	Apartment MEP		Medium	Max Duration	193	Days
7	Retail MEP		Medium	Max Duration	175	Days
8	External MEP		Medium	Max Duration	122	Days
9	Supervision of Facade		Medium	Supervisory	1	FTEs
10	Retail facade		Medium	Max Duration	61	Days
11	Apartment Facade		Medium	Max Duration	61	Days
12	Construction of additional service struct		Medium	Max Duration	123	Days
13	Comissioning & Completion Finishing Wo		Medium	Work Duration	5	Days
14	Comissioning & Completion MEP Work		Medium	Work Duration	5	Days
15	Comissioning & Completion Facade Wor		Medium	Work Duration	5	Days
16	Legal Hand over		Medium	Work Duration	15	Days

Table 15: Task properties tab (Model 2)

As evident in Table 15, the work type and work values of commissioning and completion activities and also the legal handover are kept the same as in Model 1. This is due to the undetermined start and finishes dates of the activities. Having defined the main elements of Model 2, the next step is to run the model and compare it with the actual dates. The Gantt chart shown in table 16 depicts the actual duration of activities modeled in this research. Comparing the planned and CPM dates of the Gantt chart below with the dates in Table 14 shows a more or less accurate depiction of reality in SimVision®. Thus, the model is deemed feasible for further use and comparisons.

Task	Duration (days)	Start	Finish
Milestone	**Sim. Date**	**Planned Date**	**CPM Date**
Meeting	*Duration*	*Start Date*	*Meeting Risk*
Start	**16-Mar-2021**	**16-Mar-2021**	
Hazratganj Mini	316.3	16-Mar-2021	26-Jan-2022
Finished Reinforce concrete	**16-Mar-2021**	**16-Mar-2021**	
Weekly progress meeting	*1.00 hours*	*17-Mar-2021*	*0.30*
Var. meetings	*2.00 hours*	*16-Mar-2021*	*0.30*
Daily meetings	*35.00 minutes*	*16-Mar-2021*	*0.49*
Start of MEP	**16-Mar-2021**	**16-Mar-2021**	
Apartment MEP	269.0	16-Mar-2021	10-Dec-2021
Supervision of MEP	275.3	16-Mar-2021	16-Dec-2021
Retail MEP	245.0	29-Mar-2021	29-Nov-2021
Apartment Finishes	276.0	29-Mar-2021	30-Dec-2021
Supervision of Finishing	282.2	29-Mar-2021	05-Jan-2022
Retail Finishes	248.0	02-Apr-2021	06-Dec-2021
External Finishes	196.0	28-May-2021	10-Dec-2021
External MEP	172.0	10-Jun-2021	29-Nov-2021
Construction of additional servi	173.0	10-Jun-2021	30-Nov-2021
Retail facade	85.0	15-Sep-2021	09-Dec-2021
Apartment Facade	85.0	15-Sep-2021	09-Dec-2021
Supervision of Facade	98.3	15-Sep-2021	22-Dec-2021
Comissioning & Completion M	6.3	10-Dec-2021	16-Dec-2021
Comissioning & Completion Fa	6.3	16-Dec-2021	22-Dec-2021
Comissioning & Completion Fi	6.3	30-Dec-2021	05-Jan-2022
Legal Hand over	21.0	05-Jan-2022	26-Jan-2022
Finish Haz Mini	**26-Jan-2022**	**16-Mar-2021**	
Finish	**26-Jan-2022**	**16-Mar-2021**	

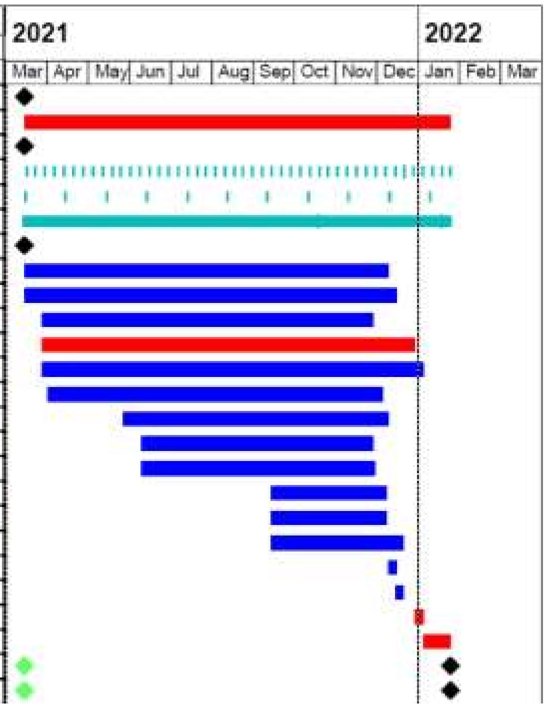


Table 16: Gantt chart (Model 2)

Similar to Model 1, the breakdown of Model 2 is also predominated by primary production work as shown in figure 22. This has the same reasoning as for Model 1; since the model is not characterized by any of the system settings, this breakdown also shows an idealistic situation.

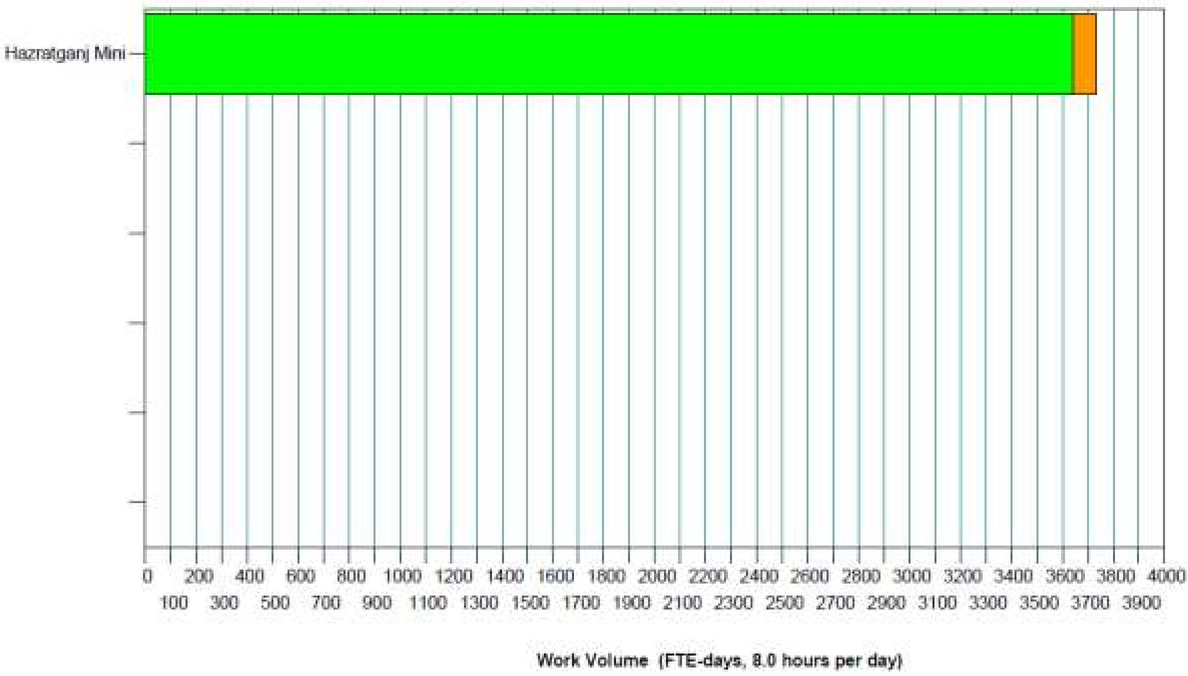


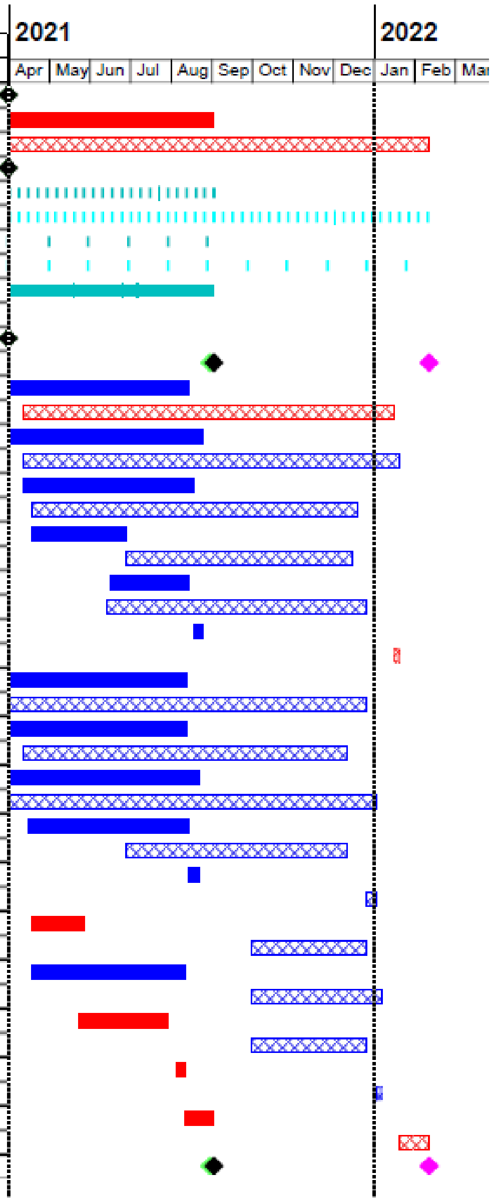
Figure 22: Work breakdown (Model 2)

3.2.3 Model 3

After creating models which represent the plans of the project (Model 1) and the reality of the project (Model 2), Model 3 reveals the actual characteristics of the project by introducing system settings. These settings are established based on logical reasoning and experimentations performed within the model. The system settings characterize different elements of the agent-based model and represent the combined reality of the project. Model 3 for this research also serves the purpose of the *Baseline model* since it mimics the existing characteristics and environment of the project and most importantly the project team.

As also explained before, SimVision® enables the users to compare two models based on their activity duration. The comparison between Model 1 and Model 2 is shown in figure 17, which forms the main point of departure for the construction of Model 3. The hard bars in the graph represent the planned duration (Model 1) corresponding to each activity whereas the hatched bars underneath it represent the actual duration (Model 2).

Task	Duration (days)	Start	Finish
Milestone	**Sim. Date**	**Planned Date**	**CPM Date**
Meeting	*Duration*	*Start Date*	*Meeting Risk*
Start	**01-Apr-2021**	**01-Apr-2021**	
Hazratganj Mini	155.1	01-Apr-2021	03-Sep-2021
	316.2	01-Apr-2021	11-Feb-2022
Finished Reinforce concrete	**01-Apr-2021**	**01-Apr-2021**	
Weekly progress meeting	*1.00 hours*	*02-Apr-2021*	*0.30*
	1.00 hours	*02-Apr-2021*	*0.30*
Var. meetings	*2.00 hours*	*01-Apr-2021*	*0.30*
	2.00 hours	*01-Apr-2021*	*0.30*
Daily meetings	*35.00 minutes*	*02-Apr-2021*	*0.44*
	35.00 minutes	*01-Apr-2021*	*0.49*
Start of MEP	**01-Apr-2021**	**01-Apr-2021**	
Finish Haz Mini	**03-Sep-2021**	**31-Aug-2021**	
Apartment Finishes	137.1	01-Apr-2021	16-Aug-2021
	280.0	12-Apr-2021	17-Jan-2022
Supervision of Finishing	147.1	01-Apr-2021	26-Aug-2021
	284.2	12-Apr-2021	21-Jan-2022
Retail Finishes	129.1	12-Apr-2021	19-Aug-2021
	245.0	19-Apr-2021	20-Dec-2021
Construction of additional servi	70.1	19-Apr-2021	28-Jun-2021
	171.0	28-Jun-2021	16-Dec-2021
External Finishes	60.1	17-Jun-2021	16-Aug-2021
	196.0	14-Jun-2021	27-Dec-2021
Comissioning & Completion Fi	7.0	19-Aug-2021	26-Aug-2021
	4.2	17-Jan-2022	21-Jan-2022
Apartment MEP	134.2	01-Apr-2021	13-Aug-2021
	270.0	01-Apr-2021	27-Dec-2021
Retail MEP	134.3	01-Apr-2021	13-Aug-2021
	245.0	12-Apr-2021	13-Dec-2021
Supervision of MEP	144.1	01-Apr-2021	23-Aug-2021
	277.3	01-Apr-2021	03-Jan-2022
External MEP	122.0	16-Apr-2021	16-Aug-2021
	168.0	28-Jun-2021	13-Dec-2021
Comissioning & Completion M	7.0	16-Aug-2021	23-Aug-2021
	7.3	27-Dec-2021	03-Jan-2022
Retail facade	39.2	19-Apr-2021	28-May-2021
	87.0	01-Oct-2021	27-Dec-2021
Supervision of Facade	116.1	19-Apr-2021	13-Aug-2021
	98.3	01-Oct-2021	07-Jan-2022
Apartment Facade	67.1	24-May-2021	30-Jul-2021
	87.0	01-Oct-2021	27-Dec-2021
Comissioning & Completion Fa	7.0	06-Aug-2021	13-Aug-2021
	4.3	03-Jan-2022	07-Jan-2022
Legal Hand over	21.0	13-Aug-2021	03-Sep-2021
	21.0	21-Jan-2022	11-Feb-2022
Finish	**03-Sep-2021**	**31-Aug-2021**	



ogram Gantt: Program (Compare to: Model 2)

Table 17: Activity comparison (Model 1 and Model 2)

Model 3 is the end product of a balancing exercise performed between Model 1 and Model 2. To elaborate, changes and system settings are to be introduced in Model 1 in such a way that they are logically justified and the activity durations of the balanced Model (Model 3) more or less match with the activity durations of Model 2.

For simplicity and better understanding, the changes and system settings introduced during the construction of Model 3 are explained using a similar chronology followed for the explanation of the construction of Model 1 i.e., by segregating the model into (1) Agents, (2) Environment (3) Agent-environment interaction. This will enable a better connection between the elements of Model 1 and Model 3 and will also systematically cover all the changes made during the balancing exercise.

3.2.3.1 System settings

The construction of Model 3 begins with copying/ replicating the existing Model 1. As can be seen in the comparison above, some activities start earlier than planned. This means the starting date in Model 3 is to be adjusted according to the earliest start time among these activities, since the start date in the replicated model corresponds to 1st April 2021.

Program	Value	Units
Name	Program	
Description		
Start Date	16/Mar/2021	
Trials	1000	
Seed	0	
WBS Separator	.	
WBS	0.0	
Calendar	Edit...	
Team Experience	High	
Centralization	High	
Formalization	Low	
Matrix Strength	Medium	
Info Exchange Prob.	0.8	
Noise Prob.	0.1	
Functional Error Prob.	0.1	
Project Error Prob.	0.1	
Behavior File	Default	
Revisions	Edit...	
Escalators	Edit...	
Hyperlinks	Edit...	

Project	Value	Units
Name	Hazrat	
Description	MEP an	
Priority	Low	
Work Day	8	☐
Work Week	5	☐
Team Experience	High	☐
Centralization	High	☐
Formalization	Low	☐
Matrix Strength	Medium	☐
Info Exchange Prob.	0.8	☐
Noise Prob.	0.1	☐
Functional Error Prob.	0.1	☐
Project Error Prob.	0.1	☐
Fixed Cost	0	
Fixed Revenue	0	
Cost Rate	0	Days
Revenue Rate	0	Days
Actual Cost	0	
Actual Revenue	0	
WBS		
Chart Color		
Categories	Edit...	
Business Drivers	Edit...	
Revisions	Edit...	
Escalators	Edit...	☑
Hyperlinks	Edit...	

Table 18: (a) Program tab (b) Project tab - Model 3

As can be seen in the Program setting Table 18a and project setting Table 18b the start date of the project is set to 16th March 2021 which corresponds to the starting date of Apartment MEP which starts the earliest among the list of activities being modeled. In doing so, SimVision® will start the simulations taking 16th March 2021 as the starting point.

In addition to this, the characteristics of the project team are also introduced in terms of Team experience, Centralisation. Formalization, Matrix strength, and various probabilities.

Team experience as defined in ePM (2005) refers to how successfully the team has previously delivered similar projects. Omaxe due to its specialty in delivering integrated township projects already possesses significant experience in the field. Moreover, through interviews, it is confirmed that the vast majority of the project team working on Hazratganj Mini was relocated from a similar township-related project. Thus, the team experience is characterized as High in the given model.

Centralization indicates the extent to which the exception-handling and decision-making responsibilities reside with the upper hierarchy or senior management of the company ePM (2005). Looking at the number of decision-making layers shown in the organizational structure of the project team (Figure 14) and also through the interviews conducted, the centralization is deemed to be High. It is found that the majority of the decisions in the company are taken by the senior management and are executed by managers and supervisors.

Formalization is an indicator of how formally or informally the communication exchange takes place among team members of the company. Owing to the working culture of the company, where most of the communications happen in the form of informal conversations and only a few communications require formal presence, the formalization in the model is set to Low.

Matrix strength gauges the collocation of team members; if a team member operates in a skill-based functional department and thus is directly being supervised by a functional manager or if they operate within a team having diverse skillset meant for specialized projects and being supervised by the project manager (ePM, 2005). Matrix strength also gauges the connectedness of the team members. Meaning, that if the team members are geographically placed farther or closer to each other. As visible through the organizational structure of the project team (Figure 14) the structure brings a mix of both function-based and Project-based placement of team members. The discipline heads act as the functional supervisor for their corresponding team however at the same time, the crucial decisions are made by the project controller and project manager. Therefore, the matrix strength is set to medium. Referring to the second definition of Matrix strength, the project team members also show a mix of geographical placement within the project team. The project owner mostly operates from the Headquarters of the company. While the construction team working on the project is also divided between the members who work on-site and the members who are mostly located in the offices. Therefore, this further strengthens the choice of medium matrix strength.

Having defined the team characteristics using the pragmatic parameters, the next step is to define probabilities that characterize the environment of a project. These probabilities are a result of experimentations performed in the model alongside the guidelines of (ePM, 2005).

Information exchange probability defines the amount of communication occurring across the tasks connected with the communication link. The guidelines suggest a range of 0.2 to 0.9 for the probability where a lower probability is to be set for the projects having lower interdependency among tasks and the tasks corresponding to routine jobs (ePM, 2005). On the other hand, a higher probability is recommended to be set for the projects which have a high degree of interdependency. Since the whole premises of the chosen case study rests on the foundation of dependency which is not only limited to activities within one project but also the activities of other projects, the information exchange probability for the case is set to 0.8.

Noise is another probability that is an indicator of the number of external disturbances caused in an ordinary working day. This is a qualitative factor that is hard to accurately quantify. The guidelines suggest this probability varies in the range of 0.01 (low) to 0.1 (significant but common) (ePM, 2005). Therefore, the probability is set to 0.1. Also considering the low formalization within the company, it should be plausible to assume that the noise can be expected to be on the higher side.

Functional error probability expresses the chance that a task will fail and require rework. It should be noted that this probability only expresses the localized failures giving rise to rework in the same task and not affecting the dependent tasks. Although the guidelines prescribe that the probability is typically set between the ranges of 0.05 to 0.1 (ePM, 2005), even a higher probability can be set for the projects involving highly innovative work or unproven technology. In consultation with the assistant manager, it was found that a separate team within the organization structure is continuously deployed to work on reworks. Therefore, a higher end of the typical range i.e., 0.1 is chosen for functional error probability.

Lastly, the project error probability refers to the chance that a task will fail and produce rework for all the tasks connected to it with a rework link. The guidelines suggest that the range of project error probability ranges between 0.05 (low) to 0.1 (significant but common) and an even higher probability can be used in projects involving nonstandard or innovative tasks (ePM, 2005). In light of the explanation given for Functional error probability, the project error probability is also set to 0.1. It should be noted that these probabilities are also experimented with in the model such that the final activity durations of Model 3 match the activity durations of Model 1.

3.2.3.2 Agents

Having established the system settings of the project, the next step is to characterize positions in the project team.

Position	Name	Description	Role	Application Experience	FTE	Salary	Work Day	🔒	Work Week	🔒
1	Project Controller		SL	High	1	0	8	☑	5	☑
2	Finishing head		ST	High	1	0	8	☑	5	☑
3	Finishing Supervisors		ST	Medium	2	0	8	☑	5	☑
4	Finishing crew (Contractor)		ST	Low	20	0	8	☑	5	☑
5	Construction head HAZ. MINI		ST	High	1	0	8	☑	5	☑
6	Construction Manager HAZ. MINI		ST	Medium	1	0	8	☑	5	☑
7	Construction supervisors HAZ. MINI		ST	Medium	1	0	8	☑	5	☑
8	Construction crew HAZ. MINI		ST	Low	7	0	8	☑	5	☑
9	MEP head		ST	High	1	0	8	☑	5	☑
10	MEP Manager		ST	Medium	1	0	8	☑	5	☑
11	MEP supervisors		ST	Medium	1	0	8	☑	5	☑
12	MEP crew (Contractor)		ST	Low	11	0	8	☑	5	☑
13	Project Manager		PM	High	1	0	8	☑	5	☑
14	Project Owner		ST	High	1	0	8	☑	5	☑
15	Stakeholder(s)		ST	Medium	2	0	8	☑	5	☑
16	Admins		ST	High	2.5	0	8	☑	5	☑
17	Finishing Foreman		ST	Medium	1	0	8	☑	5	☑
18	Construction foreman (Haz. Mini)		ST	Medium	1	0	8	☑	5	☑
19	MEP foremen		ST	Medium	1	0	8	☑	5	☑
20	Finishing Manager		ST	Medium	1	0	8	☑	5	☑
21	Facade crew (Contractor)		ST	Medium	5	0	8	☑	5	☑
22	Finishing (Jr. engineer)		ST	Medium	1	0	8	☑	5	☑

Table 19: Position properties (Model 3)

In comparing Table 5 with Table 19 some of the major changes can be easily identified. First, the FTEs of some of the positions are changed from a fractional value to a whole number. For example, the FTE of the Project manager and Project controller was initially established to be 0.25 however it is changed to 1. The fractional FTE was intended to show the shared responsibility of these positions over other tasks. However, in the final model – Model 3, an additional task is added to the list of tasks which represents the work of all the other projects in the portfolio (explained in the next section). The project team is allocated to this task to show their responsibility with other projects. Therefore, the FTEs of this project team now correspond to the actual number of members aggregated together in a position.

The second major change that can be noticed is the introduction of application experience. Application experience is a measure of how much a position is experienced with a similar kind of work. The guidelines define High application experience of the positions meaning that the position has frequently performed this kind of task, medium application experience meaning that the position has some experience with this kind of job, and Low experience implying that the position has low or no experience with the kind of task.

The application experience of the positions in this model is based on experimentation, logical reasoning, and assumptions. It is intuitive that the positions working as top management in a project team also have a higher experience, the middle management having medium experience and the workforce having medium to low experience.

***Assumption** 7:* The top management of the project team exhibits higher experience; middle management exhibits medium to experience and the workforce exhibits medium to low experience.

This assumption is attributed to the organization structure in the following way: The top management which comprises the owner, project manager, project controller, admins, and discipline heads has high application experience. The middle management which includes discipline managers and supervisors has a medium application experience and the workforce which comprises a junior engineer, discipline foremen and crew has medium to low experience.

3.2.3.3 Environment

Similar to the positions characterized in the sub-section before, the environment of the project is also attributed with characteristics by introducing system settings in the tasks involved.

Milestone	Name	Description	Type	Planned Date
1	Start of MEP		Relative	Finished Reinforce concrete work
2	Finished Reinforce concrete work		Absolute	16/Mar/2021
3	Finish Haz Mini		Relative	Start of MEP

Table 20: Milestone properties (Model 3)

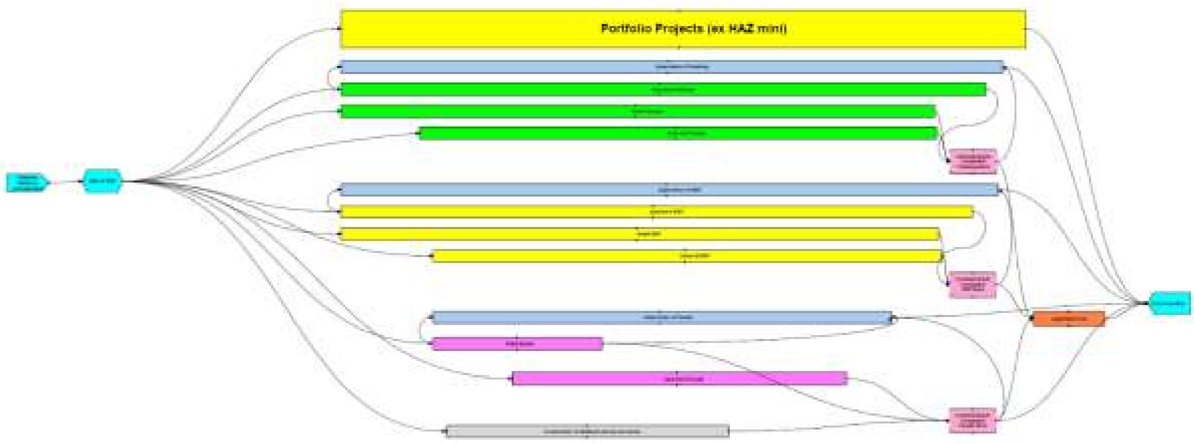


Figure 23: Task/activities - Model 3

To begin with, the starting date of the milestone – Finished Reinforced Concrete work is shifted to 16th March 2021 which corresponds to the starting date mentioned in the program and project setting tabs (table 20). This ensures that the placement of milestones in the Gantt chart formed in simulated space corresponds to the correct position. Additionally, for milestones – Start of MEP and Finish Haz Mini, the type of milestone is changed to the relative. This means that instead of following an absolute date, these milestones will be adjusted according to the successor relations defined in the tasks. This is done for the ease of comparison between Model 3 and Model 2 while performing the balancing exercise.

In addition to milestones, changes are introduced in tasks as well (Figure 24). Firstly, a new task is added to the list of tasks named – *Portfolio Projects (ex Haz mini)* which indicates the work that is to be done in parallel to Hazratganj Mini and relates to other projects in the portfolio. This task is to show the added responsibility of the project team to other tasks within the portfolio. This task is characterized by a Work duration of 20 weeks which corresponds to the number of weeks between the planned start and planned finish date i.e., between 1st April 2021 and 30 August 2021 (Table 21).

The tasks in Model 3 are characterized using four main settings – Priority, requirement complexity, solution complexity, and uncertainty. Priority, as explained in the guidelines given by ePM (2005) indicates how the positions prioritize tasks that occur simultaneously. The priority can be attributed as either High, Medium, or Low depending on the relative importance of tasks defined in the project environment. As evident from Table 24, all the activities except portfolio projects (ex Haz mini) and supervision tasks are characterized by Low priority. This is because Hazratganj mini formulates only 0.9% of the total budget of the portfolio. Keeping in view that Omaxe is a profit-seeking organization, it is plausible to assume that they would prioritize other tasks in the project portfolio more than the tasks

Name	Description	Priority	Work Type	Work Value	Units	Assignment	Skills	Requirement Complexity	Solution Complexity	Uncertainty
Supervision of Finishing		Medium	Supervisory	1	FTEs		Generic	Low	Low	Low
Apartment Finishes		Low	Work Volume	864	Days		Generic	High	Low	High
Retail Finishes		Medium	Work Volume	564	Days		Generic	High	Low	High
External Finishes		Low	Work Volume	258	Days		Generic	Medium	Medium	Medium
Supervision of MEP		Medium	Supervisory	1	FTEs		Generic	Low	Low	Low
Apartment MEP		Low	Work Volume	490	Days		Generic	High	High	High
Retail MEP		Medium	Work Volume	291	Days		Generic	High	High	High
External MEP		High	Work Volume	261	Days		Generic	Low	Low	Low
Supervision of Facade		Medium	Supervisory	1	FTEs		Generic	Low	Low	Low
Retail facade		Low	Work Volume	64	Days		Generic	Medium	Low	High
Apartment Facade		Low	Work Volume	110	Days		Generic	Medium	Low	High
Construction of additional service struct		Low	Work Volume	270	Days		Generic	Low	Low	Low
Comissioning & Completion Finishing Wo		Low	Work Duration	5	Days		Generic	Low	Low	Low
Comissioning & Completion MEP Work		Low	Work Duration	5	Days		Generic	Low	Low	Low
Comissioning & Completion Facade Wor		Low	Work Duration	5	Days		Generic	Low	Low	Low
Legal Hand over		Low	Work Duration	15	Days		Generic	Low	Low	Low
Portfolio Projects (ex HAZ mini)		High	Work Duration	20	Weeks		Generic	Medium	Low	High

Table 21: Task/ activities properties (Model 3)

in Hazratganj Mini. This is also shown by attributing High priority to portfolio projects (ex Haz mini). Supervision of tasks is however kept to medium priority. This is because the working crew hired from the contractor still needs the supervision and expertise of Omaxe to work and execute the tasks according to plans which adds some urgency to the supervision of tasks.

Requirement complexity refers to the internal project requirements which a task/activity needs to satisfy. Similar to priority, the requirement complexity can also be attributed as either High, Medium, or Low and directly affects the functional error probability related to a task. The determination of requirement complexity for the tasks in this model is mostly done through experimentations and logical reasoning. The requirement complexity of the activities is set such that the activity durations in Model 3 match more or less with the activity durations of Model 2.

Looking at table 21, it can be identified that the finishing and MEP activities for both, apartments and retail play a critical role. Comparing these activities to other tasks such as the construction of a façade, construction of additional service structures, etc., it is logical to assume that finishing and MEP activities will have much higher internal requirements. Therefore, the required complexity of MEP and finishing activities corresponding to apartment and retail is kept high. Next in the level of complexity and internal requirements comes activities like external finishing and façade work. These activities compared to the activities such as commissioning and completion, supervision of work, etc., will have a higher degree of internal requirements. Therefore, the required complexity of these activities is kept to be Medium. In addition to these activities, it can be noticed that the required complexity of Portfolio projects (ex Haz mini) is also kept medium. It should be noted that the requirement complexity in this model is also treated based on how aggregated or disaggregated the activities are to each other. Since Portfolio Projects (ex Haz mini) represent traditional activities to be carried out in parallel to the activities of Hazratganj mini, these additional activities may include some activities that rate high on requirement complexity, and others may rate medium or low on requirement complexity. However, on an aggregate level, the types of work being performed are highly traditional therefore the required complexity is deemed to be medium.

And lastly, the remaining activities which include legal handovers, commissioning and completion, construction of additional service structures, and also supervision activities are kept low on requirement complexity due to their highly traditional type of work.

Another type of complexity that SimVision® allows to model is the solution complexity. Solution complexity refers to the number of solutions to which a task contributes. If a task is critical as a solution to other tasks, its failure will also influence the course of those dependent tasks. Therefore, contrary to requirement complexity, the solution complexity affects the project error probability related to projects. Similar to requirement complexity, the determination of solution complexity also followed the experimental and logical reasoning pathway. As evident from figure 24 and table 21, the tasks show almost independent relations amongst themselves. Therefore, most of the tasks are characterized by Low solution complexity. Conversely, it can be seen that MEP activities for both apartments and retail show a high solution complexity. This is because of a dependency that is created between finishing works and MEP. MEP reworks can be disruptive in nature, for example, fixing a leak in the pipes, or installing a new electrical duct. Doing such activities also affects finishing works and causes additional work to be done. In addition to cross-discipline dependency, the MEP works are also characterized by internal dependencies. For example, the plumbing lines (sewage lines or water lines) are attached between different units. For example, the plumbing lines from apartments have to be attached to the plumbing lines from retail which are finally connected to the plumbing lines of the city. This also forms the main reason for attributing apartment and retail MEP with high solution complexity. In addition to this, it can be seen in Table 21 that external finishes are also attributed to medium solution complexity. This is because external finishes also include the leveling of land on which the additional service structure is built. Therefore, this gives rise to the dependency between the construction of additional service structures and external finishes. Hence a medium solution complexity is kept for external finishes.

The last aspect that characterizes the tasks in this model is uncertainty. The guidelines by ePM (2005) define uncertainty as the amount of communication that is required across communication links to a performed task. As can be seen from Table 21, the activities of the construction of Hazratganj minis such as apartment and retail finishes, apartment and retail MEP, and façades are attributed to High uncertainty. This is due to uncertainty rising due to the shared responsibility of project teams with other projects. Since the project teams are likely to favor the projects which result in immediate and higher rewards, additional communication is likely to arise in the construction activities related to Hazratganj Mini. These communications will be bi-directional; In addition to affecting the activities in Hazratganj mini, they will also affect the activities in other projects. Therefore, the uncertainty of Portfolio projects (ex Haz mini) is also kept high.

In addition to the constructional components, external finishes also play an integral role in the development of Hazratganj Mini. However, its criticality to Hazratganj mini is assumed to be lower compared to constructional components which engender lower additional communication. Therefore, a medium uncertainty is proposed. The remaining tasks correspond to supervision or legal related affairs which are more or less regular and traditional in nature and are to be performed as per the directions of senior management. Therefore, the uncertainty is kept low.

3.2.3.4 Agent-environment interaction

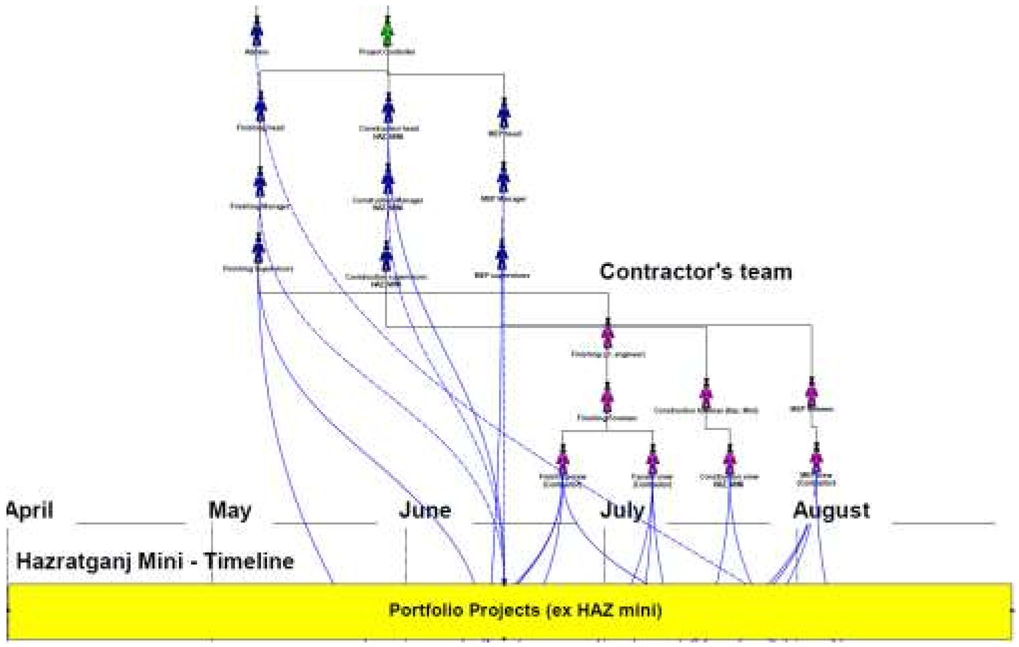


Figure 24: Agent interaction with new activity

Primary Assignment	Allocation	Connected From	Connected To
1	45	Finishing crew (Contractor)	Apartment Finishes
2	30	Finishing crew (Contractor)	Retail Finishes
3	30.5	Finishing crew (Contractor)	External Finishes
4	47.5	MEP crew (Contractor)	Not Connected
5	28	MEP crew (Contractor)	Retail MEP
6	27.5	MEP crew (Contractor)	External MEP
7	75	Construction crew HAZ MINI	Construction of additional service structures
8	30	Finishing Supervisors	Supervision of Finishing
9	30	Finishing Supervisors	Supervision of Facade
10	30	MEP supervisors	Supervision of MEP
11	45	Facade crew (Contractor)	Retail facade
12	46	Facade crew (Contractor)	Apartment Facade
13	50	MEP crew (Contractor)	Comissioning & Completion MEP Work
14	50	Facade crew (Contractor)	Comissioning & Completion Facade Work
15	35	Finishing crew (Contractor)	Comissioning & Completion Finishing Work
16	20	Construction crew HAZ MINI	Legal Hand over
17	100	Construction head HAZ MINI	Portfolio Projects (ex HAZ mini)

Table 22: Primary allocation (Model 3)

Sec. Assignment	Allocation	Connected From	Connected To
1	25	Admins	Legal Hand over
2	100	Finishing Manager	Portfolio Projects (ex HAZ mini)
3	100	Construction Manager HAZ MINI	Portfolio Projects (ex HAZ mini)
4	100	MEP Manager	Portfolio Projects (ex HAZ mini)

Table 23: Secondary allocation (Model 3)

Just like agents and their environment are individually characterized with properties, their interaction with each other also offers significant flexibility in terms of their behavior with the introduction of system settings. With the introduction of the new task – Portfolio projects (ex Haz mini), new primary and secondary assignments are also introduced.

As evident in Figure 25 and also through Table 22 the construction head of Hazratganj mini is allocated to Portfolio Projects (ex Haz mini) through a primary task assignment link (blue arrows) indicating the added responsibility of the construction head in other projects. In addition to that, the discipline managers which include the finishing manager, construction manager (Haz mini), and MEP manager are also allocated to Portfolio Projects (ex Haz mini) using secondary task assignment links (Bluedotted arrows) as evident in Figure 25 and Table 23. It can be seen from the tables above that the positions; of construction, head Haz mini, Finishing manager, construction manager (Haz. Mini), and MEP manager are attributed with 100% allocation. This is meant to show their over-allocation to other projects in the portfolio owing to the higher urgency of other projects due to profit optimizations.

In addition to the new links introduced above, another secondary link is introduced connecting Admins to the legal handovers. After confirming the role of admins with the assistant manager, the admins are allocated to Legal handovers with a secondary task assignment link. The admins are responsible for applying and obtaining relevant certificates from the government before the building can be publicly operational. In the drafts of the application, several parameters and quality checks of the building has to be theoretically conveyed to the government. These markers are obtained and quantified through on-site surveys conducted by the construction crew and under the needs and supervision of Admins. Therefore, the construction crew is allocated with the primary task assignment link.

Having discussed the new task assignment links, the agent-agent interaction is also further experimented with through meetings. As can be seen in figure 26, new meetings are created adjacent to the previously existing meetings.

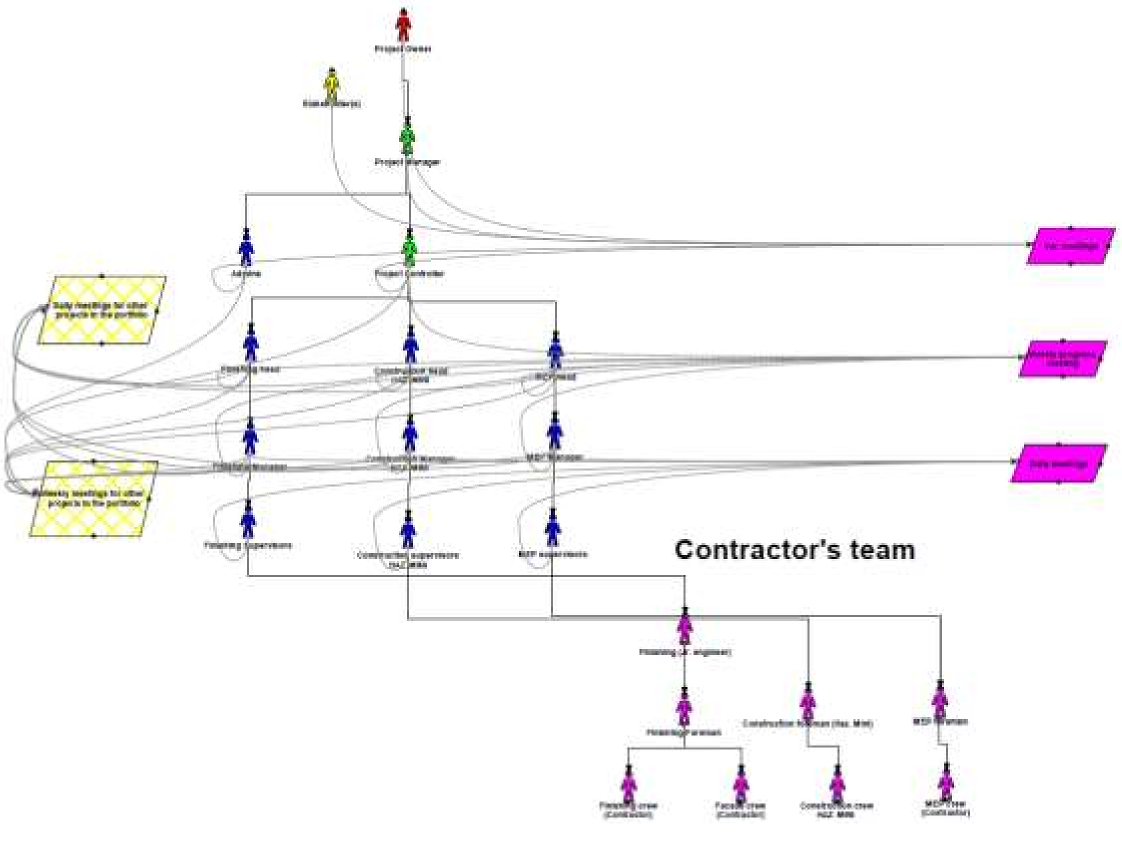


Figure 25: Meetings (Model 3)

Meeting	Name	Description	Priority	Duration	Units	Repeating	Meet Every	Units
1	Weekly progress meeting		Low	1	Hours	Yes	1	Weeks
2	Var. meetings		High	1	Hours	Yes	1	Months
3	Daily meetings		Low	35	Minutes	Yes	1	Days
4	Daily meetings for other projects in the	Daily management meetings pertaining t	High	3	Hours	Yes	1	Days
5	Weekly meetings for other projects in th	Weekly management meetings pertainin	High	3	Hours	Yes	1	Weeks

Table 24: Meeting properties

Since the entire premises and uniqueness of this case lie in the shared responsibilities of the project team over multiple projects, this behavior is also expressed in this model through Meetings. The meetings shown with Pink-quadrilateral shapes are the meetings of Hazratganj Mini while two new meetings named "daily meetings for other projects in the portfolio" and "weekly meetings for other projects in the portfolio" (Figure 26) indicate those additional meetings occurring daily and weekly respectively that the members of construction team attend in regards to other projects in the portfolio.

In addition to introducing new meetings, the meetings are also characterized by priorities. Considering a small budget allocation to Hazratganj mini (0.9%) in comparison to other projects in the portfolio, it is plausible that the project teams would give higher priorities to the tasks and engagements of other projects. Therefore, the daily meetings and weekly meetings of Hazratganj mini are attributed with low priority. This would impact if the meeting participant would attend the meeting given their other tasks. On the other hand, the meetings of other projects in the portfolio will receive higher attention and engagement from the project team members therefore the priority is set High. It can also be seen that the Various meetings of Hazratganj mini are attributed with High priority. This is because these various meetings include crucial decision-making meets such as stakeholder meetings, change control meetings, etc., which have a higher urgency and priority compared to the routine meetings of the project.

It is obvious that with the introduction of new meetings, the members of project teams are also to be appropriated to these meetings (Appendix L.2). The Middle management of the project team is heavily involved in the meetings of other projects. Depending on the type and urgency of the project in the portfolio, both discipline managers and discipline heads are a part of both daily and weekly meetings of other projects in the portfolio. Admins and Project controllers however only participate in weekly meetings.

The next aspects which cover interactions in the developed model are the rework and communication links. The rework link covers the task-task interaction by taking into account the work-related dependency between tasks while the communication links cover the agent-agent interactions inspired through the formation of an interface between activities. Figure 27 shows the combined image of both rework and communication links segregated to left and right sides respectively.

As can be seen in figure 27 new rework and communication links are established. These new links are a result of experimentation and logical reasoning within the developed model.

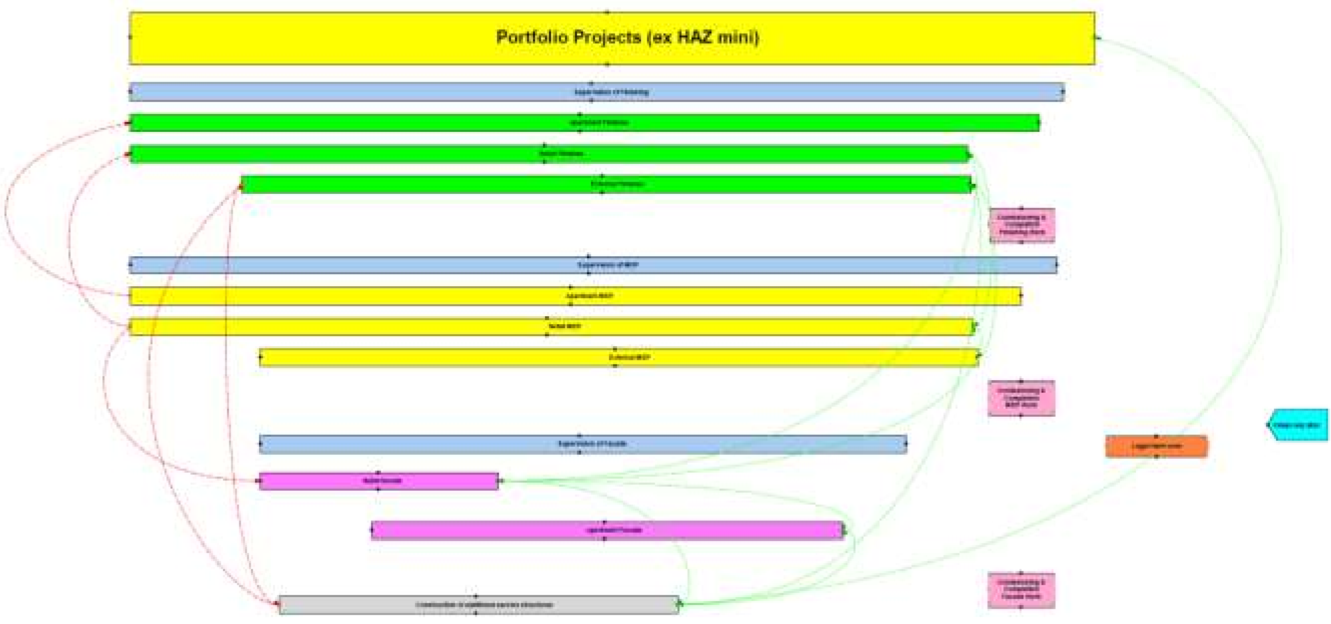


Figure 26: Rework and communication links (Model 3)

Comparing the rework links of Model 3 with the rework links of Model 1, some new connections are evident. The rework link between Retail MEP and Retail façade is introduced. This is due to the presence of MEP ducts closer to the façade. Any rework in these ducts is likely to affect the construction of the façade which is depicted using this link.

Rework	Strength	Units	Connected From	Connected To
1	1	%	Apartment MEP	Apartment Finishes
2	1	%	Retail MEP	Retail Finishes
3	2	%	Construction of additional service structures	External Finishes
4	3	%	External Finishes	Construction of additional service structures
5	7	%	Retail MEP	Retail facade

Table 25: Rework link properties

In addition to that, a two-way rework link is introduced between external finishes and the construction of additional service structures (Table 26). The leveling of the field, which is counted as a part of external finishes makes the activity construction of additional service dependent on it, and conversely, the construction of additional service structure is likely to produce additional work in terms of finishing due to the disruptive activities which take place in on-site construction. For example, the placement of raw materials in the mobilized site, concrete stains, etc., are likely to cause additional work.

In addition to the newly introduced rework links, the model is also extended by adding new communication links.

Communication	Connected From	Connected To
1	Retail MEP	Retail Finishes
2	External Finishes	Construction of additional service struct
3	Retail facade	Apartment Facade
4	External Finishes	External MEP
5	Retail MEP	Retail facade
6	Retail Finishes	Retail facade
7	Portfolio Projects (ex HAZ mini)	Construction of additional service struct
8	Apartment Facade	Construction of additional service struct
9	Retail facade	Construction of additional service struct

Table 26: Communication links (Model 3)

As also mentioned before, the guidelines suggest communication links only exist between activities that have additional requirements for communication exchange. Since the majority of activities are executed parallel to each other and also considering the parallel execution of other projects, the number of communication links is likely to be more than usual for this project as shown in figure 27.

Through experimentation, it is identified that a critical interface exists between activities carried out in retail units (Table 27). The MEP work in retail units is a critical task that affects both finishes and façade construction due to the placement of MEP ducts. Hence the three activities are connected using communication links. Similarly, external MEP and external finishes also form an interface. The laying of MEP ducts and connecting them to the city's MEP ducts may result in disruptive activities. Although the laying of pipes and ducts is performed in the earlier stages of the construction, their connection to the main lines (city ducts) is usually done in later stages. The manholes and access points are usually provided for those purposes. Therefore, to maintain this interface, a communication link is provided between external finishes and external MEP.

Another communication link is introduced between external finishes and the construction of additional service structures (Table 27). As also explained while discussing the rework link between the two activities, the construction of an additional service structure is likely to cause external damages due to construction activities which is likely to cause more rework for finishing. Therefore, an interface has to be maintained such that the construction happens systematically and the rework is limited in the external finishes as much as possible. Moreover, the finishes of the additional service structures will also be a part of external finishes which creates another interface to be managed. Therefore, the communication link is introduced.

A communication link between the retail façade and apartment façade is also introduced (Table 27). This is because both the facades are being parallelly constructed and the façade crew is divided among them. Also, the façade of the apartment is being built on top of the façade constructed for retail units which requires additional coordination hence the link is introduced.

Construction of additional service structures includes the construction of a pedestrian plaza, parking, security cabins, etc., which falls directly in front of the façades constructed for the units. Additional coordination is required to manage the spaces around the area and also make sure that the additional work is not caused due to excessive interference between them.

As can also be seen in Figure 27 and Table 27 another communication link is also formed between Portfolio projects (ex Haz Mini) and the construction of additional service structures. This is intended to simulate the effect of other projects in the portfolio on the execution of MEP and the finishing phase of Hazratganj Mini. Since the projects in the portfolio are located adjacent to each other, Omaxe wants to develop coherent exteriors of the building units to promote a sense of cohesion and consistency among them. Since the site of additional service structures mostly includes the exteriors of the building, which needs coordination in the building, a communication link is introduced.

Having combined all the elements of Model 3, the final step is to run the model and compare it with Model 2. For Model 3 to be considered as a balanced or baseline model, the activity durations of model 3 should more or less match the activity durations of Model 2. The entire Model 3 and the results are shown in the following pages.

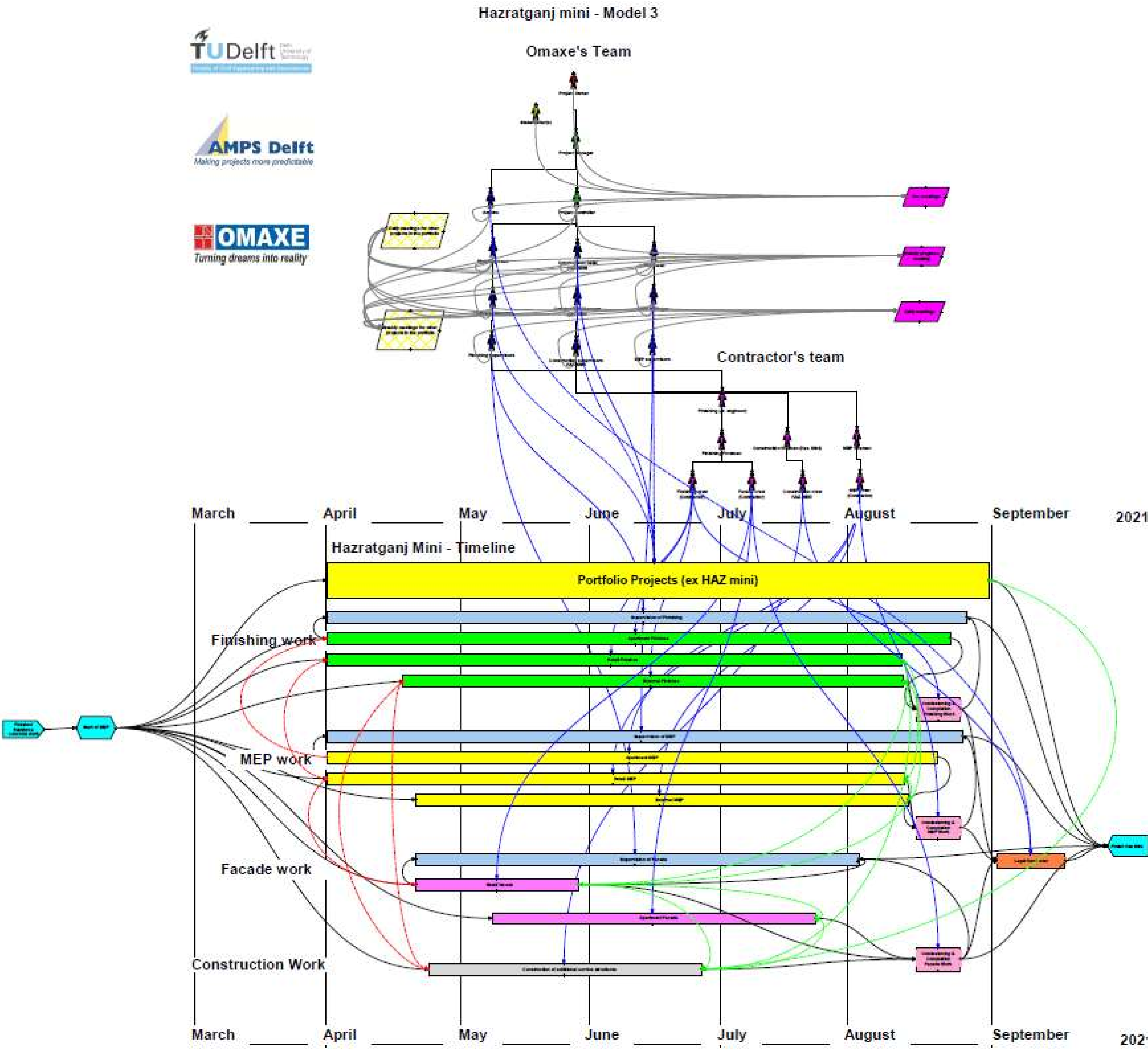
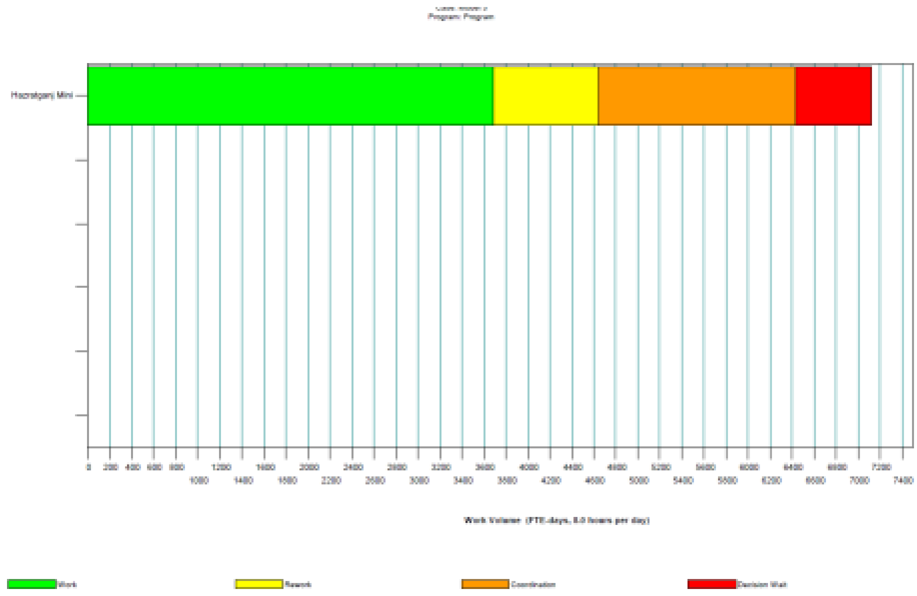
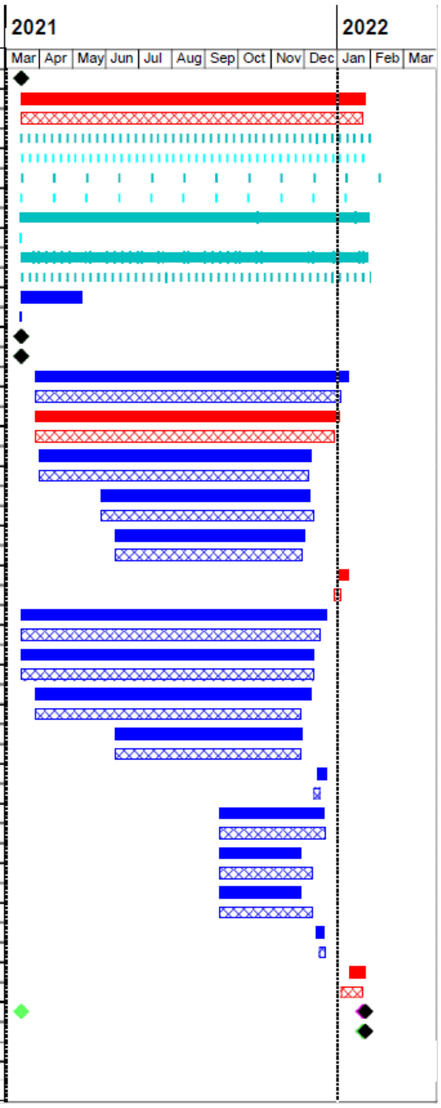


Figure 27: Model 3



Task Milestone *Meeting*	Duration (days) Sim. Date *Duration*	Start Planned Date *Start Date*	Finish CPM Date *Meeting Risk*
Start	**16-Mar-2021**	**16-Mar-2021**	
Hazratganj Mini	318.2	16-Mar-2021	28-Jan-2022
	316.3	16-Mar-2021	26-Jan-2022
Weekly progress meeting	*1.00 hours*	*16-Mar-2021*	*0.34*
	1.00 hours	*17-Mar-2021*	*0.30*
Var. meetings	*1.00 hours*	*16-Mar-2021*	*0.30*
	2.00 hours	*16-Mar-2021*	*0.30*
Daily meetings	*35.00 minutes*	*16-Mar-2021*	*0.52*
	35.00 minutes	*16-Mar-2021*	*0.49*
Daily meetings for other projec	*3.00 hours*	*16-Mar-2021*	*0.33*
Weekly meetings for other proj	*3.00 hours*	*16-Mar-2021*	*0.33*
Portfolio Projects (ex HAZ mini	55.1	16-Mar-2021	10-May-2021
	0.0	16-Mar-2021	16-Mar-2021
Finished Reinforce concrete	**16-Mar-2021**	**16-Mar-2021**	
Start of MEP	**16-Mar-2021**	**16-Mar-2021**	
Supervision of Finishing	290.0	29-Mar-2021	13-Jan-2022
	282.2	29-Mar-2021	05-Jan-2022
Apartment Finishes	280.2	29-Mar-2021	03-Jan-2022
	276.0	29-Mar-2021	30-Dec-2021
Retail Finishes	250.2	02-Apr-2021	08-Dec-2021
	248.0	02-Apr-2021	06-Dec-2021
External Finishes	193.3	28-May-2021	07-Dec-2021
	196.0	28-May-2021	10-Dec-2021
Construction of additional servi	175.1	10-Jun-2021	02-Dec-2021
	173.0	10-Jun-2021	30-Nov-2021
Comissioning & Completion Fi	9.0	04-Jan-2022	13-Jan-2022
	6.3	30-Dec-2021	05-Jan-2022
Supervision of MEP	282.2	16-Mar-2021	23-Dec-2021
	275.3	16-Mar-2021	16-Dec-2021
Apartment MEP	269.2	16-Mar-2021	10-Dec-2021
	269.0	16-Mar-2021	10-Dec-2021
Retail MEP	254.2	29-Mar-2021	08-Dec-2021
	245.0	29-Mar-2021	29-Nov-2021
External MEP	173.1	10-Jun-2021	30-Nov-2021
	172.0	10-Jun-2021	29-Nov-2021
Comissioning & Completion M	9.1	14-Dec-2021	23-Dec-2021
	6.3	10-Dec-2021	16-Dec-2021
Supervision of Facade	97.0	15-Sep-2021	21-Dec-2021
	98.3	15-Sep-2021	22-Dec-2021
Apartment Facade	75.2	15-Sep-2021	29-Nov-2021
	85.0	15-Sep-2021	09-Dec-2021
Retail facade	75.2	15-Sep-2021	29-Nov-2021
	85.0	15-Sep-2021	09-Dec-2021
Comissioning & Completion Fa	7.8	13-Dec-2021	21-Dec-2021
	6.3	16-Dec-2021	22-Dec-2021
Legal Hand over	15.0	13-Jan-2022	28-Jan-2022
	21.0	05-Jan-2022	26-Jan-2022
Finish Haz Mini	**28-Jan-2022**	**16-Mar-2021**	
Finish	**28-Jan-2022**	**26-Jan-2022**	



Program Gantt: Program (Compare to: Model 2)

Table 27: (a) Work breakdown (Model 3) (b) Gantt chart (Model 3)

In the Gantt chart shown in table 28b, the hard bars represent the durations of activities in model 3 while the hatched bars represent the durations of activities in Model 2. Having defined the model, the next step is to affirm if the model is aptly constructed and represents the true reality. For this, several verifications and validation techniques are followed in the next and final section of this chapter.

3.3 Verification and Validation

The constructed model intends to test the varying impacts of team composition and organizational structure on a team's efficiency in light of communication. This is achieved by observing the emergent behavior of the model. However, one of the biggest risks that exist is the presence of errors or bugs in the model resulting in an unrepresentative reality. Thus, it becomes necessary that steps are taken to verify if the model can aptly generate authentic results and thereby is capable of producing the right results when subjected to experimentations. To achieve this objective, several verifications and validation techniques are used.

Galán et al. (2008) mention that model verification is essentially determining if there is no disparity between *what the user thinks the model is doing* in contrast to *what the model is actually doing.* Validation on the other hand can be defined as the process to ensure that the model is accurately able to present the behavior of the system (Kerr & Goethel, 2014). Hence verification ensures that the users *built the model right* and validation ensures that the users *built the right thing* (Kreulen, 2019; van Dam et al., 2013).

3.3.1 Model Verification

This study performs two verification techniques – Single-agent verification and multi-agent verification (Van Dam et al., 2013) to identify any disparities within the model.

Single-agent verification tests if the behavior of a single agent conforms with the expectations of the modeler. Single-agent verification involves making explicit theoretical predictions on the behavior of a single agent based on the agent rules and specifications in contrast to the variation of their state variables (Van Dam et al., 2013). As the agents in the study are primarily characterized by their roles (PM, SL, and ST), and application experience, single-agent verification is also based on the variation of these variables. This study subjects working crew and discipline heads, in particular, to test this verification. The intention is to test how the behavior of the model changes upon varying the attributes of the positions that directly execute the work and on the other hand, varying the attributes of the positions that assume the role of critical decision-makers. Although several positions can be identified that have critical decision-making roles for this project, due to time consideration, this test is only subjected to working crew and discipline heads. Upon implementing single-agent verification, it is found that the constructs and rules governing the functioning of the agents are fittingly implemented in the model. Detailed single-agent verification can be found in Appendix K.

Having tested the behavior of individual agents, it is also necessary to justify the impact of multi-agent interaction in the model for which multi-agent verification is performed. Multi-agent testing is performed by carrying out a timeline sanity check which involves the explanation of model behavior based on the characteristics of the agents (Van Dam et al., 2013). The work breakdown of Model 3 (Table 28a) can be aptly justified based on the organizational structure of the project team. A high coordination time can be explained due to the multi-level hierarchy of the project team which also implicates considerable time lost in decision-wait. Meanwhile, the relatively equivalent amount of rework compared to decision-wait can be attributed to the fact that Omaxe's business case is centered around profit optimization. Therefore, Omaxe would intend to minimize the efforts that go into rework.

Hence a relatively lower value of rework is justified. With this, the multi-agent verification of the model is implemented and it is found that the model behaves as per its intentions.

3.3.2 Model Validation

Having verified the functioning of the developed baseline model, the next step is to authenticate the observations of the model. The developed model should be validated both operationally and conceptually (Kerr & Goethel, 2014; Rykiel, 1996).

Operational validity confirms if the produced results agree with the actual observations of the project (Kerr & Goethel, 2014; Rykiel, 1996). To testify to the operational validity of the model, retrospective measurement is used. As cited by Kik (2010) retrospective measurement involves the comparison of the obtained results of the model to the actual situation of the project. Just like any other construction project, the construction of Hazratganj mini is also based on the timeline developed by the construction team. Based on semi-structured interviews conducted with the assistant manager working on the integrated township project, the planned and actual dates of activities are determined (table 14). These dates are used for the creation of Model 2 which acts as the reference for the creation of Model 3. The state variables are introduced both in the agents as well as the activities such that the duration, start, and finish dates of all the activities are replicated in Model 3 when compared with Model 2. Hence, the model is found to be operationally validated. The model displays the same durations for all activities when compared to the reality of the project.

The next step is to conceptually validate the model. Conceptual validity confirms if the underlying assumptions and structure of the model make logical sense (Kerr & Goethel, 2014; Rykiel, 1996). To testify to the conceptual validity of the model a combination of structural analysis and expert validation is used. Structural analysis confirms that the activities modeled in the software follow a logical sequence (Kooy, 2012). As also explained before, to model successfully, the smaller activities are to be aggregated into larger activities which are then representative of the entire cluster. This aggregation can sometimes give rise to structural discrepancies. For example, initially, only one activity represented completion and commissioning which caused a discrepancy in appropriating responsible positions to the tasks which produced incorrect durations and skewed workload of positions for these activities. Moreover, based on the project plans of Omaxe, the legal handovers and completion and commissioning followed a parallel relation to each other – meaning that both the activities were proposed to be executed parallelly. To resolve this structural conflict, the expert opinions obtained from AMPS delft were implemented in the model. Although initially, the completion and commissioning of Hazratganj mini were viewed as one activity, the recommendations from AMPS delft segregated them into three different activities based upon the type of work being carried out – Finishing work, façade work, or MEP work. These activities were scheduled to be executed parallelly to each other but were executed by different and appropriate positions. Additionally, upon the recommendation of AMPS Delft, the completion and commissioning activities were preceded by the legal handovers which synchronized the structural flow of the activities.

In addition to resolving the structural discrepancies, it is also vital to confirm other major assumptions made in the model. One such assumption which directly affects the duration, as well as the workload of the positions, is the efficiency with which the positions perform their tasks. While developing the model, the efficiency-related assumptions were verified with the assistant manager from Omaxe. Based on the triangulation of variables, the (in)efficiencies of crew members were assumed and identified to be in the range of 30% to 50%. Upon confirmation with the assistant manager, a rough estimate of 40% (in)efficiency is determined which confirms a critical assumption taken for the construction of the model.

Additionally, the priority of a project also plays an integral role in determining how fast a project will be executed. High priority creates higher urgency which is assumed to expedite the process. Considering the budget of Hazratganj mini compared to the total budget of the portfolio (0.9%), it was assumed that Hazratganj mini will have a priority. This assumption was also testified and confirmed by the judgment of the Assistant manager enabling to verification of critical assumptions taken in the construction of the model.

3.3.3 Sensitivity Analysis

Saltelli et al. (2021) describe sensitivity analysis as a 'formal' and 'standard' element of scientific research to interpret the inferences generated from the model and its dependency on the assumptions and parameters feeding it. To elaborate, sensitivity analysis sheds light on how the uncertainty observed in the output of the results can be attributed to the uncertainty sources in the input model (Saltelli, 2002).

Since the construction of the model in this study is based on several critical assumptions, it becomes necessary to evaluate their impact on the outcome. This study takes important assumptions while establishing the values of several organizational factors: *Team experience, centralization, matrix strength, formalization, information exchange probability, and noise probability*. With the help of sensitivity analysis, the intention is to find the individual as well as collective impact of these variables on the output.

This sensitivity analysis also serves the purpose of finding appropriate team composition orientation. These factors are representative of how a team is composed and the governing principles that affect communication within the team. Subjecting the results of sensitivity analysis to statistical analysis further sheds light on the factors that are most influential in terms of composing a highly efficient team. Therefore sensitivity analysis in this study serves a dual purpose.

In terms of an equation, the setup for the sensitivity analysis can be translated as follows:

Team exp. + Centralisation + Formalisation + Matrix strength + Info. Exchange probability + Noise probability → Time

Equation 1: Sensitivity analysis setup

Since team experience, centralization, formalization, and matrix strength are qualitative pragmatic factors, their inputs in SimVision® are restricted to either High, Medium, or Low. Information exchange and noise probability on the other are quantitative factors that can have several inputs based on their degree of accuracy and ranges. Although it would be interesting to comprehensively explore the robustness of the model formed by these quantitative variables using computer programming, its computation would require the back-end programming code of SimVision® which is not available for this research. Therefore, the idea is to input the variables manually creating distinctive cases and evaluating their impact on the duration of the model. The computation of all the distinct quantitative possibilities of the factors (owing to their range and accuracy) in combination with the qualitative factors will be highly time-consuming if done manually. Therefore, for this research, the idea is to restrict the analysis by taking only the extreme and nominal values of both information exchange probability and noise probability. The nominal values enable the determination of the most commonly observed trends of the variables whereas the extreme values of the variable will take into account the boundaries defined by these variables.

Information exchange probability has a range between 0.2 to 0.9 ePM (2005). Therefore, the information exchange probability will have one input as 0.2 (nominal value) – Indicative of routine tasks ePM (2005) and 0.9 (extreme value) – the indicative of its extent. Similarly, the noise probability also ranges from 0.01 to 0.2. Therefore, to test the boundaries, the noise will also have two inputs 0.01 and 0.2.

Project	Value	Units
Name	Hazrat	
Description	MEP an	
Priority	Low	
Work Day	8	☐
Work Week	5	☐
Team Experience	Low	☐
Centralization	Low	☐
Formalization	Low	☐
Matrix Strength	Low	☐
Info Exchange Prob.	0.9	☐
Noise Prob.	0.01	☐
Functional Error Prob.	0.1	☑
Project Error Prob.	0.1	☑
Fixed Cost	0	
Fixed Revenue	0	
Cost Rate	0	Days
Revenue Rate	0	Days
Actual Cost	0	
Actual Revenue	0	

Table 28: Project tab (Sensitivity analysis)

For this experiment, the baseline case is taken as the reference. No changes are made to the settings of either agents, environment, or agent-environment interaction however the number of Monte Carlo runs in the program setting tab is set to 25 for this process to be time-efficient. The project tab acts as the main site of experimentation as can be seen in Table 29. Functional error probability and project error probability are kept to their default values (indicative through the checked box).

Considering the number of variables consisting of four qualitative factors with either High, Medium, or Low as the inputs and two quantitative factors with two input variables for both the factors (Table 30), 324 distinctive combinations ($3C_1 \times 3C_1 \times 3C_1 \times 3C_1 \times 2C_1 \times 2C_1$) can be identified. Using the Power query tool offered by MS Excel, the combinations are enlisted in the form of a table (Appendix-I)

Input Variable	**Range**
Team Experience	High, Medium, Low
Centralization	High, Medium, Low
Formalization	High, Medium, Low
Matrix strength	High, Medium, Low
Information exchange probability	Nominal value:0.20 Extreme value: 0.90
Noise Probability	Nominal value: 0.01 Extreme value: 0.2

Table 29: Variable-input table

Each of these various combinations is manually entered and processed through SimVision® to obtain the predicted duration and finish dates. These predicted durations are then compared to the duration of the baseline case to determine the % deviation (= Observed duration of the case / Duration of Baseline case * 100). The analysis shows the % deviation ranging from 87.67% to 139.67% (Appendix – I) implying a considerable collective sensitivity of these variables towards the outcome – team efficiency.

Even though the analysis shows a significant collective sensitivity, it is equally important to identify individual variables which have the most influence on the outcome. To achieve this objective, the standard deviation for each input variable is calculated. Standard deviation is the measure of how much the data deviates from the mean. A low standard deviation indicates that the spread of the data is mainly localized near the mean of the dataset and on the other hand, a high standard deviation indicates otherwise. It should be noted that the standard deviation does not comment on the type of dataset. Meaning, that the dataset can be in the form of whole numbers, integers, or fractions however, the standard deviation always produces a value equivalent to or higher than zero. Standard deviation can be objectively viewed as the distance from the mean irrespective of if the individual value is higher or lower than the mean of the dataset. Logically, the higher the standard deviation, the higher the variability of outcomes. The table below depicts an overview of the input variables and their standard deviations.

Standard deviation matrix

	Team experience	**Centralization**	**Formalization**	**Matrix strength**
High	22.34	18.2	17.49	17.23
Medium	12.62	18	17.57	17.27
Low	14.76	13.46	17.45	17.31

	Information exchange	**Noise**
0.01		17.14
0.2	17.17	17.15
0.9	17.15	

Table 30: Standard deviation matrix

From table 31, it can be seen that the input variables have a significant impact on the outcomes of the model. Evidently, team experience and centralization have the highest sensitivity towards the outcome. Not only do the *high* team experience and centralization have the highest individual standard deviations (22.34 and 18.2 respectively), the values along the lines of their inputs (High, medium, and low) also show the highest deviations making them the most sensitive variables.

4

Experimentation and Results

In the previous chapter, a chronological outlook is taken for the construction and validation of the baseline model. This chapter further extends this research by subjecting the developed model to experimentation. To successfully answer the research questions, the experimentation is broadly executed using two different types of methodologies each of which provides the insight to answer the formed questions. Firstly, the organizational structure of the model is systematically changed by taking inspiration from the Engineering Procurement and Construction (EPC) contract type. Secondly, the results obtained from the sensitivity analysis in the previous chapter are further subjected to statistical analysis for the further exploration of team composition. This chapter intends to systematically elaborate on the process of experimentation and highlight the main findings of this research.

4.1 Structural changes

Structural changes in this section refer to the changes in the organizational structure of the project team. The organizational structure of a team can be changed in several ways; Changing the reporting links between positions, adding or removing the decision layers, changing the state variables of the positions, etc. These changes together can result in innumerable organizational structure combinations. Therefore, the idea in this section is to introduce a structural change that is probable to be observed in the industry. For this purpose, Engineering Procurement Construction (EPC) contracts are taken as an inspiration to form a client-contractor relationship in this study. Again, based on the dynamics and understandings between both client and contractor, there can also be numerous variations in the EPC-inspired organization structure as well. However, in this study, the intention is to formulate one such organization in a general manner and evaluate its effects on the efficiency of the team.

Under the guidance of industry experts from AMPS Delft, the changes in the organizational structure of the project team are introduced in the ordinance with the EPC contract. The state variables of the positions are altered such that the client-contractor relation in the EPC contract is closely mimicked in the model. Again, for simplicity, the changes made in the experimentation model will also be explained by dividing the model into three parts; Agents, Environment, and Agent-environment interaction. In this way, all the changes in the elements of ABM will be comprehensively covered.

4.1.1 System settings

Before the experiments with the model can be started, the system settings are to be adjusted according to the needs of the case. Since the balanced model or the baseline model represents the reality of the project, these changes are to be introduced on the planned dates instead of actual dates. This way, the experimentation will result in another hypothetical case which can then be compared with the reality of the project (Baseline case).

Program	Value	Units
Name	Program	
Description		
Start Date	01/Apr/2021	
Trials	1000	
Seed	0	
WBS Separator	.	
WBS	0.0	
Calendar	Edit...	
Team Experience	High	
Centralization	High	
Formalization	Low	
Matrix Strength	Medium	
Info Exchange Prob.	0.8	
Noise Prob.	0.1	
Functional Error Prob.	0.1	
Project Error Prob.	0.1	
Behavior File	Default	
Revisions	Edit...	
Escalators	Edit...	
Hyperlinks	Edit...	

Project	Value	Units
Name	Hazrat	
Description	MEP an	
Priority	Low	
Work Day	8	☐
Work Week	5	☐
Team Experience	High	☐
Centralization	High	☐
Formalization	Low	☐
Matrix Strength	Medium	☐
Info Exchange Prob.	0.8	☐
Noise Prob.	0.1	☐
Functional Error Prob.	0.1	☐
Project Error Prob.	0.1	☐
Fixed Cost	0	
Fixed Revenue	0	
Cost Rate	0	Days
Revenue Rate	0	Days
Actual Cost	0	
Actual Revenue	0	
WBS		
Chart Color		
Categories	Edit...	
Business Drivers	Edit...	
Revisions	Edit...	
Escalators	Edit...	☑
Hyperlinks	Edit...	

Table 31: (a) Program tab (b) Project tab

As can be seen in table 32a, the start date of the simulations is set to 1st April 2021. Apart from the start date of the simulations, the rest of the settings in the program and project settings tabs are kept the same to get a more realistic comparison. Similar settings will ensure that change depicted in the duration of the model owing to the experiment is coming solely from the structural changes in the organization of the project team.

4.1.2 Agents

The positions representing the agents in the baseline model are the most drastically changed elements in this part of the experiment. As can be seen from Figure 29 the organizational structure of the project team is broadly classified into two teams; the client's team and the contractor's team. Since EPC contracts have a high implication of work for the contractor's team and only minimal interference from the client's side, the organization structure is divided into two parts. Despite the limited interference of the client's team they are responsible for making quality audits and taking crucial decisions depending on the needs and circumstances.

The client's team consists of an owner who is the main principle user and possessor of the project being developed. The owner is mainly represented by a project manager, who is responsible for close supervision of various projects being executed. The project manager supervises admins, senior manager, and owner's engineer. Similar to the functionality of admins in the baseline case, the admins in the experimentation case are also responsible to supervise administration, accounting, and legal-related affairs. The senior manager assists the project manager by acting as an intermediary decision-layer who at the same time supervises discipline representatives of the client's team. Lastly, the owner engineer acts as a consultant for the decisions taken by the owner.

The other side of the organization team represents the contractor's team. The contractor's team is also headed by a project manager who acts as the local head and supervises discipline managers. The discipline managers supervise local discipline supervisors who assist and guide the discipline crew to perform their tasks.

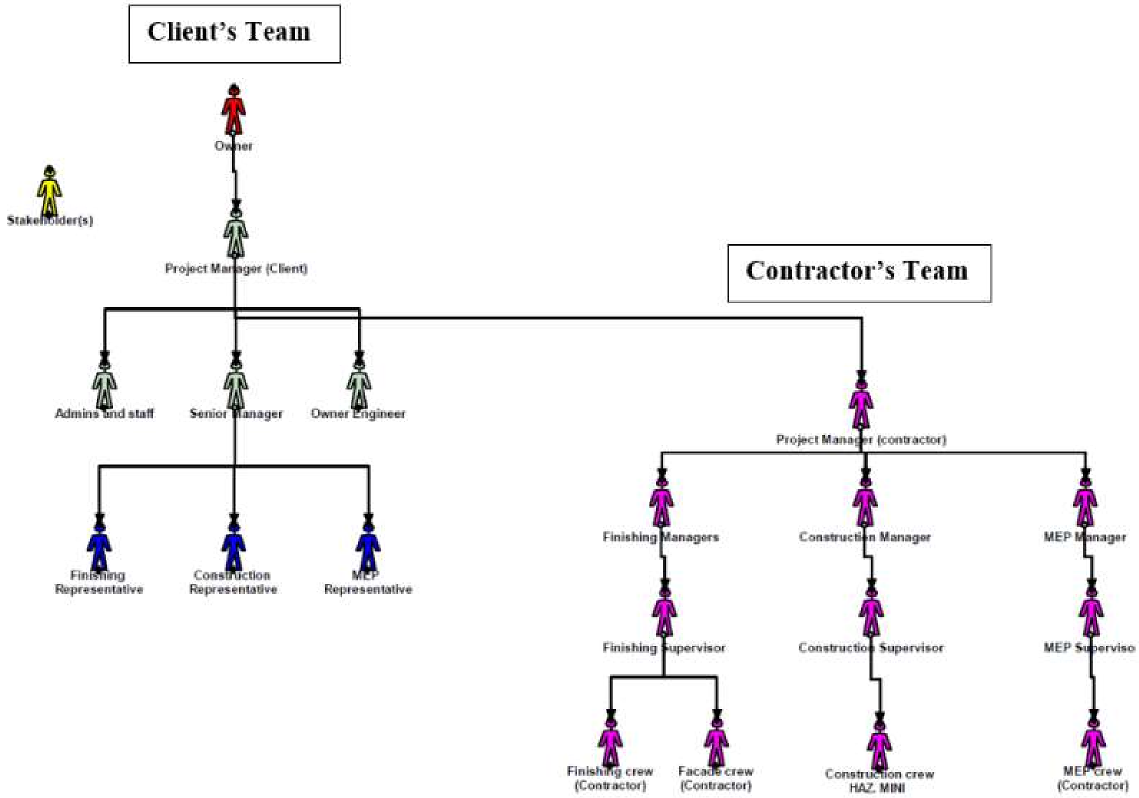


Figure 28: Organization structure (Experimental case)

Position	Name	Description	Role	Application Experience	FTE	Salary	Work Day		Work Week	
1	Finishing crew (Contractor)		ST	Low	20	0	8	✓	5	✓
2	Construction crew HAZ. MINI		ST	Low	7	0	8	✓	5	✓
3	MEP crew (Contractor)		ST	Low	11	0	8	✓	5	✓
4	Facade crew (Contractor)		ST	Medium	5	0	8	✓	5	✓
5	Finishing Supervisor		ST	High	2	0	8	✓	5	✓
6	Construction Supervisor		ST	High	1	0	8	✓	5	✓
7	MEP Supervisor		ST	High	1	0	8	✓	5	✓
8	Finishing Managers		ST	High	1	0	8	✓	5	✓
9	Construction Manager		ST	High	1	0	8	✓	5	✓
10	MEP Manager		ST	High	1	0	8	✓	5	✓
11	Project Manager (contractor)		SL	High	1	0	8	✓	5	✓
12	Owner		PM	High	1	0	8	✓	5	✓
13	Project Manager (Client)		ST	High	1	0	8	✓	5	✓
14	Admins and staff		ST	High	4	0	8	✓	5	✓
15	Senior Manager		ST	High	1	0	8	✓	5	✓
16	Owner Engineer		ST	High	1	0	8	✓	5	✓
17	Finishing Representative		ST	High	2	0	8	✓	5	✓
18	Construction Representative		ST	High	2	0	8	✓	5	✓
19	MEP Representative		ST	High	2	0	8	✓	5	✓
20	Stakeholder(s)		ST	Medium	2	0	8	✓	5	✓

Table 32: Positions tab (Experimental case)

For a justified comparison, the work volume of the tasks is kept equivalent to the baseline. To achieve this, the allocations and FTEs of crew members are kept equivalent to the baseline's case. Table 33 displays the changes in roles and application experiences of positions. These changes are streamlined to display the client contractor's relations due to EPC contracts. As also explained before, the owner acts as the principal user and possessor of the project and also takes part in crucial decision-making, the project owner is designated with the role of PM. On the other hand, the project manager from the contractor's side will hold the responsibilities regarding the execution of the project. The Project manager will be responsible for coordinating with the client's team on the regular basis in addition to supervising their team. Therefore, the project manager (contractor) is attributed to SL.

For application experience, one of the underlying assumptions in the construction of the model is regarding the purpose of hiring a contractor. Since the contractors are usually hired for their expertise in the field, the main governing body of the contractor's team is attributed with High application experience as shown in Table 33.

Having defined the properties of agents, the next step is to define the environment of the project.

4.1.3 Environment

For a fair comparison, the environment of the model is kept similar to the environment of the baseline model. Although the guidelines given by ePM (2005) suggest multiple techniques to optimize the work conditions of a project by adding/splitting/removing/merging tasks and hence optimizing the environment, this research focuses only on the impact of organizational structure. To reach the research objectives, it is therefore mandatory that the activities are kept in the same order and also characterized by the same properties.

4.1.4 Agent-Environment interaction

To simulate the agent-agent interaction in the model, the meetings are redefined and adjusted to showcase the behavior of EPC-inspired client-contractor relations.

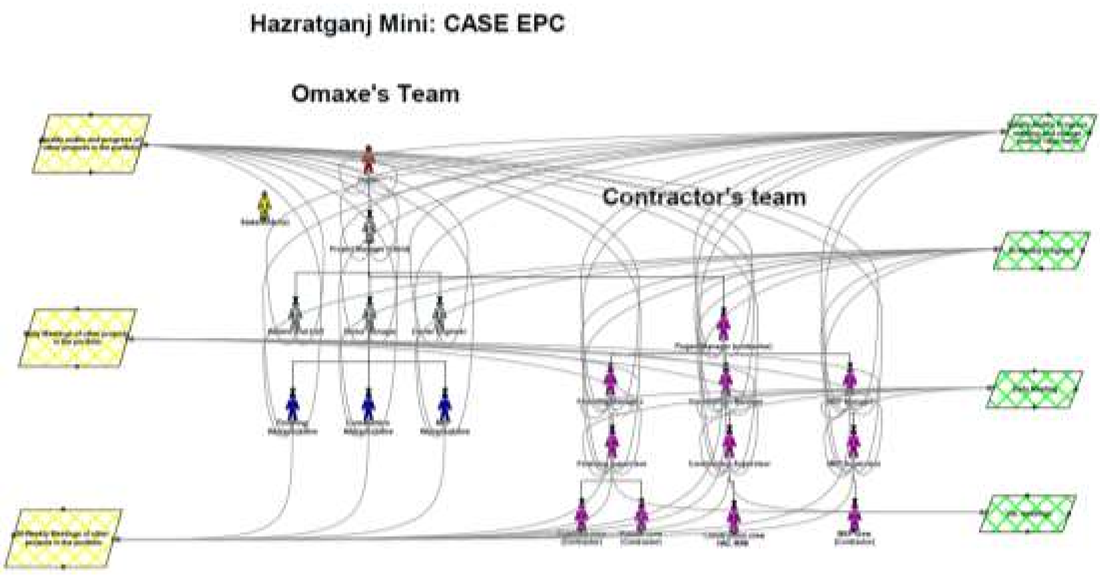


Figure 29: Meetings (Experimental case)

Meeting	Name	Description	Priority	Duration	Units	Repeating	Meet Every	Units	Start Time
1	Daily Meeting		Low	35	Minutes	Yes	1	Days	08:00 AM
2	Bi-Weekly Progress		Low	1	Hours	Yes	2	Weeks	09:00 AM
3	Daily Meetings of other projects in the p		High	2	Hours	Yes	1	Days	03:00 PM
4	Bi-Weekly Meetings of other projects in		High	2	Hours	Yes	2	Weeks	01:00 PM
5	Quality Audits, Progress meeting and ch		Low	2	Hours	Yes	1	Months	10:00 AM
6	Quality audtis and progress of other pro		High	4	Hours	Yes	2	Weeks	08:00 AM
7	'Var. meetings		Low	3	Hours	Yes	2	Weeks	12:00 PM

Table 33: Meeting properties

Figure 40 depicts the visual representation of the positions and their allocation to different project meetings. Considering that contractors are profit-seeking entities, through meetings, the prioritization of projects from the perspective of contractors is displayed. First, the frequency of regular progress meetings is changed from weekly to bi-weekly meetings. This is because these meetings are to be attended by the representatives of the client who will also have limited involvement in the actual execution of the project, therefore, less frequent contact with the contractors. Secondly, <Var. meetings> of Hazratganj mini are further bifurcated. As evident from Figure 30 and Table 34, <Quality audit, Progress meeting, and change control meeting> is depicted in addition to <Var. meetings > of Hazratganj mini. This is also reflected in other projects in the portfolio of the township project.

To show a higher inclination of the contractor towards other projects owing to higher-value production, the meetings of Hazrtagnj mini are shown with a Low priority whereas the meetings of other projects in the portfolio are shown with a high priority. Appendix L.3 further demonstrates the allocation of positions to these meetings.

Another aspect of the experimentation model that represents the agent-agent interaction is through the communication links. As evident from Figure 31, communication links are added to the list of links in the baseline case.

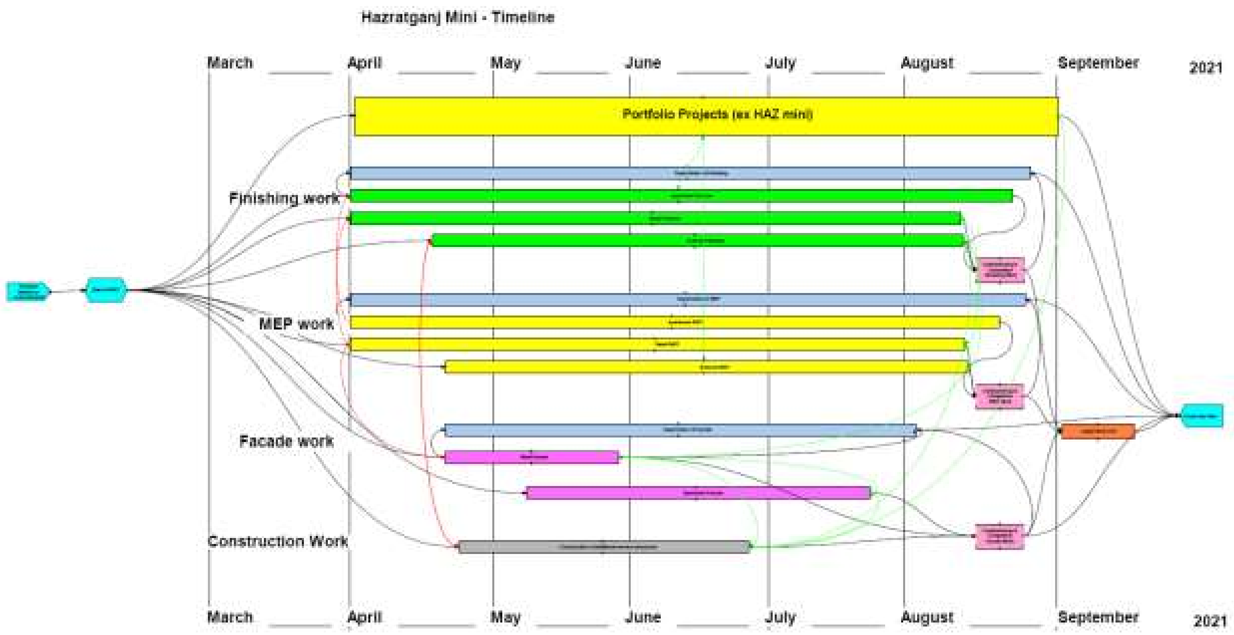


Figure 30: Rework and communication links (Experimental case)

Communication	Connected From	Connected To
1	Retail MEP	Retail Finishes
2	External Finishes	Construction of additional service struct
3	Retail facade	Apartment Facade
4	External Finishes	External MEP
5	Retail MEP	Retail facade
6	Apartment Finishes	Portfolio Projects (ex HAZ mini)
7	External MEP	Portfolio Projects (ex HAZ mini)
8	Portfolio Projects (ex HAZ mini)	Construction of additional service struct
9	Retail facade	Construction of additional service struct
10	Apartment Facade	Construction of additional service struct

Table 34: Communication links

Two new communication links are added between Portfolio projects (ex. Haz mini) and apartment finishes and also between Portfolio projects (ex. Haz mini) and external finishes (Table 35). These communication links are also added to the model to mimic the behavior of the contractor in this setting. Since the behavior of the contractor will focus on profit optimization, the intention of the contractor is assumed to finish most of the activities of the project as fast as possible. Therefore, it is plausible to assume that the contractor will try to execute the activities in parallel to each other which will require higher coordination. The added communication links intend to display this behavior. Since the apartment finishes and external MEP are one of the critical activities of Hazratganj Mini, it is assumed that their execution will be planned in parallel to activities situated in other projects. Therefore, the communication links are added.

Having defined the elements of the baseline and experimented with the organizational structure of the project team, the experimented model and its results are published on the following pages of the chapter.

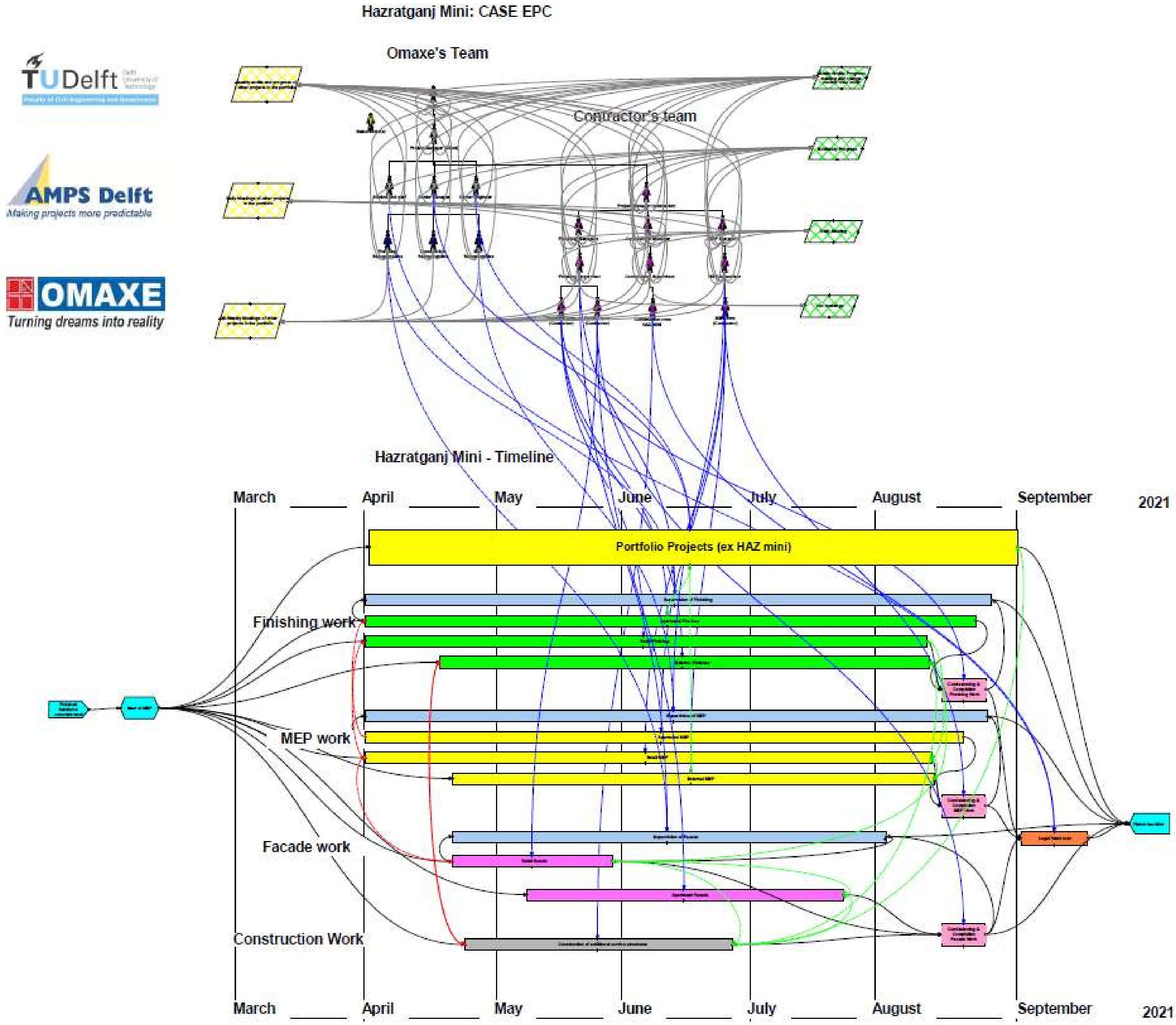


Figure 31: Experimental case

Task	Duration (days)	Start	Float
Milestone	**Sim. Date**	**Planned Date**	**Compare Date**
Meeting	*Duration*	*Start Date*	*Interval*
Start	**01-Apr-2021**	**01-Apr-2021**	
Hazratganj Mini	326.1	01-Apr-2021	21-Feb-2022
Daily Meeting	*35.00 minutes*	*01-Apr-2021*	*1.00 days*
Bi-Weekly Progress	*1.00 hours*	*01-Apr-2021*	*2.00 weeks*
Daily Meetings of other project	*2.00 hours*	*01-Apr-2021*	*1.00 days*
Bi-Weekly Meetings of other p	*2.00 hours*	*01-Apr-2021*	*2.00 weeks*
Quality Audits, Progress meeti	*2.00 hours*	*01-Apr-2021*	*1.00 months*
Quality audtis and progress of	*4.00 hours*	*01-Apr-2021*	*2.00 weeks*
`Var. meetings	*3.00 hours*	*01-Apr-2021*	*2.00 weeks*
Portfolio Projects (ex HAZ mini	53.0	01-Apr-2021	21-Feb-2022
Finished Reinforce concrete	**01-Apr-2021**	**01-Apr-2021**	
Start of MEP	**01-Apr-2021**	**01-Apr-2021**	
Supervision of Finishing	301.1	12-Apr-2021	21-Feb-2022
Apartment Finishes	290.0	12-Apr-2021	28-Jan-2022
Retail Finishes	259.0	19-Apr-2021	28-Jan-2022
External Finishes	165.2	14-Jun-2021	28-Jan-2022
Construction of additional servi	133.2	28-Jun-2021	31-Jan-2022
Comissioning & Completion Fi	10.0	28-Jan-2022	07-Feb-2022
Supervision of MEP	291.2	01-Apr-2021	21-Feb-2022
Apartment MEP	277.1	01-Apr-2021	28-Jan-2022
Retail MEP	266.2	12-Apr-2021	28-Jan-2022
External MEP	182.0	28-Jun-2021	28-Jan-2022
Comissioning & Completion M	7.1	10-Jan-2022	07-Feb-2022
Supervision of Facade	94.0	01-Oct-2021	21-Feb-2022
Apartment Facade	73.3	01-Oct-2021	24-Jan-2022
Retail facade	77.0	01-Oct-2021	28-Jan-2022
Comissioning & Completion Fa	9.8	24-Dec-2021	07-Feb-2022
Legal Hand over	13.9	07-Feb-2022	21-Feb-2022
Finish Haz Mini	**21-Feb-2022**	**01-Apr-2021**	
Finish	**21-Feb-2022**	**01-Apr-2021**	

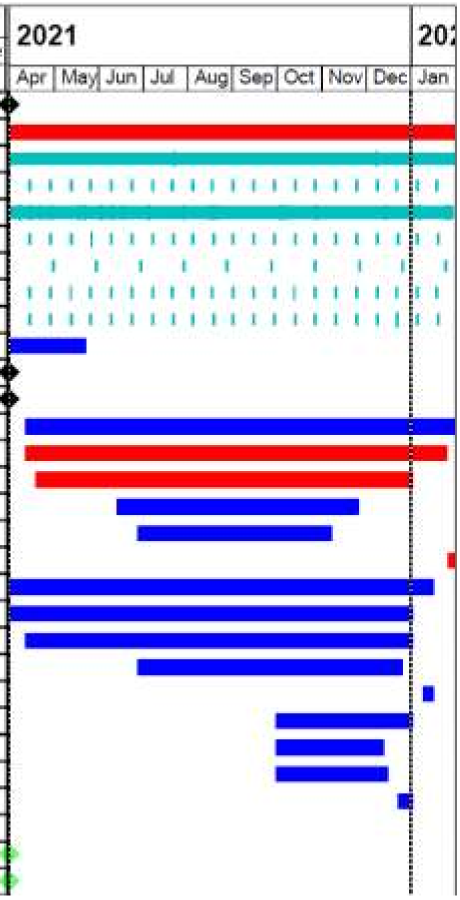


Table 35: Gantt Chart

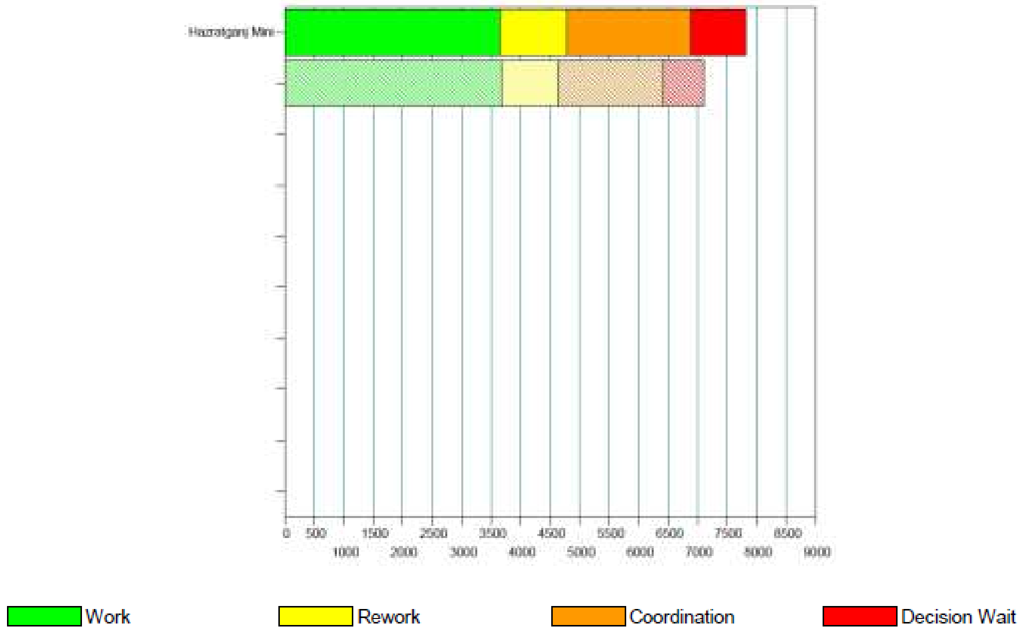


Figure 32: Work breakdown comparison

S.no	Tasks	Duration (Baseline Case) (Days)	Duration (Experimental case) (Days)	% Deviation
1	**Supervision of finishes**	290	301.1	103.8276
2	Apartment finishes	280	290	103.5714
3	Retail finishes	250.2	259	103.5172
4	External finishes	193.3	165.2	85.46301
5	**Supervision of MEP**	282.2	291.2	103.1892
6	Apartment MEP	269.2	277.1	102.9346
7	Retail MEP	254.2	266.2	104.7207
8	External MEP	173.1	182	105.1415
9	**Supervision of Facade**	97	94	96.90722
10	Retail facade	75.2	77	102.3936
11	Apartment facade	75.2	73.3	97.4734
12	Const. of addition structures	175.1	133.2	76.07082
13	Commissioning and completion (finishes)	9	10	111.1111
14	Commissioning and completion (MEP)	9.1	7.1	78.02198
15	Commissioning and completion (facade)	7.8	9.8	125.641
16	Legal handovers	15	14	93.33333

Table 36: Duration comparison (Baseline Vs. experimental)

Figure 36 displays the Gantt chart of each activity with its simulated duration, planned start date, and float (indicating the additional time that the activity can take without getting critical thus, affecting the course of execution). The last row of the Gantt chart represents the start and predicted finish dates of the project. On comparing the finish date of this experimental model with the baseline, an increase in the duration of almost a month (3% duration exceedance) has been observed. Table 37 further demonstrates this increase of one month spread among the modeled activities. T*en out of sixteen activities in the experimental case show time exceedance compared to the baseline case (Table 37)*.

However, a crucial question arises; What caused the duration of the project to increase? The volume of work to be performed in the experimental case was kept equal, no changes were introduced in the environment of the project, the activities and tasks followed the same successor relations as in the baseline model and still the duration of the project was exceeded. This observation experimentally confirms that *the duration of a project is not only bound to the environment of the project which is defined using the tasks and activities of the project*. *There exists hidden work in addition to the primary production work that impacts the total duration of the project.*

SimVision® specializes in the identification of this hidden work. Since the changes made in the experimental model were only limited to the structural change of the project team organization, the additional hidden work can also be argued to have been engendered by this structural change. Figure 50 shows the segregation of indirect work in both the baseline as well as the experimental case. The solid bar represents the split of work for the experimented model and the hatched bar underneath it represents the split of work for the baseline model. The green proportion of the bar corresponds to the primary production work. This is the absolute work that the project team has to execute for the realization of the project. The yellow proportion corresponds to the rework that is generated due to local failures of tasks causing rework. The Orange proportion represents the coordination work that is required among team members to execute a task and finally, the red proportion represents the decision wait that arises due to time lost in decision transactions across multiple layers of hierarchy.

Based on the results shown above, it can be argued that the *higher involvement of the contractor in the project by the means of an EPC contract saw an increase in both rework and coordination which eventually sourced the time delay of around 1 month* into the project. The results demonstrate an *approximate increase of 18.42% of coordination work* in the experimental case implying the need for higher communication exchange among the members to execute activities and share information. Additionally, the results also demonstrate higher delays in decision-making. The results demonstrate an *increase of almost 100%, doubling the time lost in decision delays* which in addition to increased coordination causes the project delays.

A closer look at the risk metrics shown in figure 34 also elucidates the effect of organizational change of EPC on communication.

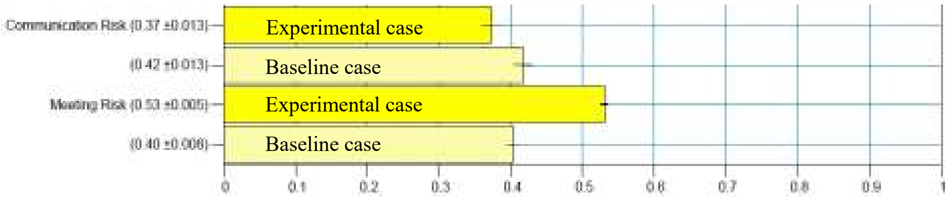


Figure 33: Risk comparison (Model 3 and Experimental case)

The metrics above compare the communication risk and meeting risk between the baseline model and experimental case. The hard-yellow bars represent the risks of the experimental case while the hatched bars represent the risks of the baseline case. Both communication and meeting risks are identified on the premises of communication and information exchange that occurs between team members. Communication risk is the quantification of the number of missed communication compared to the number of requested communication simulated across communication links in the model. Likewise, the meeting risk is also calculated by comparing the number of missed meetings and requested meetings for a position. It is evident from the results above that even though the communication risk of both, the baseline as well as the experimental case are more or less the same, the *meeting risk is increased by 32.5%.* This demonstrates that the probability of the positions missing meetings about Hazartganj mini will be higher in EPC-inspired cases which may lead to additional coordination or even perhaps more rework work due to information asymmetries.

4.2 Statistical Analysis

Sensitivity analysis performed in chapter 3 provided a short introduction of the dependencies between six organizational factors and team efficiency. The standard deviation matrix in particular showcases the impact of variables on the outcome of the model. Since standard deviation is only the measure of the spread of the data, it is necessary to explore how the variables affect the outcome (positively or negatively). To determine this, the dataset is further subjected to statistical analysis.

To determine the dominant trends of variables and their inputs, this study further subjects the best and worst cases from the sensitivity analysis to further statistical exploration. Analysis of the best and the worst cases enables to study of the extreme behaviors displayed by the model which enables to draw useful conclusions for the variables. In the sensitivity analysis, 20 cases are identified that displayed the highest team efficiency (%deviation: 87.67%) thus forming the dataset of best cases, on the other hand, 65 cases are identified that performed poorly compared to the baseline case (100% < %deviation < 139.7%). To understand the distribution of variable inputs in both, the best and worst cases, frequency tables are plotted (Table 38).

Mode / Count	Team experience	Centralisation	Formalisation	Matrix strength
Low	16	52	33	16
Medium	9	13	23	22
High	40	0	9	27
Total cases	65	65	65	65
	Information exchange probability		**Noise**	
0.01	NA		33	
0.2	32		32	
0.9	33		NA	

Best cases

Mode / Count	Team experience	Centralisation	Formalisation	Matrix strength
Low	7	0	11	11
Medium	6	5	9	6
High	7	15	0	3
Total cases	20	20	20	20
	Information exchange probability		**Noise**	
0.01	NA		10	
0.2	4		10	
0.9	16		NA	

Worst cases

Table 37: Frequency table

The frequency count for the table is plotted against the input variables for both, the worst and best cases to determine the correlations as shown in figure 35 and figure 36.

Based on the sensitivity and statistical analysis performed on the dataset, some major findings can be highlighted.

First, among the chosen variables, *team experience has the highest impact and positive correlation to team efficiency*. The positive slope of team experience in the best-case scenarios highlights this finding. However looking at the worst-case scenarios, team experience shows a constant value (indicated by a straight line curve) meaning that other influential factors dominate the composition when worst cases are encountered.

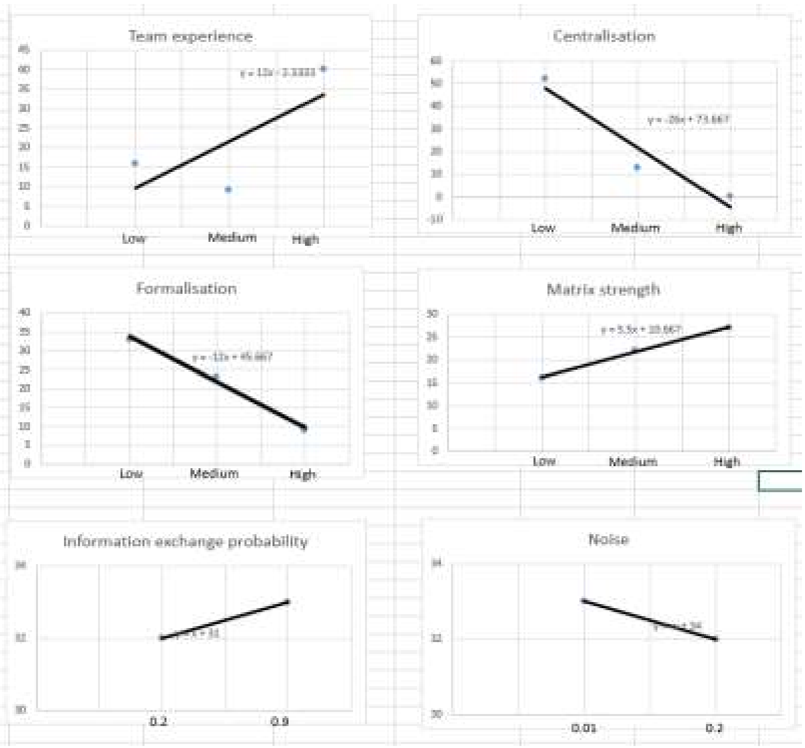


Figure 34: Correlation graphs of inputs - best cases

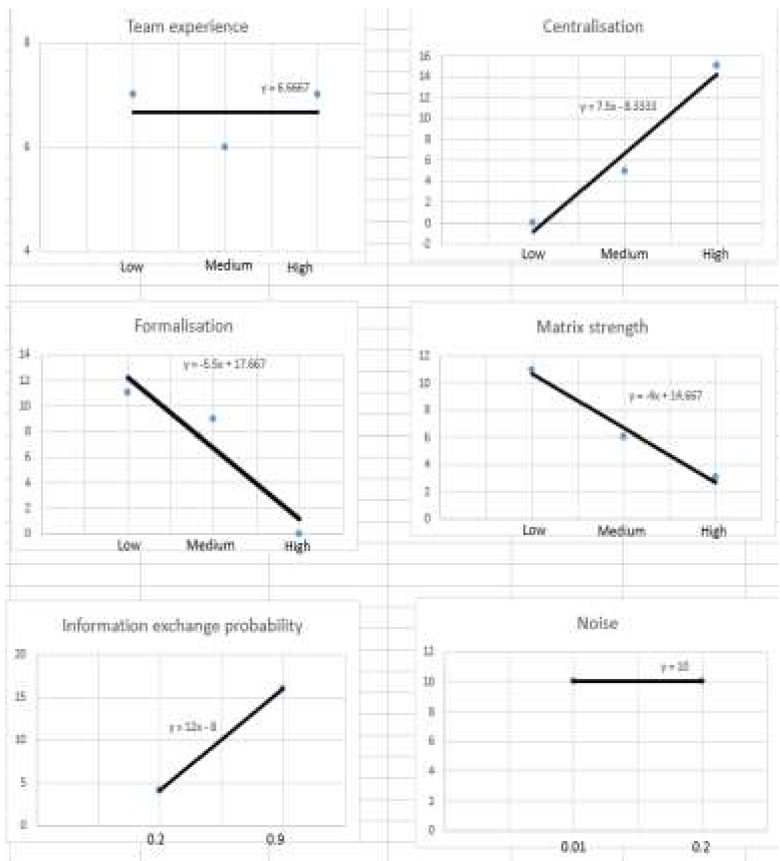


Figure 35: Correlation graphs of inputs - Worst cases

Centralization shows a similar kind of influence. *Centralization has a high impact and negative correlation with team efficiency*. Centralization shows a negative correlation with efficiency indicated by its negative slope in the best case scenarios while also showing a positive slope for worst-case scenarios which advocates this finding.

Formalization on the other hand shows a low impact and no correlation with team efficiency. Formalization shows a negative correlation in both the best and worst cases which indicates uncertainty in inputs of formalization against team efficiency. Due to this uncertainty, no visible trend can be identified in the inputs of formalization against team efficiency.

Matrix strength shows a low impact and positive correlation with team efficiency. Matrix strength shows a positive slope for the best-case scenarios and a negative slope for the worst-case scenarios which supports this claim. However as can be seen from the standard deviations calculated in chapter 3, matrix strength does not show a higher deviation along with its inputs which shows a lower impact on the variable.

Information exchange almost shows a constant value slope in best cases indicating a weak relationship however shows a positive correlation in the worst cases implying that the *information exchange is found to be high in the cases producing worst scenarios.*

Lastly, the noise shows almost constant slopes for both the best and worst cases indicating a weak correlation with team efficiency. Noise shows a constant value slope for both the best and the worst cases which supports this claim.

PART III

5

Discussions

This chapter intends to analyze the results obtained from experimentations performed on the baseline model. The aim is to relate and interpret the results such that a pragmatic link to the observations can be formed and further recommendations can be made using these results. Finally, this chapter concludes by discussing the limitations of this study

5.1 Discussions – Experimental case

This study intends to identify the impact of team compositions and organizational structure on team efficiency while taking into account the communication occurring between team members. With the help of SimVision®, a model is created to demonstrate the existing efficiency of a project team deployed on an integrated township project in India where the members of the team have multiple responsibilities. This model is further subjected to experiments that enable this study to reach its research objectives.

The experiment involves the variation of an organizational structure inspired by an EPC contract as shown in figure 37.

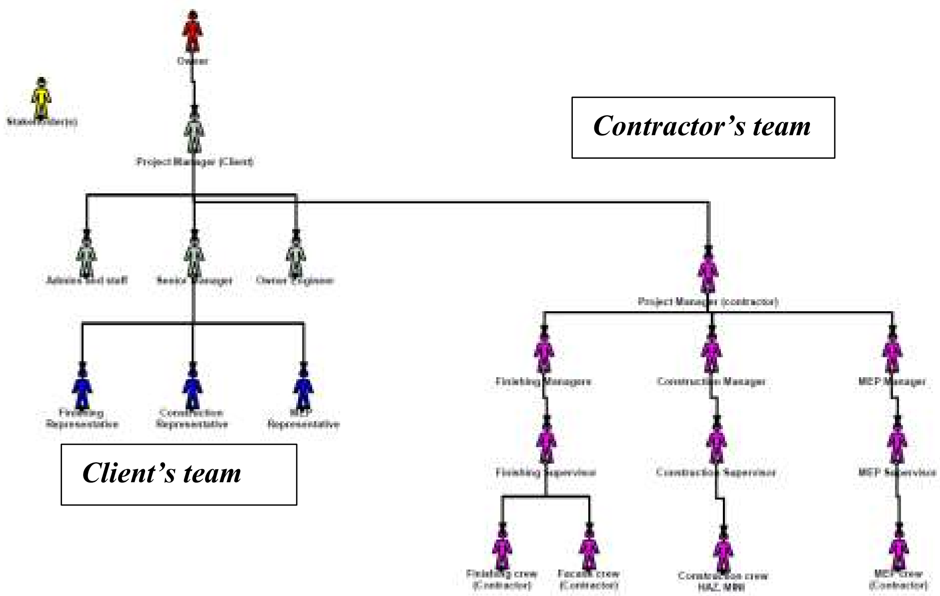


Figure 36: Project team (Experimental case)

The contractor's team in this situation acts as the main construction team and is responsible for the execution and realization of projects in the portfolio. This change when compared to the baseline case where the project owner used in-house capabilities to construct the project showed a one-month time delay in terms of project delivery. The results displayed 10 out of 16 activities to contribute to this delay in the form of added coordination (increased by approximately 18.4%) and decision-wait (Increased by approximately 100%). Due to the high prominence of the coordination and decision wait in the experimental case, these factors are further discussed.

5.1.1 Interpretation and implication - Decision-wait

One of the main highlights of the EPC contract is the introduction of an additional decision layer. The project manager of the contractor's team although the principal of the construction team has to report to the project manager from the client's side and also to the owner. In comparison to the baseline case, this decision layer is likely to add more decision time in the processes due to communicational requirements which are likely to increase the time. Most of the privately-owned companies in India work under strict hierarchical structures with multiple decision layers (Horne, 2009; Radjou, 2008). This often causes the senior management to get backlogged with decision requests which result in lost time (Jin & Levitt, 1996). Considering other projects in the portfolio, it can be argued that the decision-makers of the project will also be actively involved and be even backlogged with decision requests coming from other projects which results in this additional time loss. Especially, since Hazratganj mini only constitutes 0.9% of the total budget value of the portfolio, it is logical to assume that the project team will put more focus on the projects which are of higher investment and returns, further hampering this decision time. So, a question arises, *how can this decision time be reduced?* Quick decisions are likely to save costs, keep the employees engaged, and might also provide a competitive advantage to the companies (Booker, 2020). Referring to the breakdown of figure 33, it becomes evident that decision-wait, if reduced can significantly impact the total duration of the project.

5.1.2 Recommendations to reduce Decision Wait

Kleinman et al. (2020) advocate that among other factors, the radical flattening of hierarchies is likely to positively reinforce teams, especially in terms of decision time. They argue that even the largest firms should not have more than six decision-layers. Dalal (2016) & Ferris (2018) also advocates flatter structures where communication is quicker and there is increased democracy among team members. However, a question arises, *Is the reduction of decision-layers sufficient to reduce the decision-time without compromising other aspects of a project such as quality, cost, and safety?* The decisions can be quick but at the same time ineffective and detrimental to the project. Smet et al. (2019) cite that even the managers in the Fortune 500 companies typically waste more than 500,000 days a year on ineffective decision-making. So, how can this be resolved? How can the decisions be made which are not only fast but also ensure effectiveness and quality in the work process?

The proposition is to combine the recommendations of Kleinman et al. (2020) and Smet et al. (2019) to facilitate quick and better quality decisions. Smet et al. (2019) identify three main decision types (table 39); Big-bet decisions, cross-cutting decisions, and delegation decisions. They identified these decisions based on the risks and the frequency of such decision requests. They suggest that Big-bet decisions which are characterized by high risk but infrequent occurrences should be dealt with by the top management while the cross-cutting decisions which are also high-risk but frequent should be dealt with by the business-unit heads and finally the delegation decisions which are characterized by low risk and high frequency should be dealt by the individuals of the working team.

Types of decisions	Risk and Occurrence	Responsible person
Big-bet decisions	High risk and infrequent	Top management
Cross-cutting decisions	High risk and frequent	Business unit heads
Delegation decisions	Low risk and frequent	Work team individuals

Table 38: Risk - Frequency decision delegation

The delegation of roles and responsibilities in addition to reduced decision layers is likely to produce results that are not only quick but also effective. The impact of this responsibility delegation and reduced decision layers can also be further tested using Agent-based models. For SimVision® its direct impact would be reduced size of the organization and more decentralization of hierarchy which will result in reduced decision wait (ePM, 2005).

5.1.3 Interpretation and implication – Coordination

Another crucial work type that shows a significant growth in the experimental case is the coordination work. Coordination is the most dominant among indirect works which can be attributed as a direct consequence of simultaneous execution of activities within Hazratganj mini and also across other projects in the portfolio due to the profit optimization motives of the project team. The contractors will be motivated to complete the work as soon as possible. The shared responsibilities of team members in addition to this simultaneous execution drive up the requirement of communication among team members which is the main driver of coordination work and also results in a significant loss of time (Loch & Terwiesch, 1998). Additionally, failure to meet the communication requirements may also lead up to rework due to information asymmetries among the individuals on the project team (Loch & Terwiesch, 1998).

Another aspect that drives up the coordination work in the experimental case can be attributed to project prioritization. Again, motivated by profit optimization, the contractors will most likely prioritize projects that will generate the highest value for their efforts. The lower budget of Hazratganj mini is likely to lead the contractors to neglect the affairs related to Hazratganj mini against the affairs of other crucial projects in the portfolio.

The risk metrics in figure 34 represent, compare, and quantify this phenomenon. The meeting risk in the experimental case is higher than the risk in the baseline case. This can be attributed to project prioritization. The project team is more likely to neglect the meetings of Hazratganj mini against the affairs of other projects in the portfolio. The information deficits thus created are likely to increase the communication demand for the project.

Given the focus of this study resides in the organizational structure of a project team, the question arises, *how can the coordination work be optimized from the context of project teams?*

5.1.4 Recommendations to reduce coordination

As already stated before, since the coordination work is mainly derived from the communication and information exchange happening between the project team members, the intention should be to make this process more effective.

Formalism in workplaces has shown a substantial correlation with communication and coordination (Renani et al., 2017; Vlaar, 2006). Gulati & Singh (1998) claims that the formalism practiced through contracts, laws, and regulations helps define the boundaries of work while also streamlining the objectives of the multiple parties. Law and order in this context can be seen as a coordinating tool between different parties involved in the realization of a single project. Alliance contracts for example can be useful and motivating for both clients and contractors to streamline their motives and perform in a more coordinated way. Gulati et al. (2005) in their study also highlights the benefits of using different incentive schemes to not only produce better and coordinated action but also to reduce the opportunistic behavior of parties. This formalism can also be applied to the settings of individual teams. María Martínez-León & Martínez-García (2011) claims that low formalism in the workspace encourages more informal exchanges between employees which can result in loss of time. They claim that formalism on one side can be detrimental to creativity and innovation in the project teams but on the other side may also be a source of major time loss.

Therefore, *the proposition for the case would be to exercise higher formalism on the abstract level of project teams while maintaining flexibility in the individual teams.* This means that the usage of law, contracts, and order to define the relationship between multiple parties can benefit the coordination within teams of different parties. However, these strict measures when applied to the individual project teams for example the construction team, finishing team, design team, etc., can be excessive and damaging to the team's creativity. Therefore a moderately formal approach is proposed to be applied to these individual teams.

In addition to formalism, the experience of team members is also linked to the coordination work arising in the project (ePM, 2005; Jin & Levitt, 1996). Huckman et al. (2008) also claim that increased experience of individuals in a team owing to the learning carried out through exploring, replicating, and selecting, results in a better performance of routine tasks which directly affect the coordination. Jin & Levitt (1996) refer to this experiential learning which enables the team members to relatively understand and perform routine tasks in a more coordinated way such that the requirement and synthesis of communication become relatively easier. Therefore, *the proposition will be to employ individuals who are adept and experienced in handling such a wide scope of the project with multiple internal deliverables so that coordination can become easier.* Retaining highly skillful and experienced individuals for every project team can also be a big challenge in itself. Therefore, *training programs can also benefit to transfer the knowledge and expertise to the hired individuals which can have an initial time expense but may lead up to saving time in the long-term of the project development.*

Centralization also plays a crucial role and has an impact on coordination work (Jin & Levitt, 1996). As also stated before, the highly centralized organization requires the top management to make the decisions. The coordination effort arises when these decisions are to be conveyed and implemented through the layers of hierarchy creating reciprocal dependency (Jin & Levitt, 1996). Veetil (2016) claims that the information transmission in hierarchical structures is comparatively higher than in decentralized structures which creates a higher probability of communicational errors but at the same time enforces more coordination. The communication errors may result in rework due to information asymmetries or information deficits and as a result, may create an even higher demand for communication among individuals. This will increase the information exchange probability and thus affect the coordination. So a question arises; *What can be done to enforce coordination but at the same time minimize communicational and informational errors?*

Team Experience	High	☐
Centralization	High	☐
Formalization	Low	☐
Matrix Strength	Medium	☐
Info Exchange Prob.	0.8	☐
Noise Prob.	0.1	☐
Functional Error Prob.	0.1	☐
Project Error Prob.	0.1	☐

Table 39: Project probabilities (Baseline case)

The proposition is to optimize the information exchange probability by the means of utilizing communication technology. Table 40 shows the probabilities and parameters set for the baseline case. As evident from the figure 40, the information exchange probability for the defined case is quite extreme. The information exchange probability of 0.8 implies that on any given day, there is an 80% chance that an individual will have to communicate with co-workers regarding work being executed. This extreme value is one of the main reasons for the excessive coordination work. Dixit et al. (2021) in their study focuses on the factors that are impediments and also enablers in the adoption of Information and Communication Technology (ICT) in the construction sector of India. They point out that the construction sector in India although attempting to technologically reform itself, still has limited adoption of ICT tools. They mention that tools such as Building Information Modelling (BIM) are still not fully explored and adopted in the industry which can immensely support the communication system of teams.

Son et al. (2016) & Zambare & Dhawale (2017) also discuss the Project Management Information Systems (PMIS) as communication support for project teams. PMIS enables the creation of a common database that stores enormous amounts of information related to projects (S. H. Han et al., 2007; Son et al., 2016). PMIS databases may include contractual agreements, permits, approvals, plans, project goals, roles and responsibilities of team members, and even recordings of site activities (Zambare & Dhawale, 2017)which can act as a one-access-point for most informational requirements of the team members relating to the project. Creating tools like these might help the companies to limit communication errors meanwhile improving the reach and access of information to all the members.

5.2 Discussions - Statistical analysis

This research uses sensitivity analysis to make the best recommendations for the construction of optimal team composition. Chapter 3 introduces the method and adaptation of sensitivity analysis used in this research while chapter 4 further explains and analyses the results obtained using statistical analysis tools, based on which some meaningful implications can be drawn.

5.2.1 Interpretation and implication – Organization

Team experience shows a strong and positive correlation with team efficiency. This observation directly supports the claims made by Huckman et al. (2008) who stresses the direct relation between experience and duration of activities. Easton & Rosenzweig (2012) also claims the advantage of experience in problem-solving which in turn increases the ability of the team to perform tasks in time. The role of team experience in improving team efficiency is quite intuitive owing to the familiarity with the kind of work (ePM, 2005; Jin & Levitt, 1996).

Centralization shows a strong and negative correlation with the efficiency of the teams. The standard deviation of centralization also shows a high impact on the efficiency of the team. This observation also directly supports the claims made by Dalal (2016), Ferris (2018), and Kleinman et al., (2020) who directly challenge the utility of centralized structures especially when it comes to the speed with which the decisions are taken. Centralization not only increases the decision wait of the organization but also impacts rework; High centralization implies decisions being taken by the top management who by the virtue of their roles usually favor reworking whenever an exception is encountered (ePM, 2005).

Similar to team experience, matrix strength also shows a positive correlation with the efficiency of the team. As can be seen in Figure 35 matrix strength shows a negative relationship with % deviation in the worst cases while showing a positive relationship for the best cases. This observation supports the formation of project teams with multiple specialists – Matrix team structure, instead of creating teams based on functionality. Bazigos & Harter (2016) cite the increased coordination in the teams characterized by high matrix strength. Stuckenbruck (1979) also cites that matrix structures enable better analysis and absorption of added project information due to project complexity. Stuckenbruck (1979) states that in contrast to the functional teams, the matrix teams enable them to take into account the entire view of the process which allows them to better streamline their results with the need of the project which also reduces the effort that goes into interface management. However, the standard deviation (Table 31|) of matrix strength does not reveal a significantly higher impact on the efficiency of the team.

Formalization, information exchange probability, and noise showed a weak or no correlation with team efficiency. Formalization and information exchange, in particular, showed a negative correlation with a low impact on team efficiency for all the worst cases. Noise on the other hand shows a straight line curve for both the best cases and worst cases demonstrating no relation with team efficiency.

5.2.2 Recommendations for team composition

Based on the trends and patterns observed the proposition would be to give the *highest priority to increasing team experience.* Team experience can be raised by hiring and retaining people who are well acquainted with the types of jobs being performed and at the same time, other employees can be trained to raise their level of technical awareness. Team experience is likely to give the highest results in terms of efficiency among all the chosen factors. *After team experience, decentralized structures should be promoted*. As already stated, decentralized structures are likely to expedite the process of decision-making, the analysis suggests centralization to be paid the most attention after team experience. And *lastly, the team formation should be based on matrix-team structures*. Decentralized decision-making in addition to matrix team formation can be empowering in terms of efficiency. Matrix structure is likely to ensure contained knowledge and skills within the team while also taking into account the main objectives of the project, on the other hand, the decentralized systems are likely to ensure faster decision making and implementation.

5.3 Research limitations

This study is conducted in a conventional format by first delving into the theoretical concepts surrounding research objectives and then experimentally realizing the purpose. However, it is thought necessary to highlight the limitations of this study so that an appropriate estimation of its results viability along with its boundaries can be judged. For better understanding and chronology, the limitations of this research are segregated into four categories covering different aspects of this study; Literature limitations, case limitations, tool limitations, and finally results in limitations.

Literature limitations

While exploring different agent-based models in the literature study, an intention was to explore models that also mimicked the shared responsibilities of team members over multiple projects and inspire the creation of the organizational structure in this research based on that. The idea was to gather the characteristics of such teams so that their behavior could be adequately modeled and represented in SimVision®. For example, how would the team members prioritize between tasks or projects, or will they equally devote their time to all the allocated projects. However, due to limited research on teams where members are characterized with responsibilities over multiple projects, the modeling of organizational structure relied heavily on the expertise offered by AMPS Delft.

Case limitations

One of the major limits related to the case comes from the data limitations as a result of time constraints. The probabilities used for the construction of the model (Information exchange probability, noise, Functional error probability, Project error probability) in addition to some other system settings are based on iterative computation and experimentation in SimVision®. These settings can be surveyed and quantified by the individuals of the project team using structured surveys. However, due to time constraints, this was not possible and as a result, the settings are determined based on triangulation.

Tool limitations

Although a very effective software, SimVision® also can not take into account all the aspects of organizational dynamics. For example, the impact of trust between teams or the effect of transference of knowledge, the strategic motives of the company. These aspects can also have a great impact on the efficiency of the project teams however they cannot be directly modeled in SimVision®. The modelable factors in SimVision® are to be adjusted and transformed to mimic these impacts.

Results limitations

The main intention of this research is to determine the effects of team composition and organization structure of the project team on their efficiency in the context of communication and information exchange. Considering that every project is unique, the effects of team composition and organizational structure will also be varied as per the characteristics of the project. The project in this study is derived from a real estate company in India that is currently building a township in Uttar Pradesh. Although some of the results from this study can be generalized to apply to different projects, the face value of these results should not be exactly replicated due to differences in projects, company culture, working culture, and norms of India. Especially since the main motives of Omaxe revolves around cash optimization from the entire portfolio in contrast to duration optimization, the quantitative results from this research should be taken as an example of the case rather than taking adopting them in absolute terms.

6

Conclusions and Recommendations

To conclude the research, this chapter reflects upon the initially formed research question, *"How can ABM be used to analyze the effects of team composition and organization structures on a project team's efficiency while taking into account the effects of communication?"*. This research began with the formation of three sub-questions that systematically enabled the exploration of the main research question. This chapter first chronologically addresses the sub-questions followed by addressing the main research question of this study. This chapter also states the personal reflection highlighting the key aspects of carrying out this research. Finally, this chapter finishes by stating the main contributions of the study along with the recommendation for future works.

6.1 Answering Sub-questions

Question 1: What is team efficiency and how can it be measured?

Team efficiency, among other factors, is one of the indicators of team performance. Owing to the growing demands of the marketplace, the teams are required to produce more with minimal resource utilization. Team efficiency is one of the factors which conceptualizes this relation and enables quantifying the degree to which the team is successful in this endeavor.

The literature cites multiple definitions of team efficiency which are developed and adopted over the years. The literature points to qualitative definitions such as the ability of team members to streamline their efforts and also the quantitative definitions such as the time or cost expended by the project team as the mainstream drivers for evaluating the efficiency of a team. Time and cost are also one of the most commonly adopted definitions of team efficiency in multiple kinds of research.

However, for this research, *the amount of time expended by the project team to deliver the allocated work* is adopted as the main definition of the team's efficiency. Research suggests that the construction industry has a high potential to optimize workplace productivity by increasing team-based efficiencies and claims that an increment of productivity from 1% (currently) to 2.8% (equivalent to global economic growth) is likely to add USD 1.63 trillion to the construction industry which forms the main motivation for this study to explore efficiency from a perspective of time.

This study gives an agent-based perspective to optimize the efficiency of teams. This study utilizes SimVision®, a computer-based ABM application, as a tool to observe the effects of various factors that influence the efficiency of a team. SimVision® specializes to capture the organizational properties of a project team/company and reflect them on the project's objectives which motivated its choice of using it. On an abstract level, SimVision® takes the organizational structure, and tasks/activities of a project as the main inputs to predict the time it will take for the project team to finish the work. SimVision® further allows characterizing the organizational structure, and tasks/activities to mimic the reality of the project. For this study, the predicted time of SimVision® also known as the predicted duration of the project is taken as the main measurement for the evaluation of team efficiency.

Question 2: What are the effects of team composition, organization structure, and communication on team efficiency and how can they be modeled?

Through literature study, several factors were identified that impacted the efficiency of a team in a workplace. The study highlighted several direct factors such as knowledge, skills, experience, and several context-based factors such as leadership style, communication, and group composition to have a notable impact on the dynamics and performance of a group. However, for this research, the focus is limited to only team composition, organization structure, and communication.

Team composition is primarily concerned with how the individual members of a project team with their distinct knowledge and expertise support the functioning of the team and how the aggregate of such individuals under the culture of the team perform in conjunction with each other. The literature cites different criteria used to evaluate the composition of a team. The teams can be segregated and compared based on the education of individuals, knowledge, skills, etc. each of which directly impacts the efficiency of the team. The best team formation is still a topic of debate which motivates the choice of including team composition in this research. Since the scope of this research is limited to modeling only team characteristics without taking into consideration the individual characteristics of the team members, six pragmatic parameters are identified based on which the experimentations in SimVision® are performed. This study uses team experience, centralization, formalization, matrix strength, information exchange probability, and noise to model different team compositions. Team experience gauges the familiarity of team members on an aggregate level to perform the type of task. If the team has prior experience with the kind of job, the team experience can be set to high and vice-versa. Centralization on the other hand defines how the decisions are made in the project team. High centralization implies that the decisions are taken by the top layer of the project team. Matrix strength defines if the team is function-based (expertise in a particular discipline and reporting to the functional manager) or project-based (pool of different expertise in the team and team members report to the project manager). Formalization, information exchange, and noise define the culture of a company along with communication. Formalization implies how formally the team members interact with one another. Information exchange probability defines the likelihood of a team member on a particular day interacting with their co-workers to execute their task. And finally, Noise gauges how many external disturbances a team faces that are not related to the execution of tasks. Owing to different inputs for these variables, this study uses sensitivity analysis by taking 324 possible combinations of these variables to determine their robustness in terms of the team's efficiency. This enables the identification of team composition orientations that are promising in terms of the team's efficiency and at the same time determines the orientations that can be unfavorable for the team's efficiency.

The organizational structure of a team refers to how the individuals in a project team interact with one another owing to the hierarchy of the project team. Literature again points out two main orientations of the organizational structure of the project teams; the centralized structure and the decentralized structure. Similar to team composition, the organizational structure of a team also has an inherent dilemma when it comes to its impact on the team's efficiency. The literature points out that while a centralized system may be more efficient in enforcing coordination and control which may be better for a team's efficiency however at the same time might also give rise to friction between individuals due to differences in perspectives, and goals. Therefore, due to the diverging effects of the organizational structure of the team, the organizational structure is chosen as an independent variable for the given research. In the current research, the organizational structure of the project team is modeled using a real-life project team working on an integrated township project in India. The organizational structure is replicated using the organizational chart of the company which states the team members, decision layers, and hierarchy of the team. In SimVision®, these individuals are modeled using positions (also known as collective entities). The individuals with similar expertise and skills are aggregated together and are represented as a position in the model.

Lastly, a plethora of studies stressed the importance of effective communication in the efficiency of teams. The vitality of communication has been stressed by numerous studies which pointed out several failed projects and attributed its cause to poor communication. Communication is a context-based factor, meaning that the composition of the team and organizational structures, both have distinct impacts on how effectively the team members communicate with each other. Information exchange probability, noise, and formalization as already stated before, model some aspects of communication. The reporting links in addition to them also model the direction in which the communication flows among the positions. The positions are connected using reporting links that determine "who reports to whom" in the organization. Meetings are also used to model the formal interactions that occur between different positions. The effect of communication in SimVision® realistically simulates the effects of information exchange; Increased awareness and knowledge of positions related to the project at the expense of time lost in the communications, affecting both the quality of the product as well as the time in which the tasks are completed.

Question 3: What are the effects on team efficiency and communication when team composition and organization structures are varied?

Varying both team composition and organization structure proved to have a significant impact on the duration of the project. The baseline model when subjected to organizational changes, showed the same primary production work despite differing indirect work which confirms the variability impact of organizational structure on a team's efficiency.

The baseline model in this study represents the organizational structure of the project team that is originally working Hazratganj mini. The team is mainly driven by the in-house expertise of Omaxe and with the help of the labor workforce provided by a contractor. However, the structural changes made in the experimental case inspired by Engineering, Procurement, and Construction (EPC) contracts added a decision layer to the structure increasing the decision wait by almost 100 %. Additionally, the coordination time also increased by approximately 18.4 % owing to the concurrent execution of activities in Hazratganj mini as well as to other projects in the portfolio. These indirect works which are a direct impact of increased communication when taken together increased the overall duration of the project by almost 3%.

Team composition in this research is varied using sensitivity analysis. The results of sensitivity analysis are first used to determine the individual impact of input variables by calculating standard deviations. The standard deviation shows the spread of the data around the mean of the dataset. The higher the deviation from the mean, the higher will be the variability of the outputs implying higher influence. However standard deviation only sheds light on how much a variable is impactful without measuring if it will positively or negatively affect team efficiency.

To determine this effect, the data from sensitivity analysis is further subject to statistical analysis. Only the best cases (showing a % deviation of 87.67%) and the worst case (showing a % deviation of greater than 100%) are used for this exploration to determine the dominant trends of variables. Based on the statistical analysis, team experience and matrix strength demonstrated a positive correlation with efficiency while centralization showed a negative correlation with efficiency. Formalization, information exchange, and noise showed weaker or no correlation with the team's efficiency. The findings from both statistical analyses suggest that a team should be composed with the highest priority on having highly experienced team members. In addition to this, a matrix-based team structure should be composed of low levels of centralization to further boost team efficiency.

6.2 Recommendations for practice

Based on the findings of this research, the recommendations would be to pay the highest attention to improving team experience. Team experience has shown a considerable effect on the efficiency of the project. The proposition is to retain the highly experienced employees and train the low experienced and medium experience employees to optimize the output. The increased experience is likely to contribute towards lower time being spent in coordination and rework.

In addition to increasing the experience and knowledge of team experience, decentralized team structures should also be promoted. The proposition is to delegate decision-making based on the risk-frequency matrix. High-risk decisions with infrequent occurrences should be dealt with directly by the top management of the company and High risk, frequently occurring decisions should be dealt with by discipline/business heads. The low-risk, frequent decisions can be appropriated to the individuals of the team. In addition to a delegation of decision responses, the number of decision layers also has a significant impact on the efficiency of the team. The proposition is to limit the number of decision-layers.

To define better roles for collaborating teams, prevent the ambiguity of responsibilities, and also limit opportunistic behavior, it is recommended that the collaborating parties use detailed formal contracts and incentive systems. However, to promote creativity with the smaller and functioning teams, the formalization should be moderated. The moderation should be owed to the fact that informal communications promote work-based innovations and creativity but a highly informal environment may result in lost time. Additionally, the usage of communication tools such as Project Management Information Systems (PMIS) and Information and Communication Technology (ICT) is also recommended. These technologies are likely to support the communication within project teams by acting as a one-point locus for all the major information related to the project which will support communication between team individuals.

Lastly, team formation based on matrix structure should be promoted in contrast to functional teams. This is due to the higher capability of matrix teams to take the overall view of the project and collaborate better in terms of innovation, and information absorption coming from the increasing complexity of projects and their analysis.

6.3 Research implications

This section intends to highlight the advances made by this research and the implications of its results for both, practical and scientific communities.

6.3.1 Scientific contributions and implications

This study makes three key academic contributions.

First, it establishes a quantitative context to gauge the efficiency of project teams characterized by shared responsibilities. The research on project teams with shared responsibilities is highly limited and its extent is even more drastic in construction research. This study under the scientific underpinning explores the effects of organizational changes on such teams thus contributing to the knowledge body of project management.

Second, this study contributes to the theoretical understanding of how crucial of a role the organization plays in the efficiency of a team. Although the effects of varying team composition and organization structure are extensively theoretically explored, this study strengthens the understanding of relationships between chosen dependent and independent variables by quantitatively investigating the relations thus strengthening the knowledge.

Lastly, agent-based modeling is still a relatively novel concept in construction. With recent advancements in computational power, the topic has drawn attention in academic research. This study directly advocates the adoption of Agent-abased modeling in the construction industry by highlighting its utility advantages thus strengthening the relationship between ABM and the construction industry.

6.3.2 Practical contribution and implications

This study's results directly aim at improving business practices. The results give practical recommendations to Omaxe regarding the composition of team and organization structure that will improve communication and information flow, and thus the functioning of project teams. These findings can also be extended to other construction projects which involve multidisciplinary teams composed under an analogical organizational structure.

This study contributes to replicating the environment of a single project in the township portfolio of Omaxe and analyzing the properties of the project team. This knowledge can be useful to the project team in identifying strategies that align team actions with the team's objective for other projects in the portfolio. This implies that ABM enables organizational learning which allows the companies to learn about the organizational traits which impact their work. Based on the acquired knowledge, the companies can use this technology as a decision support tool to align their actions with project-specific objectives. This implies that ABM can be adopted as a tool from the beginning of the project to implement strategic control. Owing to the flexibility of the technique, the model can be regularly adjusted as per the dynamic conditions of the projects and fairly easily adapted. This technology can be used to identify bottlenecks in the progress of work.

6.4 Recommendations for future research

There are plenty of topics that this research does not fully explore which can be added in future research to get more comprehensive results.

The personalities of individuals play a crucial role in defining a team's efficiency (Hsu et al., 2016a; Varvel et al., 2004). Personalities not only govern how independent individuals perform in a project but also influence how they interact and contribute to other team members, enabling higher team efficiency (Hsu et al., 2016a; Varvel et al., 2004). Since this research does not take the personalities of the individuals into account, the first recommendation is to incorporate the impact of individual personalities towards gauging the relationship between team composition, organizational structure communication, and team efficiency.

Additionally, this research only evaluates the impact of organizational factors on team efficiency. The uniqueness of this research lies in its project team with the individuals having multiple responsibilities and the recommendations to improve the efficiency are thus only limited to organizational changes. Another interesting area to explore would be to evaluate how environmental factors (relating to tasks and activities) can impact such teams. ePM (2005) recommends changes in activities (changing the successor relations/ merging activities/ deleting activities etc.) that can be experimented with to make a general framework that can be used to improve the work environment and thus the efficiency of teams with shared responsibilities.

Lastly, this research predominantly focuses on the duration of the project as the main marker of team efficiency. A literature study has proven that the efficiency of a team can be measured on multiple fronts. Therefore, the last recommendation is to incorporate other dependent variables to interpret team efficiency. Team efficiency can be interpreted in terms of quantitative factors such as costs or profits (Liu & Cross, 2016; McComb et al., 2007) and also in terms of qualitative factors such as the contribution of individual team members (Piccoli et al., 2004), innovation or the quality (Lisbona et al., 2020; Liu & Cross, 2016). The addition of these variables would enable us to look at more comprehensive solutions.

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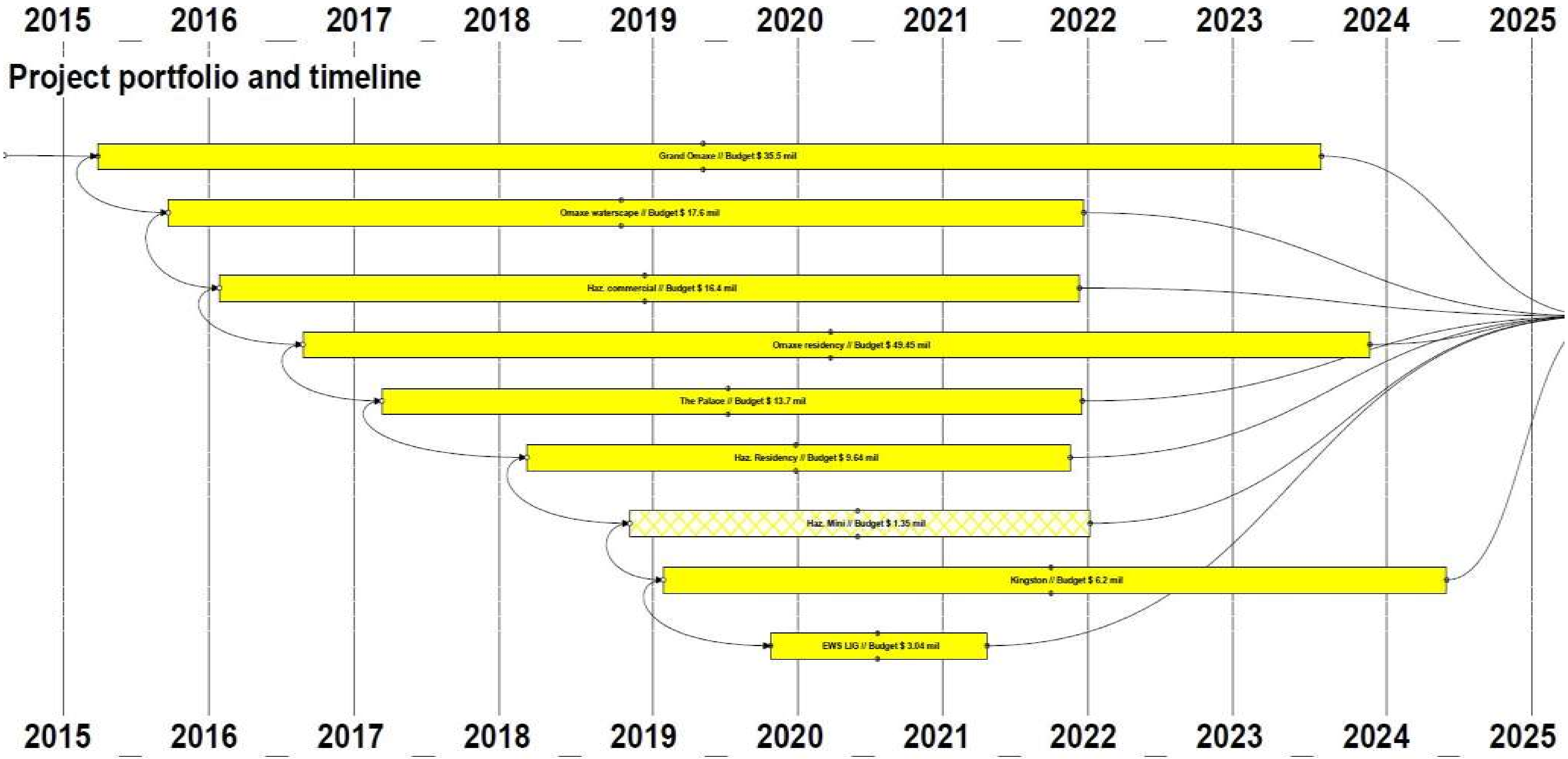
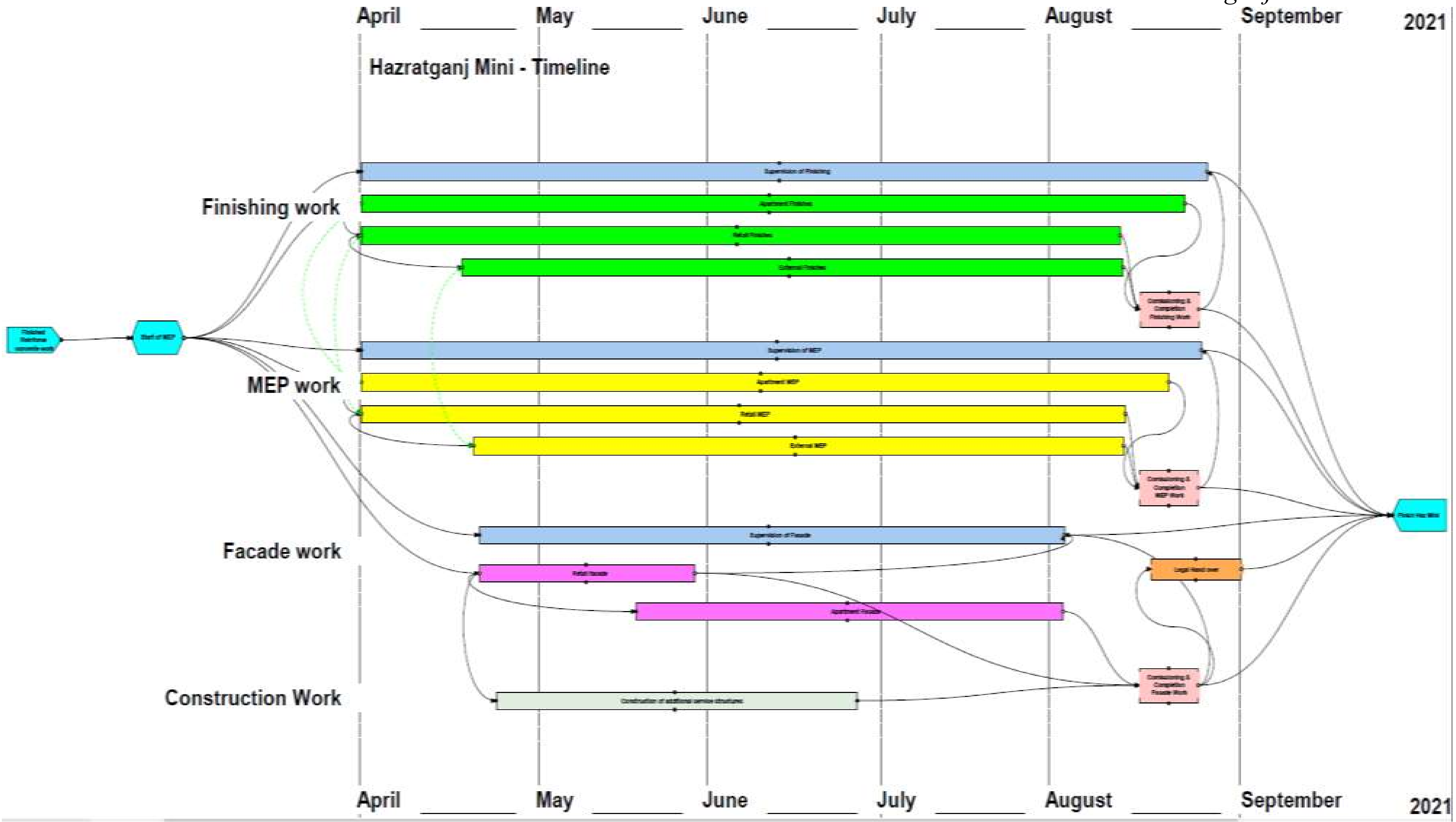
Appendix – A

Portfolio of Projects



Appendix – B

Hazratganj Mini – Timeline



Appendix - C

Modeling Plan

Baseline Case

The baseline case, also known as the first scenario intends to mimic the reality of the project as closest as possible. To have a better structure for the construction of Baseline, three distinct initial models will be developed. The first model will assume default settings of the software SimVision® while mentioning the organization structure as well as the main activities involved in the MEP and finishing phase of the project. It is to be noted that the duration or work volumes of the activities will be entered according to the planned dates (referring to the project schedule). Next, a copy of first model will be taken (renamed as model 2) and the schedule will be adjusted according to the actual start and finish dates. This model will act as the reference point for the baseline. Finally, another copy of model 1 will be taken and renamed model 3 and will be populated using the recommended values of various settings as in ePM guide. The idea is to balance out the settings of model 3 in such a way that model 3 is a close representation of model 2. This will be an iterative process achieved through varying the settings as recommended by the ePM guide for SimVision®.

MODEL 1

Architecture

Do we need a portfolio model or a single project?

- *Although the project under study is an integrated project consisting of 9 sub-projects consisting of both residential and commercial type, the focus of this model is to analyze only one such sub-project which is Hazratganj Mini. However to demonstrate the integrated project and to make it visually more understandable, all the sub-projects will be mentioned as portfolio in the software but the main modelling will be done only for Hazratganj mini.*

What is the time frame from start to finish?

- *The construction of the integrated project started on 8th April 2016 however it was only in march 2018 that the construction of Hazratganj Mini was started. The construction (RCC structure) of Hazratganj mini was completed on 9th April 2019 however, the further development of the project was put on "Management hold" for almost an year. Currently, hazratganj mini is in its finishing stage and is planned to be fully handed over to the clients in coming weeks.*

What simulation probabilities will we use; why?

- Information Exchange: *Default*
- Noise: *Default*
- Functional Exception: *Default*
- Project Exception: *Default*

Do we need to use Team Experience; why?

- *Default*

Do we need to use Matrix Strength; why?

- *Default*

Do we need to use Centralization; why?

- *Default*

Do we need to use Formalization; why?

- *Default*

"As also explained above, the first model will not input any different values for probabilities or parameters mentioned above." .

Do we need to use Work Breakdown Structure; why?

WBS can be used in the model. Since there are several milestones in the schedule, it would be a good idea to sort the activities pertaining to each milestone together so that an easy display in Gantt and statistics chart would enable better comparisons.

Work Process

What tasks will comprise the work process part of the model?

- *Since the model aims to simulate the finishing and MEP part of Hazratganj mini, there were 13 major aggregated activities identified from the schedule provided by the company. These activities represents the finishing of units, construction of façade, construction of additional external structure and finally the commissioning and completion of Hazratganj Mini.*

Do we have all the work volumes; If not, how and when will we obtain them?

- *We do not have the work volumes directly provided by the company however we do have the information on the durations (Planned start, planned finish, actual start and percentage completion), the number of people working on it (Using FTEs) and an allocation (say 80%). Using the work-volume calculator provided in SimVision®, the work-volumes can be calculated for each task using the inputs.*

Which tasks will require skills?

- *As also mentioned before, the modelling is done on a traditional project comprising of traditional or routine activities therefore, there are no such tasks that will require any additional skills. Moreover, the aim of the thesis is to take into account the group characteristics rather than focusing on the individual properties which limits the input for required skills.*

Which tasks need non-standard:

- Requirement complexity
  - *Default*
- Solution complexity
  - *Default*
- Uncertainty
  - *Default*

What tasks do we need to add that are not part of the client's project plan or operating plan? For example:

- Management: *Additional components of Management are proposed to be added. The Client or the project owner has to be added.*
- Customer relationships: *A sales and marketing team is proposed to be added.*
- Off-project influences: *External stakeholders (x2)*
- Design reviews: *Since design reviews are majorly carried out when the construction is being carried out, in the finishing phase, I think the design reviews might not be necessary.*

Which activities will be modeled with duration tasks; why?

- *All the activities will be modelled using task volumes and not duration this is because all the tasks are highly dependent on the number of crew members working on the task.*

Do we need supervisory tasks; why?

- *Supervisory tasks can be added for Finishing, MEP, façade and completion related activities. This is because the immediate supervisors of the crew will be resp[onsbile for overlooking tasks being carried out.*

Do we understand the predecessor-successor relationships among the tasks?

- *Yes, the predecessor and successor relation can be assessed using the MS Project file which shows the aggregated activities and these activities can be sorted according to their start dates. The duration in addition to the start dates of the activities in the MS Project file will reveal the predecessor-successor relation.*

How will we represent design reviews, quality audits, customer meetings and similar "gates?"

- Tasks
- Meetings

- *Quality audits can be represented using meetings. In addition to this, the consultations and tender for MEP and Finishes can also be represented using Meetings.*

Complete this table or attach a source document that has all the same information. A Gantt or flow chart that does not include work volumes, for example, is not sufficient.

	Task	Type	Work Volume	Position	Planned Duration
1	Supervision of finishes	Supervision	1 FTE	Finishing supervisors	-
2	Apartment Finishes	Volume	864 FTE Days	Finishing crew	108 Days
3	Retail Finishes	Volume	564 FTE Days	Finishing crew	94 Days
4	External Finishes	Volume	258 FTE Days	Finishing crew	43 Days
5	Supervision of MEP	Supervision	1 FTE	MEP supervisors	-
6	Apartment MEP	Volume	490 FTE Days	MEP Crew	98 Days
7	Retail MEP	Volume	291 FTE Days	MEP Crew	97 Days
8	External MEP	Volume	261 FTE Days	MEP Crew	87 Days
9	Supervision of facade	Supervision	1 FTE	Finishing supervisors	-
10	Apartment Facade	Volume	110 FTE Days	Facade crew	55 Days
11	Retail Facade	Volume	64 FTE Days	Facade crew	32 Days
12	Construction of additional service structure	Volume	270 FTE Days	Construction crew	54 Days
13	Supervision of completion	Supervision	1 FTE	Construction Supervisor, MEP supervisor and Finishing supervisor	-
14	Commissioning and completion <finishing work>	Max durarion	5 Days	Finishing crew, Finishing supervisor	9 Days
15	Commissioning and completion <MEP work>	Max durarion	5 days	MEP crew, MEP supervisor	9 Days
16	Commissioning and completion <Facade work>	Work duration	5 days	Façade crew, Finishing supervisor	9 Days
15	Legal handovers	Work duration	15 Days	Construction crew, Admins	19 days

Milestones

What milestones are required in the model?

The following milestones can be used for the model:

- *Completion of RCC structure*
- *Start of MEP and Finishing phase*
- *Completion of Finishes*
- *Completion of MEP*
- *Completion of Facade*
- *Completion of structure*

Do we understand the predecessors and successors for each one?

The table below is populated according to the planned dates and not the actual dates

Activity	Duration (Days)	Start (DD-MM-YYYY)	Finish (DD-MM-YYYY)
Apartment Finishes	108 Days	01-04-2021	30-08-2021
Retail Finishes	94 Days	01-04-2021	16-08-2021
External Finishes	43 Days	01-04-2021	14-08-2021
Apartment MEP	98 Days	11-04-2021	19-08-2021

Retail MEP	*97 Days*	*15-04-2021*	*29-06-2021*
External MEP	*87 Days*	*15-04-2021*	*14-08-2021*
Apartment Facade	*55 Days*	*15-04-2021*	*30-05-2021*
Retail Facade	*32 Days*	*15-05-2021*	*30-07-2021*
Construction of additional service structure	*54 Days*	*16-06-2021*	*15-08-2021*
Commissioning	*9 Days*	*01-08-2021*	*11-08-2021*
Completion	*19 days*	*05-08-2021*	*31-08-2021*

Complete this table or attach a source document that has all the same information.

The table below is populated according to the planned dates and not the actual dates

	Milestone	Planned Date (DD- MM-YYYY)	Predecessors (Entry)	Successors (Exit)
1	*Completion of RCC structure*	*01-04-2021*	*-*	*Start of MEP and finishes*
2	*Start of MEP and finishes*	*01-04-2021*	*Completion of RCC structure*	*Completion of apartment* *Completion of Retail* *Completion of externals*
3	*Completion of structure*	*31-08-2021*	*Start of MEP and Finishing phase*	*-*

Organization

What positions do we need in the organization portion of the model?

We need the following positions in the model representing different layers of hierarchy:

- *The Owner (Representing the CMD – Chief managing director of Omaxe) – Top layer*
- *Project manager (The personnel responsible for construction of integrated project) – 2nd Layer*
- *External stakeholders – Intermediate layer (Not in the reporting link)*
- *Project controller (The personnel acting as an intermediate between team leads and project manager) and admins –3rd Layer*
- *Team leads (the persons leading different disciplinary teams ex., construction, MEP, Finishing etc.) – 4th Layer*
- *Team managers (The persons acting as an intermediate between team leads and on-site supervisors) – 5th Layer*
- *On-site Supervisors (The persons responsible for managing workforce from Omaxe) – 6th Layer*
- *Jr. Engineer Finishes (Person supervising finishing staff and working alongside foremen) – Layer 7th*
- *Foremen – local supervisors of the working crew – Layer 8th*
- *Workforce (the people responsible for actualizing the project) – 9th Layer*

Do we need to represent customers, suppliers, or other positions that are not part of the client's project or operation?

- *Yes, we do need to represent other positions which are not the part of the main organization structure but play a crucial role in the project itself. Example can be the project owner, admin teams, project teams executing other sub-projects etc.*

Will all positions have direct work assigned?

- *No, not all the positions will have direct works assigned to them. Some of them will be assigned to meetings which are also an essential part of the model. Moreover, the top hierarchies will also be responsible for the dealing with the exceptions generated in the project.*

If not, what will they do?

- Attend meetings
- Make decisions
- Supervise

- *Most of the positions will either attend meetings, or make decisions in regards to the exceptions generated. The team managers (5th layer) will be responsible for the supervision.*

Positions such as these are typically part-time.

- *There are multiple positions who are allocated over multiple tasks as can be seen in the table below.*

What does the organization structure look like? Complete this table or attach the organization charts provided by the client. An organization chart without FTEs, for example, is not sufficient.

Position	FTEs	Role	Application Experience	Tasks Assigned	Supervisor
Project owner	*0.25*	*SL*	*High*	-	-
External stakeholders	*2*	*SL*	*Medium*	-	-
Project manager	*0.25*	*PM*	*High*	-	*Project owner*
Project controller	*0.25*	*SL*	*High*	-	*Project manager*
Admins	*2.5*	*SL*	*High*	-	*Project manager*
Finishing Head	*0.3*	*SL*	*High*	-	*Project controller*
Finishing manager	*1*	*SL*	*High*	-	*Finishing Head*
Finishing Supervisors	*2*	*SL*	*High*	*Supervision of finishing, façade and completion*	*Finishing manager*
Finishing (Jr. Engineer)	*1*	*ST*	*Medium*	-	*Finishing Supervisors*
Finishing Foreman	*1*	*ST*	*Medium*	-	*Finishing (Jr. Engineer)*
Finishing crew	*20*	*ST*	*Medium*	*Finishing of Apartments, retail and external*	*Finishing Foreman*
Façade crew	*5*	*ST*	*Medium*	*Façade of apartment and retail*	*Finishing Foreman*
Construction Head (Haz. Mini)	*0.5*	*SL*	*High*	-	*Project controller*
Construction manager (Haz. Mini)	*0.5*	*SL*	*High*	-	*Construction Head (Haz. Mini)*
Construction supervisors (Haz. Mini)	*1*	*ST*	*High*	*Supervision of completion*	*Construction manager (Haz. Mini)*
Construction Foreman	*1*	*ST*	*Medium*	-	*Construction supervisors (Haz. Mini)*
Construction crew (Haz. Mini)	*7*	*ST*	*Medium*	*Construction of additional service strucutre*	*Construction Foreman*
MEP head	*0.2*	*SL*	*High*	-	*Project controller*
MEP manager	*0.2*	*SL*	*Medium*	-	*MEP head*
MEP supervisors	*1*	*SL*	*Medium*	*Supervision of MEP at apartments, retail and external, and supervision of completion*	*MEP manager*
MEP Foreman	*1*	*ST*	*Medium*	-	*MEP supervisors*
MEP Crew (Contractor)	*11*	*ST*	*Medium*	*MEP at apartments, retail and external*	*MEP Foreman*

If we don’t have position capacities (FTEs), how and when will we obtain them?

- *We have used the official organization chart of the project team to identify the main members of the team and to further populate it with the FTEs, semi-structured interviews were conducted with the asst. manager (MIS and coordination) of the project. Therefore, we have the FTEs of the major elements and for the rest, assumptions will be used.*

Which positions will use Application Experience; why?

- *Everyone except the working crew (Contractors side) is considered to have a high experience while the application experience of working crew is kept medium.*

Which positions need skills assigned; why?

- *None of the positions need skills assigned to them besides the generic skills that they already have. This is mainly because the kind of activities being performed are traditional in nature. There is no separate skills required for them.*

Do we need a staffed model; why?

- *Yes, we do need a staffed model. This is because we use positions to describe the actors in the modelling. These positions may consist of several team members who may have similar skills and designation in the hierarchy.*

Rework

How will we use rework links?

- *Rework links are used represent the additional work which is generated in any activity if one or multiple of successor activities generate rework. For this reason, the activities with MEP (unit-wise – Meaning either apartment, retail or external) should be linked to finishing (Unit-wise). For example, a problem in MEP of apartment is likely to cause rework in finishing of apartment as well.*

What real life phenomena will they represent?

- *The represent the dependency of one element on another.*

How much rework volume does the customer typically experience?

- *The rework expected to be generated is around 2 weeks (for the finishing in all the unit-types: Apartments, retail and external.*

How will we set rework link strengths?

- *In model 1, the strength of rework links will be kept to default. All the changes and adjustments will be made in model 3.*

How will we validate those settings?

- *Not required for Model 1.*

Communication

How will we use communication links?

- *The communication links represent the additional effort that is required for the coordination. In the given project, the MEP, Finishes and façade work is being parallelly executed. In these situation, coordination is important. Therefore a communication link will be used.*

Will we adhere strictly to the parallel process coordination definition?

- *Not really. Since most of the communication also happens during daily meetings or progress meetings. The communication links are to be used only where there is high level of overlap or complexity is involved.*

What real life phenomena will they represent?

- *The communication links represents the additional effort that is required for the coordination of activities. Two activities, when interlinked and parallel demand cooperation from two or more different teams. This coordination needs efforts of communication which in this model is expressed through the communication link.*

How much communication volume does the customer typically experience?

- *Depending on the activities, the customer can experience somewhere around 5 days to 7 days of communication volume.*

Meetings

Complete this table or attach a source document that has all the same information.

	Meeting	Duration	Frequency	Attendees	Start	End
1	*Various meetings*	*2 hours*	*Every month*	*Project owner* *Project manager* *Project controller* *External stakeholders* *Admins*	*11:00 AM*	*01:00 AM*
2	*Daily meetings*	*35 Mins*	*Every day*	*Finishing Manager* *Finishing Supervisor* *Construction manager* *Construction supervisor* *MEP Manager* *MEP supervisor*	*8:00 AM*	*8:35 AM*
3	*Weekly progress meetings*	*1 hour*	*Every Week*	*Project controller* *Finishing Head* *Finishing Managers* *MEP head* *MEP manager* *Construction head* *Construction managers*	*4 PM*	*5 PM*

Categories

How will we use categories? Complete this table.

	Category	Description	Members
1	*Senior management*	*Representing the top hierarchy of the project team*	*Project owner, Project Manager, Project controller*
2	*Construction team*	*Representing the inhouse members working on the project*	*Finishing head, Finishing manager, Finishing supervisors, Jr. engineer finishes, finishes foreman, Finishing crew Finishing head, façade crew, Construction head, construction manager, construction supervisor, construction foreman construction crew, MEP head, MEP manager, MEP supervisor, MEP foreman, MEP crew and admins*
5	*Other members*	*Representing stakeholders*	*External stakeholders*

Colors

How will we use colors in the model diagram; what will they represent?

- Organization elements
  - *The project owner can be assigned a different color (say red), the inhouse team can be represented using the default color (= green) and the contracted personnel (the workforce) can be represented using a different color (say= orange)*
- Processes or functions
  - *A unique color can be used to represent similar kind of activity. For example, all the finishing activities will be represented using blue color, all the MEP activities will be represented using orange color likewise for other activities too.*
- Business units
  - *Not required in my opinion.*
- Project phases
  - *Since the model is just about the finishing phase of the project, this is also not required.*

MODEL 2

"This portion only intends to highlight the areas which will be modified in model 1. The rest of the elements will remain the same as model 1."

Complete this table or attach a source document that has all the same information. A Gantt or flow chart that does not include work volumes, for example, is not sufficient.

This table is populated according to the "actual dates" pertaining to the project.

How is the work volume calculated?

Ans: Most of the activities mentioned below are still in progress. In the interview with Asst. Manager (MIS and Coordination) conducted on 25th November 2021, I got to know the actual start time of these activities and the percentage completion (on the date of interview). Assuming a linear relation between the percentage completion and planned duration of activities, actual finishes are calculated by extrapolation. Example, the planned start and planned finish dates (1/04/21 and 30/08/21) of the activity - Apartment finishes has a duration of 151 days. However, the actual start date of the project is 28/03/21 and as of 25th November 2021, the activity was 55% complete. Extrapolating it with respect to the interview date, the anticipated finish date will be 31/01/22 {interview date + (1 – Percentage completion)* planned duration = 25/11/21 + ((1-0.55)*151) = 31/01/22). These work durations are then converted to the work volumes using work-volume calculator provided in SimVision®.

	Task	Type	Work Volume	Position	Planned Duration
1	*Supervision of Finishes*	*FTE*	*1 FTE*	*Finishing head*	*-*
2	*Apartment Finishes*	*Max Duration*	*198 days*	*Finishing crew*	*34 weeks*
3	*Retail Finishes*	*Max Duration*	*176 days*	*Finishing crew*	*30 weeks*
4	*External Finishes*	*Max Duration*	*140 days*	*Finishing crew*	*24 weeks*
5	*Supervision of MEP*	*FTE*	*1 FTE*	*MEP head*	*-*
6	*Apartment MEP*	*Max Duration*	*193 days*	*MEP Crew*	*33 weeks*
7	*Retail MEP*	*Max Duration*	*175 days*	*MEP Crew*	*30 weeks*
8	*External MEP*	*Max Duration*	*122 days*	*MEP Crew*	*21 weeks*
9	*Supervision of facade*	*FTE*	*1 FTE*	*Finishing head*	*-*
10	*Apartment Facade*	*Max Duration*	*61 days*	*Finishing crew*	*11 weeks*
11	*Retail Facade*	*Max Duration*	*61 days*	*Finishing crew*	*11 weeks*
12	*Construction of additional service structure*	*Max Duration*	*123 days*	*Construction crew*	*21 weeks*
13	*Commissioning and completion <Finishes>*	*Max Duration*	*5 days*	*Finishing crew and finishing supervisors*	*9 days*
14	*Commissioning and completion <MEP>*	*Max Duration*	*5 days*	*MEP crew ad MEP supervisor*	*9 days*
15	*Commissioning and completion <Facade>*	*Max Duration*	*5 days*	*facade crew and facade supervisors*	*9 days*
14	*Legal handovers*	*Max Duration*	*15 days*	*Construction crew and admins*	*22 days*

Do we understand the predecessors and successors for each one?

The table below is populated using actual start and predicted actual finish dates

Activity	*Duration (Days)*	*Start (DD-MM-YYYY)*	*Finish (DD-MM-YYYY)*
Apartment Finishes	*200 days*	*28-03-2021*	*30-12-2021*
Retail Finishes	*177 days*	*02-04-2021*	*06-12-2021*
External Finishes	*141 days*	*28-05-2021*	*10-12-2021*
Apartment MEP	*194 days*	*16-03-2021*	*10-12-2021*
Retail MEP	*177 days*	*28-03-2021*	*28-11-2021*
External MEP	*123 days*	*10-06-2021*	*28-11-2021*
Apartment Facade	*62 days*	*15-09-2021*	*09-12-2021*
Retail Facade	*62 days*	*15-09-2021*	*09-12-2021*
Construction of additional service structure	*124 days*	*10-06-2021*	*30-11-2021*
Commissioning	*9 days*	*01-12-2021*	*11-12-2021*
Completion	*21 days*	*05-12-2021*	*31-12-2021*

Complete this table or attach a source document that has all the same information.

	Milestone	Planned Date (DD- MM-YYYY)	Predecessors (Entry)	Successors (Exit)
1	*Completion of RCC structure*	*11-07-2019*	*Start*	*Start of MEP and finishes*
2	*Start of MEP and finishes*	*06-03-2021*	*Completion of RCC structure*	*Completion of apartment* *Completion of Retail* *Completion of externals*
3	*Completion of structure*	*31-12-2021*	*Start of MEP and Finishing phase*	

MODEL 3

"MODEL 3 will be a copy of MODEL 1 with average values for different parameters and probabilities as suggested in ePM guide. This section of the modelling plan only discusses the elements that will be changed in comparison to the model 1."

Architecture

What simulation probabilities will we use; why?

- Information Exchange: 0.20
- Noise: 0.10
- Functional Exception: 0.05
- Project Exception: 0.05

- *The above mentioned probabilities are planned to be used in the baseline model.*
- *Information exchange probability is proposed to be set to 0.20 since the tasks involved are mainly routine. Therefore, the number of communications expected to be generated are less.*
- *The noise probability is more of a cultural value in my opinion and in my experience, the companies in India do have a bit higher noise compared to the western countries (A wild assumption though). As recommended in the ePM guide, the common probability is 0.1 which is high in value but also common*
- *Since, functional exception probability refers to the errors generated to the self-checks whose value can be more if a new method or technology is used. Since the given project only aims to model the finishing phase of the Hazratganj mini., the techniques followed are largely traditional. Therefore, I expect a value on the lower side of the spectrum hence 0.05 is proposed.*

- *Project exception or project error probability is a measure of how the dependent activities are likely to produce additional rework if the proceeding activity fails. As recommended by ePM guide, a value on lower side should be used for standard tasks. Again since the model aims to simulate the finishing phase of the sub-project, it mainly involves routine tasks. Therefore, a value of 0.05 is proposed.*

Do we need to use Team Experience; why?

- *Initially, Team experience is proposed to be kept checked (default in SimVision®, meaning a medium Team experience). However, for the later experimentation the team experience is proposed to be kept high. This is because, the teams deployed not on;ly for Hazratganj mini but also for other sub-projects have background for the construction of similar kind of projects- integrated projects.*

Do we need to use Matrix Strength; why?

- *Similar to Team experience, Matrix strength is proposed to be kept locked or constant, initially. In the experimentation stage, the matrix strength is proposed to set to medium or low. This is because, as evident from the organization structure of the project team, the team is mainly composed of specialist groups and managed by functional managers.*

Do we need to use Centralization; why?

- *Similar to above, the centralization is also proposed to be kept locked or constant, initially. After that it is proposed that the centralization should be kept as high. This is to demonstrate highly hierarchical structure in Omaxe.*

Do we need to use Formalization; why?

- *Similar to above, the Formalization is also proposed to be kept locked or constant in the beginning and should be experimented with different iterations. I believe that the formalization should be set to either medium or low since the working culture in India is more relationship-based which typically indicate more informal interactions within team members. However, the hierarchy in the teams also demand formalization to some extent. Therefore, I think a medium formalization would more closely suit the for the purpose of modelling.*

Rework

How much rework volume does the customer typically experience?

- *The rework expected to be generated is around 2 weeks FTE (for the finishing in all the unit-types: Apartments, retail and external.*

How will we set rework link strengths?

- *The strength of the rework link can be set by iterating model 3 in such a way that model 3 closely resembles the activities in model 2.*

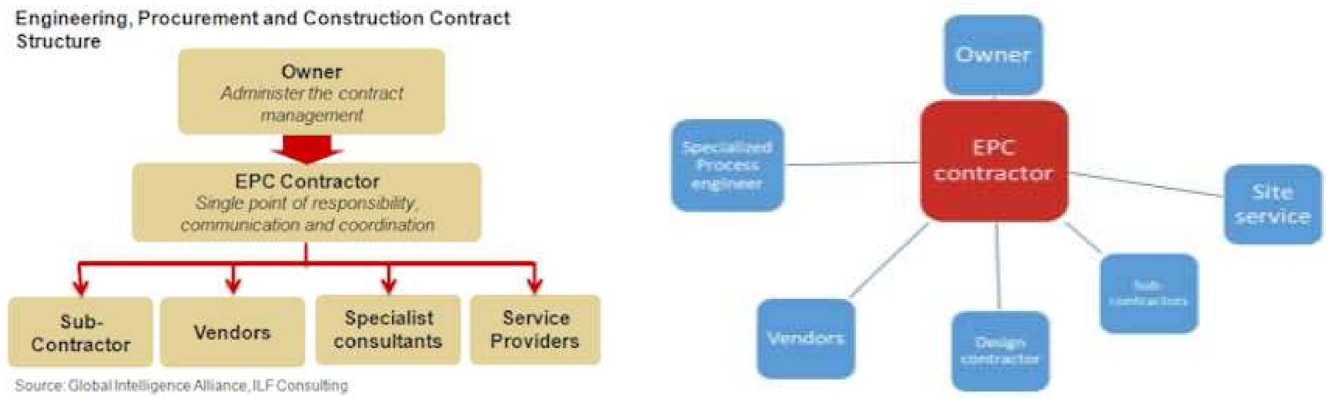
How will we validate those settings?

- *Those settings can be validated by both, comparing it to the reference model (MODEL 2) and also through consultation with company personnel.*

Comparative Case No. 1 (Case EPC)

This comparative case proposes to change team composition and organization structure of the project team by using EPC (Engineering Procurement and Construction) delivery system between the client (Omaxe) and a contractor.

EPC stands for engineering, procurement and construction in which the hired contractor is responsible for the design and construction of the project within agreed-upon duration and cost. This contract is very much similar to turn-key delivery system and sometimes the terms are used interchangeably. The final project should be able to deliver the quality measures defined in the contracts and contractor holds liabilities for any performance related deviations.



General structure of the EPC

Purpose and Scope

What risk from the Business Case will this simulation case address?

- *This case will simulate the effect of having an outside contractor executing the work on site which will largely limit the direct involvement of client itself. However, the client will have to be involved in regular quality audits and payments. The main risks that this business case will address is that of success markers. More specifically, the risks pertaining to the duration of the project.*

What Business Case questions will this simulation case answer quantitatively?

- *This business case can answer questions like what percentage of duration was expected to be shortened by using EPC contracts for a sub-project in integrated project.*

From which simulation case will this one be derived?

- *This business case will be derived from the baseline model (having the balanced settings – a product of iterations for model 3)*

To which simulation case(s) will this one be compared?

- *The model will be compared to the baseline model as well as other comparative cases, discussed further.*

Work Process

What specific changes will we make to the work process?

- Work volumes – *Remains the same since the activities do not change.*
- Assignments – *NA*
- Predecessors – *No changes since the activities do not change. An assumption is that the works carried out by the contractors will follow the exact same path as Omaxe did.*
- Successors - *No changes since the activities do not change. An assumption is that the works carried out by the contractors will follow the exact same path as Omaxe did*
- Consolidating tasks – *No Changes*
- Decomposing tasks – *No changes*
- Deleting tasks – *No changes*
- Creating new tasks – *Maybe quality audits?*
- Complexity – *No changes*
- Uncertainty- *No changes*
- Skill - *No changes*

How will these changes enable us to answer the business case questions?

- *The changes especially the addition of quality audits will add more time that will be consumed towards quality audit meetings.*

What is the expected impact on simulation results?

- *Increased time in exchange of better quality.*

Does the source case (from which this one is derived) contain the work components necessary for these changes?

- *Yes, the activities majorly remain more or less the same.*

Does the comparison case contain the work components necessary for comparison?

- *Yes, since the intention is just to change the organizational properties and not the work environment itself, the comparison case will have the same work components.*

Organization

What specific changes will we make to the organization?

- Capacity – *An assumption would be that the contractors hired for a sub-project will dedicate their sole attention for one sub-project which in this case is Hazratganj Mini. Therefore, the FTEs of personnel will not be distributed over multiple projects. The idea is to have a client (FTE 3 – Owner, PM and PC) who are the owners of the project, contractor head (FTE 1) for Haz. Mini who will supervise construction, finishing and MEP supervisors (FTEs 1, 2 and 1 respectively). These supervisors will then execute the works by deploying the man force which will be in exact numbers as how Omaxe is doing it (Finishing: 20 FTEs, MEP: 12 FTEs and Construction: 8 FTEs). The work executed by the contractor will be periodically audited by quality auditors (3 FTEs).*
- Role: *The contractor head will assume the position of PM, the supervisors the role of SL and rest, ST.*
- Skill: *The skills will not be modelled.*
- Application experience: *High for all since the contractors are usually hired for having expertise in the specific field.*
- Supervision: *The supervisors will be responsible for overlooking their respective activities. For example, finishing supervisor will supervise the finishing related tasks and the finishing man force/crew will directly report to the finishing supervisor.*
- Assignments: *The workforce will be attributed to their respective activities. The supervisors will be given the supervisory assignment for the tasks.*
- Meeting attendance: *Meetings are explained in detail in coming parts of the comparative case.*
- Consolidating positions: *The team of client which will compose of Project owner, Project manager and Project controller can be combined together. Since they do not have any distinctive roles in this case and yet they are main entities as stakeholders, they can be merged together.*
- Decomposing positions: *NA*
- Deleting positions: *All the positions from the inhouse team will be deleted. These positions include: Admin heads, admin staff, entire construction team, finishing team and also MEP team. The only positions remaining will be that of top hierarchy.*
- Creating new positions: *Quality auditors (3 FTEs). The assumption here is that each auditor will have their respective expertise in construction, finishing and MEP.*
- Staffing: *Look at the table below:*

Position	FTEs	Role	Application Experience	Tasks Assigned	Supervisor
Owner	*1*	*PM*	*High*	-	-
Project manager (Client)	*1*	*ST*	*High*	-	*Owner*
Project manager (contractor)	*1*	*SL*	*High*	-	*Project manager (clientr)*
Construction manager	*1*	*ST*	*High*	-	*Project manager (contractor)*
Finishing manager	*1*	*ST*	*High*	-	*Project manager (contractor)*

Position	FTEs	Role	Application Experience	Tasks Assigned	Supervisor
MEP manager	*1*	*ST*	*High*	-	*Project manager (contractor)*
Admins	*4*	*ST*	*High*	-	*Project manager (contractor)*
Senior manager	*1*	*ST*	*High*	-	*Project manager (contractor)*
Owner engineer	*1*	*ST*	*High*	-	*Project manager (contractor)*
Finishing representative	*2*	*ST*	*High*	*Supervision (finishes)*	*Senior manager*
MEP representative	*2*	*ST*	*High*	*Supervision (MEP)*	*Senior manager*
Facade representative	*2*	*ST*	*High*	*Supervision (Façade)*	*Senior manager*
Construction Supervisor (contractor)	*1*	*SL*	*High*	*Supervise construction*	*Construction manager*
Finishes Supervisor (contractor)	*2*	*SL*	*High*	*Supervise finishes*	*Finishes manager*
MEP Supervisor (contractor)	*1*	*SL*	*High*	*Supervise MEP*	*MEP manager*
Construction crew (Contractor)	*8*	*ST*	*High*	*Construction activity*	*Construction Supervisor (contractor)*
Finishes crew (Contractor)	*20*	*ST*	*High*	*Finishing activities*	*Finishes Supervisor (contractor)*
MEP crew (Contractor)	*12*	*ST*	*High*	*MEP activities*	*MEP Supervisor (contractor)*

How will these changes enable us to answer the business case questions?

- *The business case attaches the contract type of EPC between client and the contractor. The number of layers in the organization structure will reduce affecting the organization structure. Similarly, the composition will also change owing to the application experiences of positions. Therefore, this will create a business case which will have a distinctive impact on the duration of the project.*

What is the expected impact on simulation results?

- *In my opinion, the duration should decrease. The main reasons would be due to reduction in layers of hierarchy which will impact the speed at which the decisions are made. Additionally, a high application experience will enable a better quality product as well.*

Does the source case (from which this one is derived) contain the organization components necessary for these changes?

- *Not all the organizational components from the source case are necessary for this comparative case. The main organizational components required are the ones from the top layer of the hierarchy.*

Does the comparison case contain the organization components necessary for comparison?

- *Yes. All the main components are included in the comparison case.*

Milestones

What specific changes will we make to the milestones?

- Planned date
- Predecessors
- Successors

- *No changes*

How will these changes enable us to answer the business case questions?

What is the expected impact on simulation results?

Rework

What <u>specific</u> changes will we make to rework?

- Adding links
- Removing links
- Rearranging links
- Changing link strength
- Changing PEP
- Changing FEP

- *No changes*

Can we justify changing rework values with real-world examples? Topological changes and changes to Application Experience, Complexity or Uncertainty are typically easier to explain and justify than simply altering rework strength or probability.

How will these changes enable us to answer the business case questions?

What is the expected impact on simulation results?

Communication

What <u>specific</u> changes will we make to communication?

- Adding links
- Removing links
- Rearranging links
- Information Exchange Probability

- *No changes*

Can we justify changing parameter values with real-world examples? Topological changes and changes to Application Experience, Complexity, Uncertainty or Formalization are typically easier to explain and justify than simply altering probability.

- *No changes*

How will these changes enable us to answer the business case questions?

What is the expected impact on simulation results?

- *No changes*

Meetings

What <u>specific</u> changes will we make to meetings?

- Adding meetings
- Removing meetings
- Attendees
- Priorities
- Schedules

	Meeting	Duration	Frequency	Attendees	Start	End
1	*Daily meeting*	*35 mins*	*everyday*	*Discipline supervisors and managers*	*08:00 AM*	*8:35 AM*
2	*Bi-weekly progress meeting*	*1 Hr.*	*Every 2 weeks*	*Discipline Managers, supervisors, Project manager (contractor), representatives*	*09:00 AM*	*10:00 AM*
3	*Daily meeting (other projects)*	*2 Hr*	*everdays*	*Discipline supervisors and managers*	*3 PM*	*5 PM*
4	*Bi-weekly meetings (other projects)*	*2 Hr*	*Every 2 weeks*	*Discipline Managers, supervisors, Project manager (contractor), representatives*	*1 PM*	*3 PM*
5	*Quality audits, progress and change control*	*2 Hr*	*Every month*	*All the staff except supervisors and crew members*	*10 AM*	*12 PM*
6	*Quality audits, progress and change control (other projects)*	*4 Hr.*	*Every two weeks*	*All the staff except supervisors and crew members*	*8 AM*	*12 PM*
7	*Var. meetings*	*3 Hr.*	*Every 2 weeks*	*Supervisors*	*12 PM*	*3 PM*

How will these changes enable us to answer the business case questions?

- *These changes will limit the engagement of top hierarchy in meetings. They can take a back seat in the process and view the progression of their project.*

What is the expected impact on simulation results?

- *Previously, the top hierarchy was highly occupied in the meetings and was also able to dedicate lesser time for individual sub-projects which I suspect would increase the decision-backlogs on top management. With reduced layers and meetings, the time lost in decision making will be somewhat recouped which will expediate the process of construction.*

Architecture

What specific changes will we make to:

- Probabilities: *No changes*
- Centralization: *No changes*
- Formalization*: No changes*
- Team Experience: *No changes*
- Matrix Strength: *No changes*

Can we explain and justify these changes with real-world examples?

How will these changes enable us to answer the business case questions?

What is the expected impact on simulation results?

Comparative Case No. 2 (Robustness case)

The intention for this case is to perform an open exploration with respect to different settings inputs (Team experience, centralization, formalization, matrix strength, information exchange probability and noise). Since the research question also focuses on the aspects of communication and information flow, I believe, an open exploration should be able to provide an insight into how the cultural properties of any organization affect communication and hence in turn, the duration of the project.

Purpose and Scope

What risk from the Business Case will this simulation case address?

- *This business case will address the impact of company's culture (essentially the factors that impact communication and information exchange) on the duration of the project.*

What Business Case questions will this simulation case answer quantitatively?

- *What is the most dominant team factor that effects the duration of the project and how significant of a change can it make?*

From which simulation case will this one be derived?

- *This simulation case will be derived from the baseline case.*

To which simulation case(s) will this one be compared?

- *This simulation case will be compared only to the baseline case. Since the objective is independently judge the impact of the variables on duration, this can only be achieved by comparing the comparative case with the source case.*

Work Process

What specific changes will we make to the work process?

- Work volumes – *No change*
- Assignments– *No change*
- Predecessors– *No change*
- Successors– *No change*
- Consolidating tasks– *No change*
- Decomposing tasks– *No change*
- Deleting tasks– *No change*
- Creating new tasks– *No change*
- Complexity– *No change*
- Uncertainty– *No change*
- Skill– *No change*

How will these changes enable us to answer the business case questions?

What is the expected impact on simulation results?

Does the source case (from which this one is derived) contain the work components necessary for these changes?

Does the comparison case contain the work components necessary for comparison?

Organization

What specific changes will we make to the organization?

- Capacity– *No change*
- Role– *No change*
- Skill– *No change*
- Application experience– *No change*
- Supervision– *No change*
- Assignments– *No change*
- Meeting attendance– *No change*
- Consolidating positions– *No change*

- Decomposing positions– *No change*
- Deleting positions– *No change*
- Creating new positions– *No change*
- Staffing– *No change*

How will these changes enable us to answer the business case questions?

What is the expected impact on simulation results?

Does the source case (from which this one is derived) contain the organization components necessary for these changes?

Does the comparison case contain the organization components necessary for comparison?

Milestones

What specific changes will we make to the milestones?

- Planned date– *No change*
- Predecessors– *No change*
- Successors– *No change*

How will these changes enable us to answer the business case questions?

What is the expected impact on simulation results?

Rework

What specific changes will we make to rework?

- Adding links– *No change*
- Removing links– *No change*
- Rearranging links– *No change*
- Changing link strength– *No change*
- Changing PEP– *No change*
- Changing FEP– *No change*

Can we justify changing rework values with real-world examples? Topological changes and changes to Application Experience, Complexity or Uncertainty are typically easier to explain and justify than simply altering rework strength or probability.

How will these changes enable us to answer the business case questions?

What is the expected impact on simulation results?

Communication

What specific changes will we make to communication?

- Adding links– *No change*
- Removing links– *No change*
- Rearranging links– *No change*
- Information Exchange Probability– *No change*

Can we justify changing parameter values with real-world examples? Topological changes and changes to Application Experience, Complexity, Uncertainty or Formalization are typically easier to explain and justify than simply altering probability.

How will these changes enable us to answer the business case questions?

What is the expected impact on simulation results?

Meetings

What specific changes will we make to meetings?

- Adding meetings– *No change*
- Removing meetings– *No change*
- Attendees– *No change*
- Priorities– *No change*
- Schedules– *No change*

How will these changes enable us to answer the business case questions?

What is the expected impact on simulation results?

Architecture

What specific changes will we make to:

- Probabilities
- Centralization:
- Formalization:
- Team Experience:
- Matrix Strength:

Input Variable	***Range***
Team Experience	*High, Medium, Low*
Centralisation	*High, Medium, Low*
Formalisation	*High, Medium, Low*
Matrix strength	*High, Medium, Low*
Information exchange probability	*Nominal value:0.2* *Extreme value: 0.90*
Noise Probability	*Nominal value: 0.01* *Extreme value: 0.2*

The idea is to create a combination table using the power query tool in excel and use the above mentioned ranges for the input variables to determine different outputs in regards to the duration of the project. The results will then be analyzed to determine the most influential variable.

How will these changes enable us to answer the business case questions?

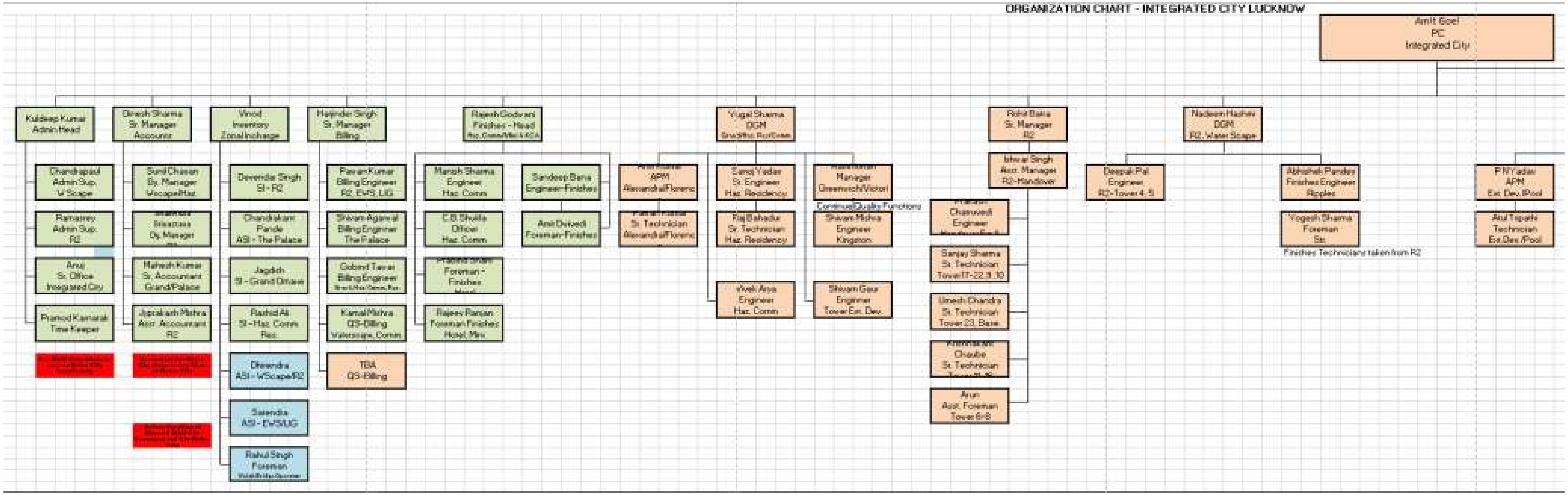
- *The analysis of the table will enable to identify different trends with respect to the inputs of different variables (Setting parameters). Their impact on duration will enable to justify their cruciality on the efficiency of project teams.*

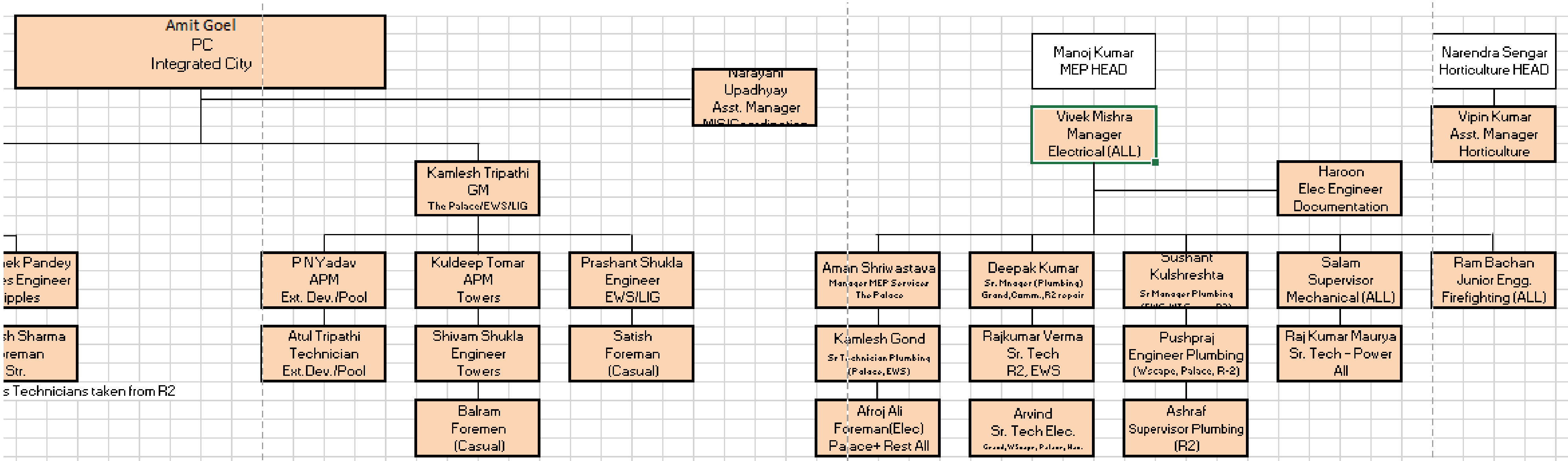
What is the expected impact on simulation results?

- *The identification of crucial variables (Settings parameters) will enable to reduce the duration of the project.*

Appendix – D

Official organizational chart of Omaxe





Amit Goel
PC
Integrated City
Upadhyay
Asst. Manager
Kamlesh Tripathi
GM
The Palace/EWS/LIG
ek Pandey
es Engineer
ipples
h Sharma
reman
Str.
s Technicians taken from R2
P N Yadav
APM
Ext. Dev./Pool
Atul Tripathi
Technician
Ext.Dev./Pool
Kuldeep Tomar
APM
Towers
Shivam Shukla
Engineer
Towers
Balram
Foremen
(Casual)
Prashant Shukla
Engineer
EWS/LIG
Satish
Foreman
(Casual)
Manoj Kumar
MEP HEAD
Vivek Mishra
Manager
Electrical (ALL)
Haroon
Elec Engineer
Documentation
Aman Shriwastava
Manager MEP Services
The Palace
Kamlesh Gond
Sr Technician Plumbing
(Palace, EWS)
Afroj Ali
Foreman(Elec)
Palace+ Rest All
Deepak Kumar
Sr. Mnager (Plumbing)
Grand,Comm.,R2 repair
Rajkumar Verma
Sr. Tech
R2, EWS
Arvind
Sr. Tech Elec.
Sushant
Kulshreshta
Sr Manager Plumbing
Pushpraj
Engineer Plumbing
(Wscape, Palace, R-2)
Ashraf
Supervisor Plumbing
(R2)
Salam
Supervisor
Mechanical (ALL)
Raj Kumar Maurya
Sr. Tech - Power
All
Ram Bachan
Junior Engg.
Firefighting (ALL)
Narendra Sengar
Horticulture HEAD
Vipin Kumar
Asst. Manager
Horticulture

Appendix – E

Position properties

Position	Name	Description	Role	Application Experience	FTE	Salary	Work Day		Work Week	
1	Project Controller		SL	High	1	0	8	☑	5	☑
2	Finishing head		ST	High	1	0	8	☑	5	☑
3	Finishing Supervisors		ST	Medium	2	0	8	☑	5	☑
4	Finishing crew (Contractor)		ST	Low	20	0	8	☑	5	☑
5	Construction head HAZ. MINI		ST	High	1	0	8	☑	5	☑
6	Construction Manager HAZ. MINI		ST	Medium	1	0	8	☑	5	☑
7	Construction supervisors HAZ. MINI		ST	Medium	1	0	8	☑	5	☑
8	Construction crew HAZ. MINI		ST	Low	7	0	8	☑	5	☑
9	MEP head		ST	High	1	0	8	☑	5	☑
10	MEP Manager		ST	Medium	1	0	8	☑	5	☑
11	MEP supervisors		ST	Medium	1	0	8	☑	5	☑
12	MEP crew (Contractor)		ST	Low	11	0	8	☑	5	☑
13	Project Manager		PM	High	1	0	8	☑	5	☑
14	Project Owner		ST	High	1	0	8	☑	5	☑
15	Stakeholder(s)		ST	Medium	2	0	8	☑	5	☑
16	Admins		ST	High	2.5	0	8	☑	5	☑
17	Finishing Foreman		ST	Medium	1	0	8	☑	5	☑
18	Construction foreman (Haz. Mini)		ST	Medium	1	0	8	☑	5	☑
19	MEP foremen		ST	Medium	1	0	8	☑	5	☑
20	Finishing Manager		ST	Medium	1	0	8	☑	5	☑
21	Facade crew (Contractor)		ST	Medium	5	0	8	☑	5	☑
22	Finishing (Jr. engineer)		ST	Medium	1	0	8	☑	5	☑

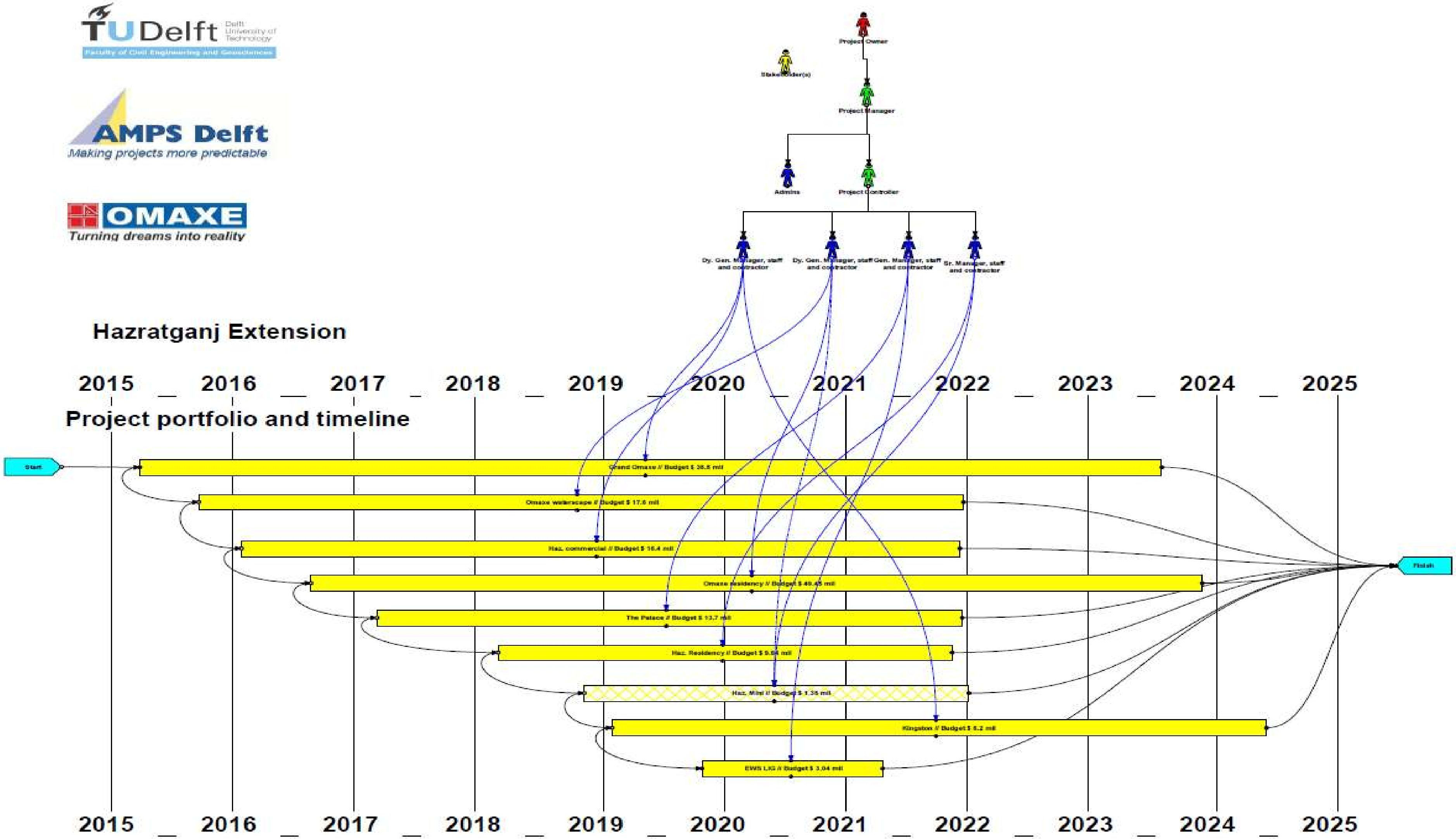
Appendix – F

Activity properties

Task	Name	Description	Priority	Work Type	Work Value	Units	Assignment	Skills	Requirement Complexity	Solution Complexity	Uncertainty
1	Supervision of Finishing		Medium	Supervisory	1	FTEs		Generic	Low	Low	Low
2	Apartment Finishes		Low	Work Volume	864	Days		Generic	High	Low	High
3	Retail Finishes		Medium	Work Volume	564	Days		Generic	High	Low	High
4	External Finishes		Low	Work Volume	258	Days		Generic	Medium	Medium	Medium
5	Supervision of MEP		Medium	Supervisory	1	FTEs		Generic	Low	Low	Low
6	Apartment MEP		Low	Work Volume	490	Days		Generic	High	High	High
7	Retail MEP		Medium	Work Volume	291	Days		Generic	High	High	High
8	External MEP		High	Work Volume	261	Days		Generic	Low	Low	Low
9	Supervision of Facade		Medium	Supervisory	1	FTEs		Generic	Low	Low	Low
10	Retail facade		Low	Work Volume	64	Days		Generic	Medium	Low	High
11	Apartment Facade		Low	Work Volume	110	Days		Generic	Medium	Low	High
12	Construction of additional service struct		Low	Work Volume	270	Days		Generic	Low	Low	Low
13	Comissioning & Completion Finishing Wo		Low	Work Duration	5	Days		Generic	Low	Low	Low
14	Comissioning & Completion MEP Work		Low	Work Duration	5	Days		Generic	Low	Low	Low
15	Comissioning & Completion Facade Wor		Low	Work Duration	5	Days		Generic	Low	Low	Low
16	Legal Hand over		Low	Work Duration	15	Days		Generic	Low	Low	Low
17	Portfolio Projects (ex HAZ mini)		High	Work Duration	20	Weeks		Generic	Medium	Low	High

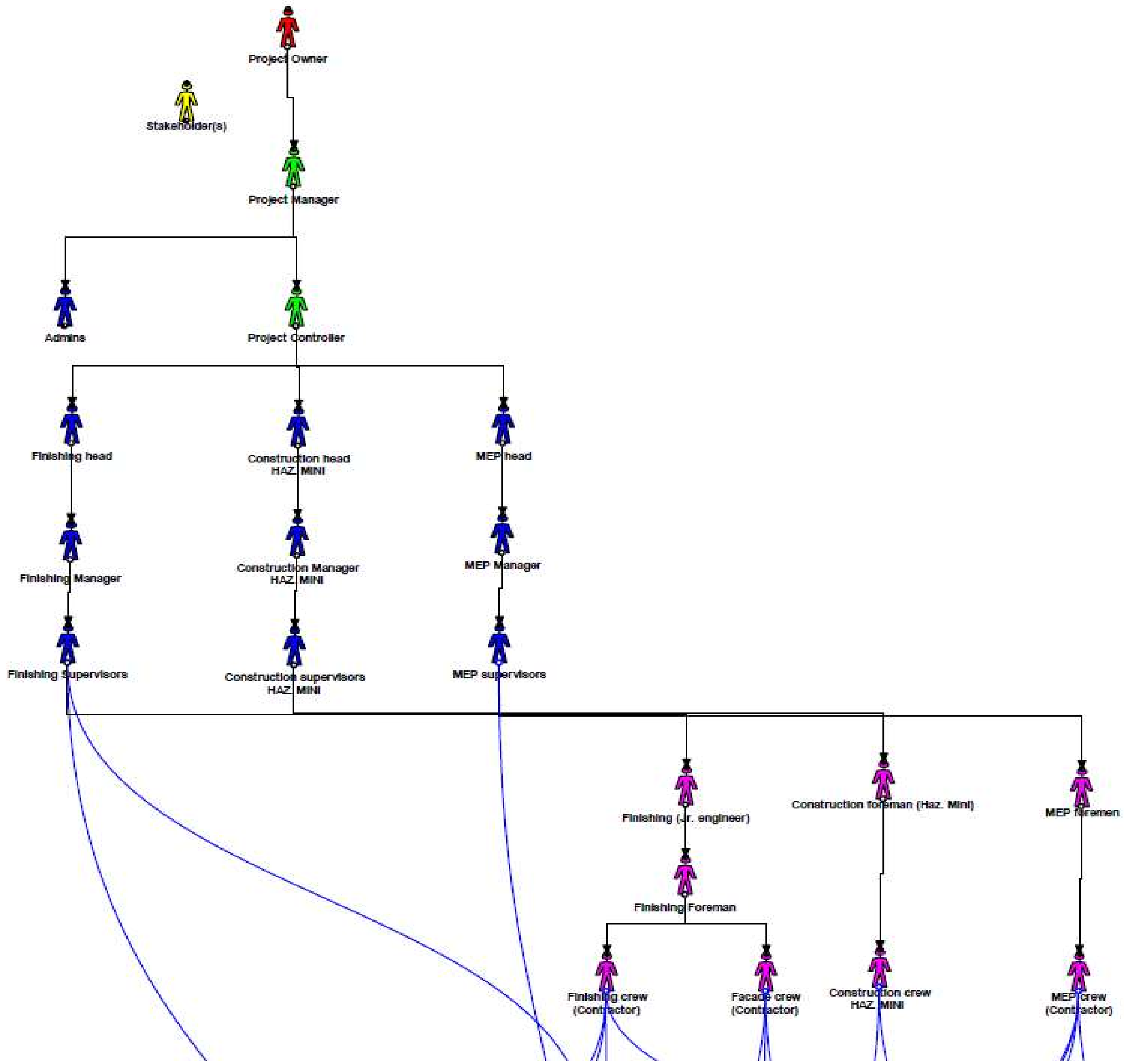
Appendix – G.1

Portfolio team



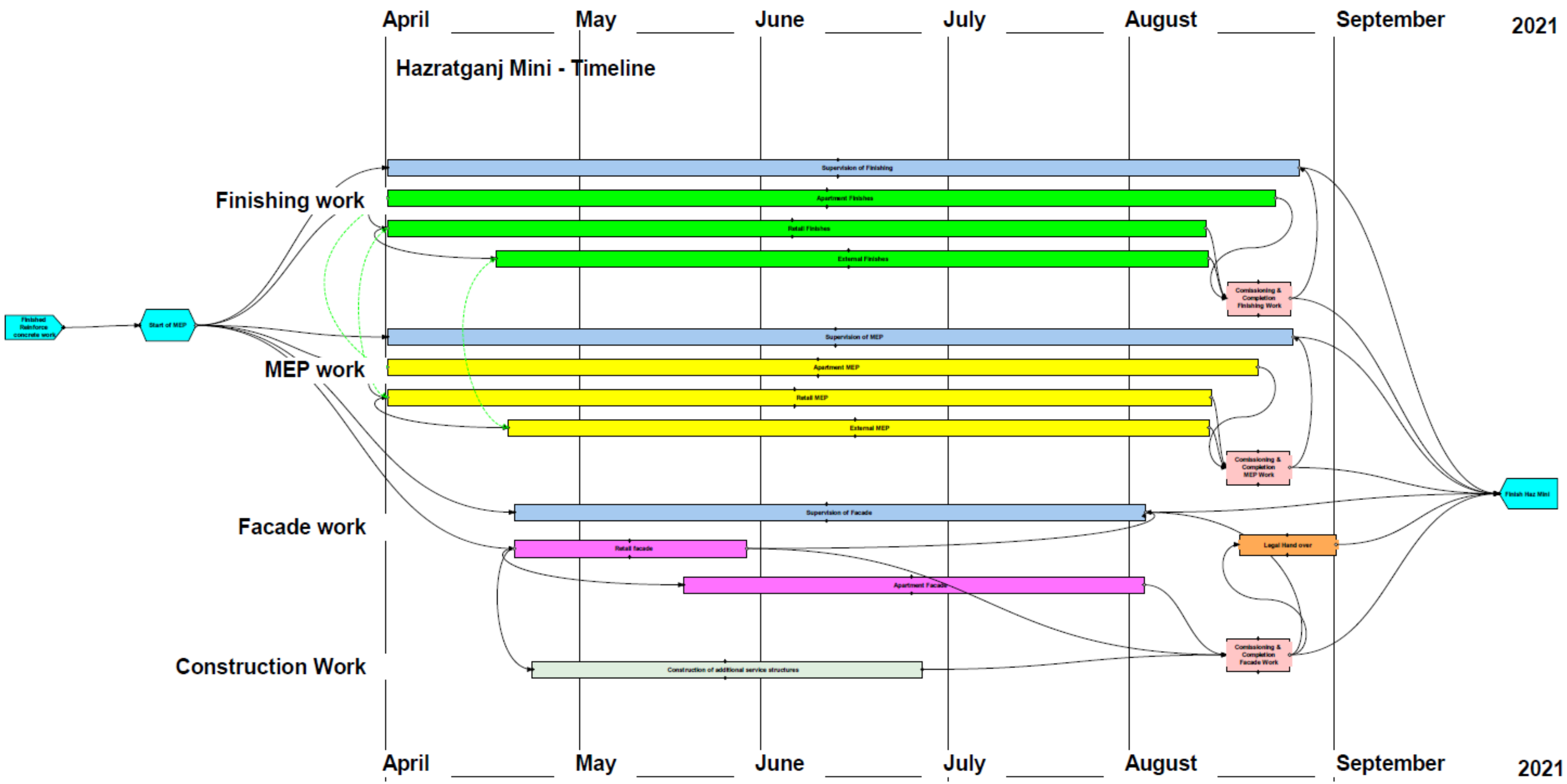
Appendix – G.2

Organization structure (Model 1)



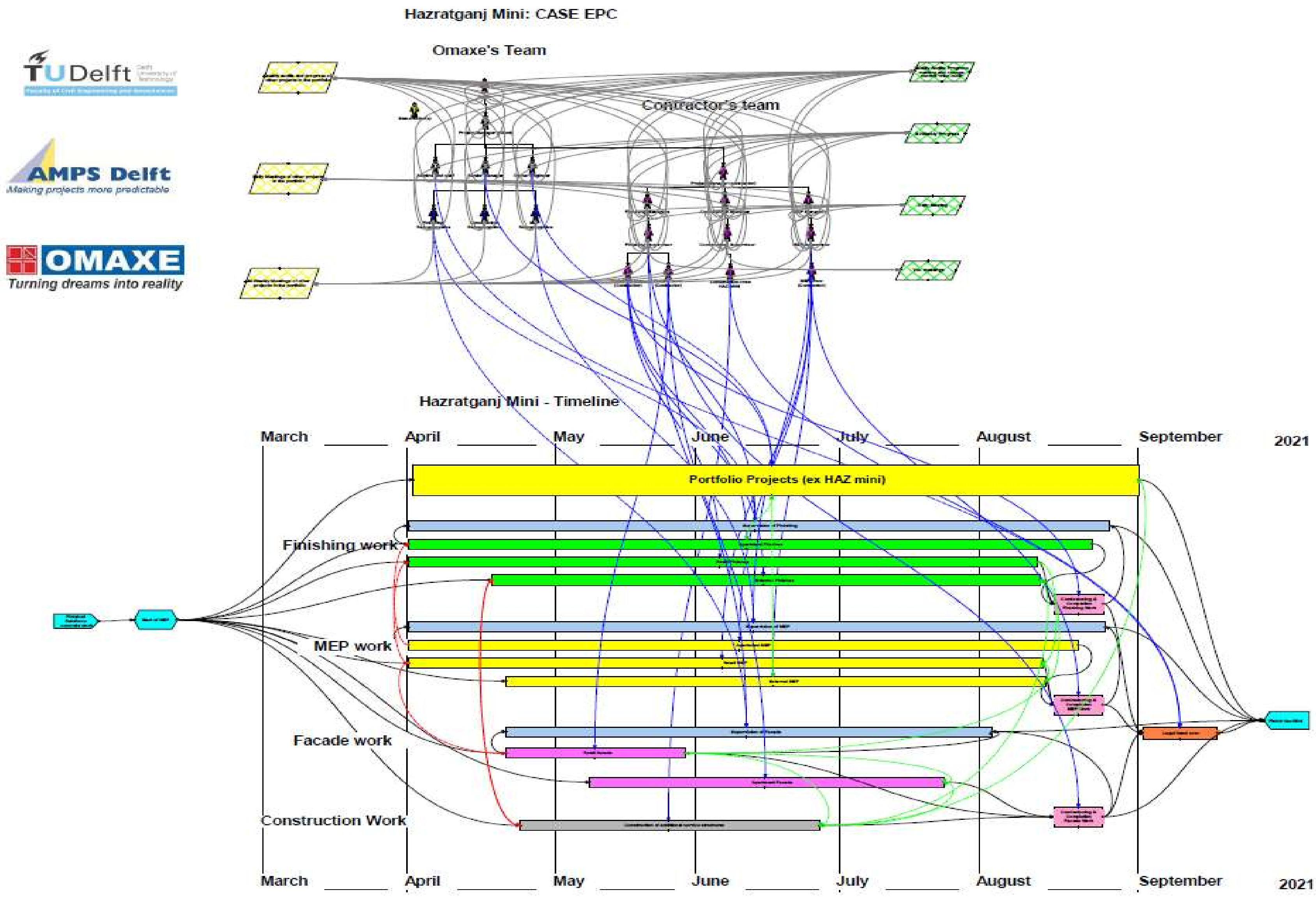
Appendix – G.3

Timeline and links (Model 1)



Appendix – H

Experimental Model



Appendix – I

Robustness test / Sensitivity analysis

Planned start date	01-04-2021
Actual date of completion	26-01-2022
Baseline Duration	300

Team experience	Centralisation	Formalisation	Matrix strength	Info. Exchange	Noise	Date of completion	Deviation	Duration	% Deviation
High	High	High	High	0.9	0.01	05-01-2022	21	279	93
High	High	High	High	0.9	0.2	10-01-2022	16	284	94.66666667
High	High	High	High	0.2	0.01	04-01-2022	22	278	92.66666667
High	High	High	High	0.2	0.2	05-01-2022	21	279	93
High	High	High	Medium	0.9	0.01	11-01-2022	15	285	95
High	High	High	Medium	0.9	0.2	11-01-2022	15	285	95
High	High	High	Medium	0.2	0.01	07-01-2022	19	281	93.66666667
High	High	High	Medium	0.2	0.2	05-01-2022	21	279	93
High	High	High	Low	0.9	0.01	04-01-2022	22	278	92.66666667
High	High	High	Low	0.9	0.2	13-01-2022	13	287	95.66666667
High	High	High	Low	0.2	0.01	10-01-2022	16	284	94.66666667
High	High	High	Low	0.2	0.2	10-01-2022	16	284	94.66666667
High	High	Medium	High	0.9	0.01	07-01-2022	19	281	93.66666667
High	High	Medium	High	0.9	0.2	07-01-2022	19	281	93.66666667
High	High	Medium	High	0.2	0.01	04-01-2022	22	278	92.66666667
High	High	Medium	High	0.2	0.2	05-01-2022	21	279	93
High	High	Medium	Medium	0.9	0.01	24-01-2022	2	298	99.33333333
High	High	Medium	Medium	0.9	0.2	26-01-2022	0	300	100
High	High	Medium	Medium	0.2	0.01	07-01-2022	19	281	93.66666667
High	High	Medium	Medium	0.2	0.2	04-01-2022	22	278	92.66666667
High	High	Medium	Low	0.9	0.01	28-01-2022	-2	302	100.6666667
High	High	Medium	Low	0.9	0.2	31-01-2022	-5	305	101.6666667
High	High	Medium	Low	0.2	0.01	13-01-2022	13	287	95.66666667
High	High	Medium	Low	0.2	0.2	13-01-2022	13	287	95.66666667
High	High	Low	High	0.9	0.01	17-01-2022	9	291	97
High	High	Low	High	0.9	0.2	13-01-2022	13	287	95.66666667
High	High	Low	High	0.2	0.01	05-01-2022	21	279	93
High	High	Low	High	0.2	0.2	04-01-2022	22	278	92.66666667
High	High	Low	Medium	0.9	0.01	28-01-2022	-2	302	100.6666667
High	High	Low	Medium	0.9	0.2	27-01-2022	-1	301	100.3333333
High	High	Low	Medium	0.2	0.01	14-01-2022	12	288	96
High	High	Low	Medium	0.2	0.2	11-01-2022	15	285	95

High	High	Low	Low	0.9	0.01	02-02-2022	-7	307	102.3333333
High	High	Low	Low	0.9	0.2	10-02-2022	-15	315	105
High	High	Low	Low	0.2	0.01	19-01-2022	7	293	97.66666667
High	High	Low	Low	0.2	0.2	21-01-2022	5	295	98.33333333
High	Medium	High	High	0.9	0.01	23-12-2021	34	266	88.66666667
High	Medium	High	High	0.9	0.2	23-12-2021	34	266	88.66666667
High	Medium	High	High	0.2	0.01	23-12-2021	34	266	88.66666667
High	Medium	High	High	0.2	0.2	23-12-2021	34	266	88.66666667
High	Medium	High	Medium	0.9	0.01	23-12-2021	34	266	88.66666667
High	Medium	High	Medium	0.9	0.2	23-12-2021	34	266	88.66666667
High	Medium	High	Medium	0.2	0.01	23-12-2021	34	266	88.66666667
High	Medium	High	Medium	0.2	0.2	23-12-2021	34	266	88.66666667
High	Medium	High	Low	0.9	0.01	23-12-2021	34	266	88.66666667
High	Medium	High	Low	0.9	0.2	23-12-2021	34	266	88.66666667
High	Medium	High	Low	0.2	0.01	23-12-2021	34	266	88.66666667
High	Medium	High	Low	0.2	0.2	23-12-2021	34	266	88.66666667
High	Medium	Medium	High	0.9	0.01	20-04-2022	-84	384	128
High	Medium	Medium	High	0.9	0.2	07-01-2022	19	281	93.66666667
High	Medium	Medium	High	0.2	0.01	07-02-2022	-12	312	104
High	Medium	Medium	High	0.2	0.2	25-05-2022	-119	419	139.6666667
High	Medium	Medium	Medium	0.9	0.01	31-12-2021	26	274	91.33333333
High	Medium	Medium	Medium	0.9	0.2	28-12-2021	29	271	90.33333333
High	Medium	Medium	Medium	0.2	0.01	23-12-2021	34	266	88.66666667
High	Medium	Medium	Medium	0.2	0.2	27-02-2022	-32	332	110.6666667
High	Medium	Medium	Low	0.9	0.01	30-12-2021	27	273	91
High	Medium	Medium	Low	0.9	0.2	30-12-2021	27	273	91
High	Medium	Medium	Low	0.2	0.01	23-12-2021	34	266	88.66666667
High	Medium	Medium	Low	0.2	0.2	23-12-2021	34	266	88.66666667
High	Medium	Low	High	0.9	0.01	20-12-2021	37	263	87.66666667
High	Medium	Low	High	0.9	0.2	20-12-2021	37	263	87.66666667
High	Medium	Low	High	0.2	0.01	20-12-2021	37	263	87.66666667
High	Medium	Low	High	0.2	0.2	20-12-2021	37	263	87.66666667
High	Medium	Low	Medium	0.9	0.01	20-12-2021	37	263	87.66666667
High	Medium	Low	Medium	0.9	0.2	20-12-2021	37	263	87.66666667
High	Medium	Low	Medium	0.2	0.01	20-12-2021	37	263	87.66666667
High	Medium	Low	Medium	0.2	0.2	20-12-2021	37	263	87.66666667

High	Medium	Low	Low	0.9	0.01	06-01-2022	20	280	93.33333333
High	Medium	Low	Low	0.9	0.2	11-01-2022	15	285	95
High	Medium	Low	Low	0.2	0.01	24-12-2021	33	267	89
High	Medium	Low	Low	0.2	0.2	28-12-2021	29	271	90.33333333
High	Low	High	High	0.9	0.01	20-12-2021	37	263	87.66666667
High	Low	High	High	0.9	0.2	20-12-2021	37	263	87.66666667
High	Low	High	High	0.2	0.01	20-12-2021	37	263	87.66666667
High	Low	High	High	0.2	0.2	20-12-2021	37	263	87.66666667
High	Low	High	Medium	0.9	0.01	20-12-2021	37	263	87.66666667
High	Low	High	Medium	0.9	0.2	20-12-2021	37	263	87.66666667
High	Low	High	Medium	0.2	0.01	20-12-2021	37	263	87.66666667
High	Low	High	Medium	0.2	0.2	20-12-2021	37	263	87.66666667
High	Low	High	Low	0.9	0.01	23-12-2021	34	266	88.66666667
High	Low	High	Low	0.9	0.2	23-12-2021	34	266	88.66666667
High	Low	High	Low	0.2	0.01	22-12-2021	35	265	88.33333333
High	Low	High	Low	0.2	0.2	23-12-2021	34	266	88.66666667
High	Low	Medium	High	0.9	0.01	20-12-2021	37	263	87.66666667
High	Low	Medium	High	0.9	0.2	20-12-2021	37	263	87.66666667
High	Low	Medium	High	0.2	0.01	20-12-2021	37	263	87.66666667
High	Low	Medium	High	0.2	0.2	20-12-2021	37	263	87.66666667
High	Low	Medium	Medium	0.9	0.01	20-12-2021	37	263	87.66666667
High	Low	Medium	Medium	0.9	0.2	20-12-2021	37	263	87.66666667
High	Low	Medium	Medium	0.2	0.01	20-12-2021	37	263	87.66666667
High	Low	Medium	Medium	0.2	0.2	20-12-2021	37	263	87.66666667
High	Low	Medium	Low	0.9	0.01	20-12-2021	37	263	87.66666667
High	Low	Medium	Low	0.9	0.2	20-12-2021	37	263	87.66666667
High	Low	Medium	Low	0.2	0.01	20-12-2021	37	263	87.66666667
High	Low	Medium	Low	0.2	0.2	20-12-2021	37	263	87.66666667
High	Low	Low	High	0.9	0.01	20-12-2021	37	263	87.66666667
High	Low	Low	High	0.9	0.2	20-12-2021	37	263	87.66666667
High	Low	Low	High	0.2	0.01	20-12-2021	37	263	87.66666667
High	Low	Low	High	0.2	0.2	20-12-2021	37	263	87.66666667
High	Low	Low	Medium	0.9	0.01	20-12-2021	37	263	87.66666667
High	Low	Low	Medium	0.9	0.2	20-12-2021	37	263	87.66666667
High	Low	Low	Medium	0.2	0.01	20-12-2021	37	263	87.66666667
High	Low	Low	Medium	0.2	0.2	20-12-2021	37	263	87.66666667

High	Low	Low	Low	0.9	0.01	20-12-2021	37	263	87.66666667
High	Low	Low	Low	0.9	0.2	20-12-2021	37	263	87.66666667
High	Low	Low	Low	0.2	0.01	20-12-2021	37	263	87.66666667
High	Low	Low	Low	0.2	0.2	20-12-2021	37	263	87.66666667
Medium	High	High	High	0.9	0.01	07-01-2022	19	281	93.66666667
Medium	High	High	High	0.9	0.2	06-01-2022	20	280	93.33333333
Medium	High	High	High	0.2	0.01	03-01-2022	23	277	92.33333333
Medium	High	High	High	0.2	0.2	06-01-2022	20	280	93.33333333
Medium	High	High	Medium	0.9	0.01	11-01-2022	15	285	95
Medium	High	High	Medium	0.9	0.2	11-01-2022	15	285	95
Medium	High	High	Medium	0.2	0.01	07-01-2022	19	281	93.66666667
Medium	High	High	Medium	0.2	0.2	07-01-2022	19	281	93.66666667
Medium	High	High	Low	0.9	0.01	10-01-2022	16	284	94.66666667
Medium	High	High	Low	0.9	0.2	13-01-2022	13	287	95.66666667
Medium	High	High	Low	0.2	0.01	12-01-2022	14	286	95.33333333
Medium	High	High	Low	0.2	0.2	05-01-2022	21	279	93
Medium	High	Medium	High	0.9	0.01	13-01-2022	13	287	95.66666667
Medium	High	Medium	High	0.9	0.2	11-01-2022	15	285	95
Medium	High	Medium	High	0.2	0.01	03-01-2022	23	277	92.33333333
Medium	High	Medium	High	0.2	0.2	03-01-2022	23	277	92.33333333
Medium	High	Medium	Medium	0.9	0.01	31-01-2022	-5	305	101.6666667
Medium	High	Medium	Medium	0.9	0.2	28-01-2022	-2	302	100.6666667
Medium	High	Medium	Medium	0.2	0.01	07-01-2022	19	281	93.66666667
Medium	High	Medium	Medium	0.2	0.2	10-01-2022	16	284	94.66666667
Medium	High	Medium	Low	0.9	0.01	27-01-2022	-1	301	100.3333333
Medium	High	Medium	Low	0.9	0.2	03-02-2022	-8	308	102.6666667
Medium	High	Medium	Low	0.2	0.01	14-01-2022	12	288	96
Medium	High	Medium	Low	0.2	0.2	18-01-2022	8	292	97.33333333
Medium	High	Low	High	0.9	0.01	19-01-2022	7	293	97.66666667
Medium	High	Low	High	0.9	0.2	19-01-2022	7	293	97.66666667
Medium	High	Low	High	0.2	0.01	05-01-2022	21	279	93
Medium	High	Low	High	0.2	0.2	04-01-2022	22	278	92.66666667
Medium	High	Low	Medium	0.9	0.01	02-02-2022	-7	307	102.3333333
Medium	High	Low	Medium	0.9	0.2	02-02-2022	-7	307	102.3333333
Medium	High	Low	Medium	0.2	0.01	14-01-2022	12	288	96
Medium	High	Low	Medium	0.2	0.2	20-01-2022	6	294	98

Medium	High	Low	Low	0.9	0.01	03-02-2022	-8	308	102.6666667
Medium	High	Low	Low	0.9	0.2	02-02-2022	-7	307	102.3333333
Medium	High	Low	Low	0.2	0.01	21-01-2022	5	295	98.33333333
Medium	High	Low	Low	0.2	0.2	25-01-2022	1	299	99.66666667
Medium	Medium	High	High	0.9	0.01	23-12-2021	34	266	88.66666667
Medium	Medium	High	High	0.9	0.2	22-12-2021	35	265	88.33333333
Medium	Medium	High	High	0.2	0.01	23-12-2021	34	266	88.66666667
Medium	Medium	High	High	0.2	0.2	23-12-2021	34	266	88.66666667
Medium	Medium	High	Medium	0.9	0.01	23-12-2021	34	266	88.66666667
Medium	Medium	High	Medium	0.9	0.2	23-12-2021	34	266	88.66666667
Medium	Medium	High	Medium	0.2	0.01	23-12-2021	34	266	88.66666667
Medium	Medium	High	Medium	0.2	0.2	23-12-2021	34	266	88.66666667
Medium	Medium	High	Low	0.9	0.01	24-12-2021	33	267	89
Medium	Medium	High	Low	0.9	0.2	23-12-2021	34	266	88.66666667
Medium	Medium	High	Low	0.2	0.01	23-12-2021	34	266	88.66666667
Medium	Medium	High	Low	0.2	0.2	23-12-2021	34	266	88.66666667
Medium	Medium	Medium	High	0.9	0.01	23-12-2021	34	266	88.66666667
Medium	Medium	Medium	High	0.9	0.2	23-12-2021	34	266	88.66666667
Medium	Medium	Medium	High	0.2	0.01	23-12-2021	34	266	88.66666667
Medium	Medium	Medium	High	0.2	0.2	23-12-2021	34	266	88.66666667
Medium	Medium	Medium	Medium	0.9	0.01	28-12-2021	29	271	90.33333333
Medium	Medium	Medium	Medium	0.9	0.2	23-12-2021	34	266	88.66666667
Medium	Medium	Medium	Medium	0.2	0.01	23-12-2021	34	266	88.66666667
Medium	Medium	Medium	Medium	0.2	0.2	23-12-2021	34	266	88.66666667
Medium	Medium	Medium	Low	0.9	0.01	03-01-2022	23	277	92.33333333
Medium	Medium	Medium	Low	0.9	0.2	30-12-2021	27	273	91
Medium	Medium	Medium	Low	0.2	0.01	23-12-2021	34	266	88.66666667
Medium	Medium	Medium	Low	0.2	0.2	23-12-2021	34	266	88.66666667
Medium	Medium	Low	High	0.9	0.01	23-12-2021	34	266	88.66666667
Medium	Medium	Low	High	0.9	0.2	23-12-2021	34	266	88.66666667
Medium	Medium	Low	High	0.2	0.01	23-12-2021	34	266	88.66666667
Medium	Medium	Low	High	0.2	0.2	23-12-2021	34	266	88.66666667
Medium	Medium	Low	Medium	0.9	0.01	23-12-2021	34	266	88.66666667
Medium	Medium	Low	Medium	0.9	0.2	23-12-2021	34	266	88.66666667
Medium	Medium	Low	Medium	0.2	0.01	05-01-2022	21	279	93
Medium	Medium	Low	Medium	0.2	0.2	23-12-2021	34	266	88.66666667

Medium	Medium	Low	Low	0.9	0.01	06-01-2022	20	280	93.33333333
Medium	Medium	Low	Low	0.9	0.2	11-01-2022	15	285	95
Medium	Medium	Low	Low	0.2	0.01	29-12-2021	28	272	90.66666667
Medium	Medium	Low	Low	0.2	0.2	28-12-2021	29	271	90.33333333
Medium	Low	High	High	0.9	0.01	23-12-2021	34	266	88.66666667
Medium	Low	High	High	0.9	0.2	23-12-2021	34	266	88.66666667
Medium	Low	High	High	0.2	0.01	23-12-2021	34	266	88.66666667
Medium	Low	High	High	0.2	0.2	23-12-2021	34	266	88.66666667
Medium	Low	High	Medium	0.9	0.01	23-12-2021	34	266	88.66666667
Medium	Low	High	Medium	0.9	0.2	23-12-2021	34	266	88.66666667
Medium	Low	High	Medium	0.2	0.01	23-12-2021	34	266	88.66666667
Medium	Low	High	Medium	0.2	0.2	23-12-2021	34	266	88.66666667
Medium	Low	High	Low	0.9	0.01	22-12-2021	35	265	88.33333333
Medium	Low	High	Low	0.9	0.2	22-12-2021	35	265	88.33333333
Medium	Low	High	Low	0.2	0.01	23-12-2021	34	266	88.66666667
Medium	Low	High	Low	0.2	0.2	23-12-2021	34	266	88.66666667
Medium	Low	Medium	High	0.9	0.01	23-12-2021	34	266	88.66666667
Medium	Low	Medium	High	0.9	0.2	23-12-2021	34	266	88.66666667
Medium	Low	Medium	High	0.2	0.01	23-12-2021	34	266	88.66666667
Medium	Low	Medium	High	0.2	0.2	22-12-2021	35	265	88.33333333
Medium	Low	Medium	Medium	0.9	0.01	20-12-2021	37	263	87.66666667
Medium	Low	Medium	Medium	0.9	0.2	20-12-2021	37	263	87.66666667
Medium	Low	Medium	Medium	0.2	0.01	20-12-2021	37	263	87.66666667
Medium	Low	Medium	Medium	0.2	0.2	23-12-2021	34	266	88.66666667
Medium	Low	Medium	Low	0.9	0.01	24-12-2021	33	267	89
Medium	Low	Medium	Low	0.9	0.2	20-12-2021	37	263	87.66666667
Medium	Low	Medium	Low	0.2	0.01	20-12-2021	37	263	87.66666667
Medium	Low	Medium	Low	0.2	0.2	23-12-2021	34	266	88.66666667
Medium	Low	Low	High	0.9	0.01	24-12-2021	33	267	89
Medium	Low	Low	High	0.9	0.2	20-12-2021	37	263	87.66666667
Medium	Low	Low	High	0.2	0.01	23-12-2021	34	266	88.66666667
Medium	Low	Low	High	0.2	0.2	20-12-2021	37	263	87.66666667
Medium	Low	Low	Medium	0.9	0.01	21-12-2021	36	264	88
Medium	Low	Low	Medium	0.9	0.2	23-12-2021	34	266	88.66666667
Medium	Low	Low	Medium	0.2	0.01	20-12-2021	37	263	87.66666667
Medium	Low	Low	Medium	0.2	0.2	21-12-2021	36	264	88

Medium	Low	Low	Low	0.9	0.01	20-12-2021	37	263	87.66666667
Medium	Low	Low	Low	0.9	0.2	30-12-2021	27	273	91
Medium	Low	Low	Low	0.2	0.01	23-12-2021	34	266	88.66666667
Medium	Low	Low	Low	0.2	0.2	23-12-2021	34	266	88.66666667
Low	High	High	High	0.9	0.01	11-01-2022	15	285	95
Low	High	High	High	0.9	0.2	14-01-2022	12	288	96
Low	High	High	High	0.2	0.01	07-01-2022	19	281	93.66666667
Low	High	High	High	0.2	0.2	05-01-2022	21	279	93
Low	High	High	Medium	0.9	0.01	13-01-2022	13	287	95.66666667
Low	High	High	Medium	0.9	0.2	13-01-2022	13	287	95.66666667
Low	High	High	Medium	0.2	0.01	12-01-2022	14	286	95.33333333
Low	High	High	Medium	0.2	0.2	07-01-2022	19	281	93.66666667
Low	High	High	Low	0.9	0.01	18-01-2022	8	292	97.33333333
Low	High	High	Low	0.9	0.2	18-01-2022	8	292	97.33333333
Low	High	High	Low	0.2	0.01	13-01-2022	13	287	95.66666667
Low	High	High	Low	0.2	0.2	14-01-2022	12	288	96
Low	High	Medium	High	0.9	0.01	17-01-2022	9	291	97
Low	High	Medium	High	0.9	0.2	17-01-2022	9	291	97
Low	High	Medium	High	0.2	0.01	04-01-2022	22	278	92.66666667
Low	High	Medium	High	0.2	0.2	31-12-2021	26	274	91.33333333
Low	High	Medium	Medium	0.9	0.01	27-01-2022	-1	301	100.3333333
Low	High	Medium	Medium	0.9	0.2	28-01-2022	-2	302	100.6666667
Low	High	Medium	Medium	0.2	0.01	10-01-2022	16	284	94.66666667
Low	High	Medium	Medium	0.2	0.2	14-01-2022	12	288	96
Low	High	Medium	Low	0.9	0.01	31-01-2022	-5	305	101.6666667
Low	High	Medium	Low	0.9	0.2	03-02-2022	-8	308	102.6666667
Low	High	Medium	Low	0.2	0.01	20-01-2022	6	294	98
Low	High	Medium	Low	0.2	0.2	21-01-2022	5	295	98.33333333
Low	High	Low	High	0.9	0.01	19-01-2022	7	293	97.66666667
Low	High	Low	High	0.9	0.2	18-01-2022	8	292	97.33333333
Low	High	Low	High	0.2	0.01	07-01-2022	19	281	93.66666667
Low	High	Low	High	0.2	0.2	08-01-2022	18	282	94
Low	High	Low	Medium	0.9	0.01	26-01-2022	0	300	100
Low	High	Low	Medium	0.9	0.2	31-01-2022	-5	305	101.6666667
Low	High	Low	Medium	0.2	0.01	24-01-2022	2	298	99.33333333
Low	High	Low	Medium	0.2	0.2	26-01-2022	0	300	100

Low	High	Low	Low	0.9	0.01	09-02-2022	-14	314	104.6666667
Low	High	Low	Low	0.9	0.2	02-02-2022	-7	307	102.3333333
Low	High	Low	Low	0.2	0.01	31-01-2022	-5	305	101.6666667
Low	High	Low	Low	0.2	0.2	26-01-2022	0	300	100
Low	Medium	High	High	0.9	0.01	22-12-2021	35	265	88.33333333
Low	Medium	High	High	0.9	0.2	23-12-2021	34	266	88.66666667
Low	Medium	High	High	0.2	0.01	24-12-2021	33	267	89
Low	Medium	High	High	0.2	0.2	23-12-2021	34	266	88.66666667
Low	Medium	High	Medium	0.9	0.01	23-12-2021	34	266	88.66666667
Low	Medium	High	Medium	0.9	0.2	23-12-2021	34	266	88.66666667
Low	Medium	High	Medium	0.2	0.01	23-12-2021	34	266	88.66666667
Low	Medium	High	Medium	0.2	0.2	23-12-2021	34	266	88.66666667
Low	Medium	High	Low	0.9	0.01	23-12-2021	34	266	88.66666667
Low	Medium	High	Low	0.9	0.2	24-12-2021	33	267	89
Low	Medium	High	Low	0.2	0.01	24-12-2021	33	267	89
Low	Medium	High	Low	0.2	0.2	23-12-2021	34	266	88.66666667
Low	Medium	Medium	High	0.9	0.01	20-12-2021	37	263	87.66666667
Low	Medium	Medium	High	0.9	0.2	20-12-2021	37	263	87.66666667
Low	Medium	Medium	High	0.2	0.01	20-12-2021	37	263	87.66666667
Low	Medium	Medium	High	0.2	0.2	20-12-2021	37	263	87.66666667
Low	Medium	Medium	Medium	0.9	0.01	06-01-2022	20	280	93.33333333
Low	Medium	Medium	Medium	0.9	0.2	11-01-2022	15	285	95
Low	Medium	Medium	Medium	0.2	0.01	28-12-2021	29	271	90.33333333
Low	Medium	Medium	Medium	0.2	0.2	24-12-2021	33	267	89
Low	Medium	Medium	Low	0.9	0.01	04-01-2022	22	278	92.66666667
Low	Medium	Medium	Low	0.9	0.2	04-01-2022	22	278	92.66666667
Low	Medium	Medium	Low	0.2	0.01	24-12-2021	33	267	89
Low	Medium	Medium	Low	0.2	0.2	24-12-2021	33	267	89
Low	Medium	Low	High	0.9	0.01	28-12-2021	29	271	90.33333333
Low	Medium	Low	High	0.9	0.2	23-12-2021	34	266	88.66666667
Low	Medium	Low	High	0.2	0.01	22-12-2021	35	265	88.33333333
Low	Medium	Low	High	0.2	0.2	20-12-2021	37	263	87.66666667
Low	Medium	Low	Medium	0.9	0.01	01-03-2022	-34	334	111.3333333
Low	Medium	Low	Medium	0.9	0.2	19-01-2022	7	293	97.66666667
Low	Medium	Low	Medium	0.2	0.01	11-01-2022	15	285	95
Low	Medium	Low	Medium	0.2	0.2	08-01-2022	18	282	94

Low	Medium	Low	Low	0.9	0.01	06-01-2022	20	280	93.33333333
Low	Medium	Low	Low	0.9	0.2	05-01-2022	21	279	93
Low	Medium	Low	Low	0.2	0.01	31-12-2021	26	274	91.33333333
Low	Medium	Low	Low	0.2	0.2	03-01-2022	23	277	92.33333333
Low	Low	High	High	0.9	0.01	28-12-2021	29	271	90.33333333
Low	Low	High	High	0.9	0.2	23-12-2021	34	266	88.66666667
Low	Low	High	High	0.2	0.01	23-12-2021	34	266	88.66666667
Low	Low	High	High	0.2	0.2	22-12-2021	35	265	88.33333333
Low	Low	High	Medium	0.9	0.01	23-12-2021	34	266	88.66666667
Low	Low	High	Medium	0.9	0.2	24-12-2021	33	267	89
Low	Low	High	Medium	0.2	0.01	20-12-2021	37	263	87.66666667
Low	Low	High	Medium	0.2	0.2	22-12-2021	35	265	88.33333333
Low	Low	High	Low	0.9	0.01	23-12-2021	34	266	88.66666667
Low	Low	High	Low	0.9	0.2	22-12-2021	35	265	88.33333333
Low	Low	High	Low	0.2	0.01	23-12-2021	34	266	88.66666667
Low	Low	High	Low	0.2	0.2	23-12-2021	34	266	88.66666667
Low	Low	Medium	High	0.9	0.01	23-12-2021	34	266	88.66666667
Low	Low	Medium	High	0.9	0.2	23-12-2021	34	266	88.66666667
Low	Low	Medium	High	0.2	0.01	23-12-2021	34	266	88.66666667
Low	Low	Medium	High	0.2	0.2	22-12-2021	35	265	88.33333333
Low	Low	Medium	Medium	0.9	0.01	28-12-2021	29	271	90.33333333
Low	Low	Medium	Medium	0.9	0.2	31-12-2021	26	274	91.33333333
Low	Low	Medium	Medium	0.2	0.01	22-12-2021	35	265	88.33333333
Low	Low	Medium	Medium	0.2	0.2	23-12-2021	34	266	88.66666667
Low	Low	Medium	Low	0.9	0.01	20-12-2021	37	263	87.66666667
Low	Low	Medium	Low	0.9	0.2	20-12-2021	37	263	87.66666667
Low	Low	Medium	Low	0.2	0.01	22-12-2021	35	265	88.33333333
Low	Low	Medium	Low	0.2	0.2	21-12-2021	36	264	88
Low	Low	Low	High	0.9	0.01	20-12-2021	37	263	87.66666667
Low	Low	Low	High	0.9	0.2	20-12-2021	37	263	87.66666667
Low	Low	Low	High	0.2	0.01	20-12-2021	37	263	87.66666667
Low	Low	Low	High	0.2	0.2	20-12-2021	37	263	87.66666667
Low	Low	Low	Medium	0.9	0.01	23-12-2021	34	266	88.66666667
Low	Low	Low	Medium	0.9	0.2	23-12-2021	34	266	88.66666667
Low	Low	Low	Medium	0.2	0.01	21-12-2021	36	264	88
Low	Low	Low	Medium	0.2	0.2	20-12-2021	37	263	87.66666667

Low	Low	Low	Low	0.9	0.01	20-12-2021	37	263	87.66666667
Low	Low	Low	Low	0.9	0.2	20-12-2021	37	263	87.66666667
Low	Low	Low	Low	0.2	0.01	20-12-2021	37	263	87.66666667
Low	Low	Low	Low	0.2	0.2	21-12-2021	36	264	88

Appendix J
ODD Protocols

The ODD protocol consists of seven sequential elements as tabularized below:

Overview	Purpose and patterns
	Entities, state variables, and scales
	Process overview and scheduling
Design	Design Concept - Basic principle - Emergence - Adaptation - Objectives - Learning - Prediction - Sensing - Interaction - Stochasticity - Collectives - Observation
Details	Initialization
	Input data
	Sub-models

Table 40: Updated ODD Protocols

Purpose and patterns

The purpose of a model should define the problem or gap that is intended to be solved by using the agent-based model without actually stressing how the model will work (Grimm et al., 2010). This can be considered the starting point of the modeling process. Having a definitive purpose allows to navigate the construction of the model as per the needs of the study and helps identify the variables that are of utmost importance for the construction of the model (ePM, 2005). Patterns, on the other hand, establish criteria through which the aptness and usefulness of the model are vouched (Grimm et al., 2020b). Patterns are a set of observations on either individual or system-level which when qualified, ensures an optimum realism in the created model is achieved (Grimm et al., 2020a).

The purpose of this research is to study the impact of team composition and organization structure on team efficiency while also taking into account the role of communication and information flow. The intention is to quantitatively explore the impact of these independent variables on team efficiency by first constructing a baseline model capable of mimicking the existing environment of the project and then changing the team composition and organization structure of the project teams motivated by a contract type. Different contract types result in different reporting systems in project teams which impacts the hierarchies, information and communication observed in the project team (Cusimano, 2011; J. Han et al., 2019; Mishra et al., 2015; Moree, 2013; Suprapto et al., 2016). At the same time, contract forms also alter aspects such as skill level, experience, etc., within project teams which impacts the team composition. Hence, the organization structure inspired by a contract type is used for creating a comparative scenario case which is then evaluated against the baseline case to identify durations in which the activities appropriated to the project team are finished. Additionally, to have a view of the company's culture which in turn impacts the communication and information flow within project teams, a robustness test/ sensitivity analysis is also performed on system settings which are explained further.

For the patterns, the baseline model is primarily constructed by using an iterative process of balancing out system settings until the model resembles the project environment. To elaborate, the actual and planned duration of the activities are used to create two distinctive models which are uninfluenced by any system settings such as Information exchange probability, noise, and level of team experience. Keeping the model with actual dates as the reference, the system settings are iteratively introduced and manipulated in the model with planned durations till the point that the latter resembles the former in terms of activity durations. This ensures that the system settings realistically represent the properties that influence the project activities, project team, and interaction of the project team with project activities.

This study is performed on an ongoing integrated township project being carried out in India. The integrated township project is composed of nine discreet sub-projects among which, the focus of this research is limited to just one sub-project. The ambition is to analyze the efficiency of the integrated project team whose responsibilities are spread throughout different projects in the portfolio and how this affects the construction of only a single project. The description of the case study is comprehensively elaborated in chapter 4.

Entities, state variables, and scales

The entities refer to distinct objects or agents, that interact with one another and are influenced by the external environment (Grimm et al., 2010). These agents can be of an individual or collective nature (also described later). These agents are further appropriated with attributes that help distinguish them from each other in their initial state. These attributes are called State variables (Grimm et al., 2010). To make a successful agent-based model, it is necessary to define the agents with their distinct state variables since these variables characterize agents with different features which in turn kindles interactions amongst themselves and also the environment. ABM is potent in predicting the emergent behavior of these interactions (Crooks & Heppenstall, 2012a). Common examples of state variables could be gender, work experience, and educational background.

The owner, members of the integrated project team, external stakeholders, and contractor's team form the main entities for the agent-based model created in this research. The members of the integrated project team are further classified into the members who work on the project selected for this study and team members who are also working on other projects in the portfolio which are represented as collectives. Albeit there could be more influential entities that play an indirect role in the execution of the project, for example, the local politicians, and banks; the entities used for this model mostly represents the individual or collectives which have direct impacts on the execution of the activities while the indirect entities are aggregated and displayed as external stakeholders. These entities are described using the state variables; role, application experience, and full-time equivalents (FTE) as can be seen in Appendix E.

Scales define the spatial extent of the model which in simple words explains the resolution of the model by defining the length of time steps (Grimm et al., 2020a). For this research, the model first broadly represents the portfolio of the projects which are extended through the years (Appendix A). The model then focuses on the selected project in which the activities are defined in terms of days and weeks (Appendix B), depending upon the resolution of the task. The predicted duration of the agent-based model in terms of its output is in simulated days.

The data about entities is derived from the official organizational chart of the company and through the semi-structured interviews conducted with the Assistant manager (MIS and Coordination) working on the integrated project. The organization chart of the company (Appendix D) is used to determine the most important personnel/positions that are directly or indirectly designated for the tasks carried out in the chosen project. On the other hand, the semi-structured interviews helped identify other main agents that were not part of the integrated project team but have their roles in the affairs related to the integrated project such as banks or the contractors. Additionally, the interviews also shed light on the state variables of the agents. The information especially regarding the application experience and FTE is determined by asking questions about every single agent that is modeled in this study.

Process overview and scheduling

The process overview and scheduling are mainly related to the inputs of *"Who does what and in what order?"*(Grimm et al., 2010). Process overview and scheduling define the environment and also establish a connection between agents and the environment for the modeling. The process overview and scheduling help to introduce the duration of activities as either discreet or continuum hence introducing a main component of ABM; time in simulated space (Grimm et al., 2010).

Any complex project can have up to thousands of activities or even more (Autodesk Construction Cloud, 2020). Modeling such projects with numerous activities can thus be time-consuming and intricate. Therefore, an appropriate level of abstraction has to be chosen that not only represents the essence of the model but also does so with a limited number of tasks (Jin & Levitt, 1996). To limit the number of activities, the technique of clustering is used. As the list of activities to be modeled in the study are plentiful, they are clustered together to form an activity that is representative of the entire aggregate and has a start and finish date equivalent to the starting date and ending date of the first and last sub-activity respectively. For example, the construction of the building can be aggregated into two clusters; construction of substructure and construction of superstructure in which both the clusters entail detailed activities required to realize the cluster activities. An overview of clustered activities can be seen in Appendix B.

The inputs for "Who does what and in what order?" are obtained through the official schedules of the sub-project and also through the semi-structured interviews conducted with the Assistant Manager (MIS and Coordination) working on the integrated project. The schedules are primarily used to determine the sequences of activities and tasks which derive the completion of the project while the semi-structured interviews are used to attach the responsibilities of different team members to particular tasks. Since the activities to be performed can be complex, multi-disciplinary, and constrained by resources, the interviews mainly helped identify factors that incorporate realism in the model such as which member is mainly responsible for carrying out a certain task, who else is involved in the task, if an exception may arise, who takes the decisions, how much time a particular member spends doing a particular job. It should be noted that due to data constraints, the schedules used for modeling pertain only to the MEP and Finishing phase of the project which was initiated after the completion of the RCC structure of the chosen project.

Design concept

The design concept is useful in defining how the agent-based model is characterized (Grimm et al., 2020a). Grimm et al. (2020a) mention that not all the elements of design concepts are used in all the Agent-based models and those elements should explicitly state their non-implementation. The recommended guidelines for documenting the model design are used below to describe the constructed model.

Basic principles

Basic principles aim to highlight the main theories, concepts, and hypotheses that underlie the model's design (Grimm et al., 2010). It mainly relates the abstract concepts to the functionality of the model. Basic principles enable a better scientific understanding of how the modeling software works and allow users to carefully choose if the software will be useful in demonstrating the real-life scenarios, they intend to simulate (Grimm et al., 2010).

As mentioned earlier, this study uses SimVision® to reach its modeling objectives. SimVision® is built based on contingency theory (Jin & Levitt, 1996) put forward by Jay Galbraith in 1973 which claims that there is no best way to organize and the management practices highly depend on the situational factors (Cook, 2001). Jin & Levitt, (1996) developed SimVision® to interpret the impact of some of these situational factors on the markers that define and impact the project's success; time, cost, and quality.

The true strength of SimVision® lies in its ability to predict additional work engendering due to the organizational properties of the project team or a company (Jin & Levitt, 1996). As also mentioned before, the entities are defined using state variables which produce a unique set of situational factors which might influence the behavior of the system. SimVision® analyses these state variables and predicts the impact of these situational variables in the form of primary production work and additional indirect work. Since the objectives of the study also intend to evaluate the impact of mainly two organizational properties; Team composition and organization structure under the context of communication and information exchanges, this software is considered to fit aptly for the purpose.

Emergence

Emergence refers to the observed cumulative behavior of the model in terms of its output which is based upon the microlevel behavior of agents, their interactions with one another, and the environment (Crooks & Heppenstall, 2012a; Grimm et al., 2010).

Based upon the organizational properties and characteristics of agents defined in SimVision®, the software predicts the explicit work, which is defined as the primary production work as well as the implicit work which includes rework, coordination, and decision-wait (Jin & Levitt, 1996).

Rework as simply defined by ePM (2005) means to re-attempt a failed task. The rework can be generated in a task due to exceptions observed in a particular task or due to exceptions generated in the driver task which also impact the dependent task (ePM, 2005). On the other hand, coordination work as explained by Jin & Levitt (1996) is a function of how an organization is structured. Motivated by Galbraith's theory, the coordination work attempts to quantity the efforts required by different agents to cooperate and collaborate in the forms of interactions and information exchange (Jin & Levitt, 1996). And lastly, the decision wait as described by Jin & Levitt (1996) quantifies the additional time that the decision-makers for different activities will require owing to their primary responsibilities, the number of decisions they have to make, and informational transactions. The explicit and implicit works form the main basis for the simulated duration of any event or activity thus displaying the emergent behavior of the model. This study uses the emergent duration as the main variable for cross-comparisons.

Adaptation

Adaptation refers to how the actors make decisions or respond to the dynamics of the environment (Grimm et al., 2010). Different individuals may have different perspectives and diverse roles within the same company or project team, and they tend to interact and make decisions based on them (Geminiani et al., 2013; P. Zhang et al., 2019). Adaptation tends to highlight the mechanism of how the decision-making in contrast to the changing environment is done.

In SimVision®, a position; used to denote an aggregate of personnel with similar skillset (Also explained in collectives) can be assigned to certain tasks using primary and secondary assignment links. Owing to the probabilistic approach of SimVision®, the model will be encountered with certain exceptions (Jin & Levitt, 1996). Based upon the reporting links (Line of Hierarchy) and also the degree of centralization, the exception handling will be either dealt with on the point of contact or will be transferred up to the top management. In SimVision® the degree of centralization can be either high, medium, or low which determines the extent to which the decision-making is centralized.

Another adaptive trait that is displayed by positions is that of deciding between tasks. A position in SimVision® can be characterized by Full-time equivalents (FTE) which represents the number of full-time employees. These positions in combination with FTEs can also be attributed to allocation percentage which determines how much time the positions dedicate to executing a task (Jin & Levitt, 1996). Based upon the factors such as task priority, and also the available time modeled through FTEs and allocation, the positions choose which tasks need to be performed.

An environment-based factor that influences the adaptation is the task complexity. ePM (2005) cites solution complexity and requirement complexity with which the tasks can be characterized. Solution complexity refers to the number of solutions towards which this particular task contributes. The solution complexity demonstrates the interdependency of tasks and solutions. Higher solution complexity indicates a higher dependency which increases the probability of generating exceptions. Requirement complexity on the other hand represents the degree of internal checks and balances that an activity must satisfy to be deemed completed. The tasks with higher internal requirements will statistically be prone to higher errors. Based on the inputs of the solution and the requirement complexity of a particular task, SimVision® statistically generates exceptions (ePM, 2005). Based on the above, the positions can either perform rework or a quick fix or can choose to completely ignore the generated exception. The choice of decision-making in response to the exception is generally dependent upon the roles of the positions (ePM, 2005). A position can have one of three roles: PM (Project manager), SL (Team leader), or ST (Team member). The decision made by PM is generally in favor of rework, ST on the other end tends to ignore the exceptions generated.

For the model constructed in the current study, the information regarding the FTEs and roles is accurately determined by conducting semi-structured interviews with the Asst. Manager (MIS and Coordination). The information such as how many full-time and part-time employees worked on a particular task, helped identify the FTEs. The Application role and application experience values are also populated based on these interviews to get a realistic view of the project team organization.

Objectives

Objectives can be defined as the results that the agents seek to achieve in the model and varying the adaptive characteristics of the agents impacts the likelihood of obtaining these objectives (Grimm et al., 2010). To elaborate, the objectives tend to focus on the characteristics of the agents which when played with impact the direct objectives of the study.

Since the main objective of this research is to focus on the duration of the project, the application experience of a position plays a crucial in determining the pace and quality at which the activities will be done. High application experience would imply that the position has prior experience with a similar kind of work and will therefore require less time to understand and adapt according to the needs of the new project. This will in turn reduce the duration of the project.

Learning

Learning tends to define how the positions usually change their traits over time owing to their experiences (Grimm et al., 2010). Learning is not implemented in this model. To interpret learning, however, the state variables of the positions can be changed to construct distinctive scenarios and can be compared to each other.

Prediction

The prediction is the explicit or implicit estimate of the future based on the adaptive traits of the agents (Grimm et al., 2020a). The model uses various implicit assumptions in regards to the decisions made which finally affect the outcomes (Grimm et al., 2020a). Predictions highlight these assumptions on the emergent behavior of the model.

Team experience is the system setting of the model which enables to define how well-acquainted the project team is with the kind of work being performed. If team experience is set high, an underlying assumption is that the amount of information flow is decreased owing to the past experiences of the team members which decreases the coordination time (ePM, 2005).

Likewise, high centralization is assumed to produce additional rework (ePM, 2005). Since the decisions are made by the top management, it is assumed that more quality will be demanded by the top management which will come at the expense of additional rework (Jin & Levitt, 1996). Moreover, the high centralization is again assumed to be linked with delays caused due to decision wait (ePM, 2005). It is assumed that the top management due to their limited decision-making capacities will be backlogged which will require additional time for them to make decisions that will extend the project duration (Jin & Levitt, 1996).

Similarly, the degree of formalization in communication also has some underlying assumptions which are as follows:

High formalization means that the decorum of communication and information exchanges is highly formal (ePM, 2005). The underlying assumption is that the predicted amount of information exchange will be halved if the communications are highly formal (ePM, 2005). Information exchange probability determines the likelihood of the communication exchanges to occur among workers to do their jobs. High formalization halves this likelihood (ePM, 2005).

Medium formalization on the other hand means that the decorum of the communication is balanced between formal and informal. With medium formalization, the assumption is that the information exchange probability remains unchanged (ePM, 2005). Meaning, that the information exchanges between workers will not be affected by the formalization of the team or the company.

And similarly, low formalization would mean that the communication and information exchanges occurring are informal. An underlying assumption is that low formalization will double the information exchange probability (ePM, 2005). Meaning, that on any given day, the likelihood of workers interacting with each other for matters of work will double.

Matrix strength is another parameter with implicit assumptions which are as follows:

Matrix strength intends to model the connectedness of a team/company by also varying the effects of information exchange (ePM, 2005; Jin & Levitt, 1996). Similar to the above-mentioned parameters, the matrix strength can also be either high, medium, or low and all the inputs have underlying implicit assumptions associated with them.

Project teams or companies characterized by high matrix strength have skilled positions working in project teams that are directly supervised by the project manager (ePM, 2005). Owing to the diversity of the teams, it is assumed that the team members generally engage in information exchanges which lowers the perception of workers to attend meetings (Jin & Levitt, 1996). SimVision® assumes that the members of teams characterized with high matrix strength attend 60% of meetings and on the other hand, attend 90% of informal communications occurring within the team (ePM, 2005).

On the other hand, the teams characterized with medium matrix strength assume that the team members make equal efforts to attend formal meetings as well as engage in informal communications (ePM, 2005). SimVision® assumes that the members of such teams attend 70% of both formal and informal meetings (ePM, 2005).

Lastly, the teams characterized by low matrix strength are functionality-based (ePM, 2005). Members in such teams are supervised by the functional manager. SimVision® assumes that the members of such a team attend up to 90% of formal meetings and attend 60% of informal communication within the team (ePM, 2005).

Sensing

The concept of sensing is based on the perception or awareness of agents about themselves and their environment (Grimm et al., 2020a). The concept covers, what the agent is aware of and how they behave owing to those state variables (Grimm et al., 2020a).

For the agent-based model constructed in this study, the primary state variables that are acknowledged by the agents are their roles (PM, SL, ST), their reporting system, their skill level, the time available to them, and the percentage of time they are allocated to a certain activity. These variables have a direct impact on how the work is carried out by the agents and its implications on the success markers of the project (Time, cost, and quality). The rationale behind the roles and reporting system is to channel how the information flow within the organization occurs. However, the quality of work and duration of the project among other factors is primarily determined by the skill level, the time available to the agents, and also how much time they spend on particular activities.

Interaction

Interaction can be defined as how actors engage with each other and also the environment (Grimm et al., 2020a). Grimm et al. (2020a) identify primarily two types of interactions (1) Direct and (2) Mediated. Direct interactions are the ones in which one agent identifies with other agents and influences them directly and on the other hand, the mediated interactions are the ones in which the actors indirectly affect each other for example by consuming a shared resource. Communication is closely associated with the interactional concept of the model design (Grimm et al., 2020a).

The model constructed for this research promotes direct communication in terms of formal meetings, reporting links, and primary and secondary assignment links (ePM, 2005; Jin & Levitt, 1996). The first two elements of direct communication which are formal meetings and reporting links relate to the interaction amongst agents while the primary and secondary assignment links mainly relate to the agent-activity interaction. Communication between actors might take place either through formally scheduled meetings or informal conversations, depending upon the formalization of the company. SimVision® gives the option to create formal meetings in the model. The meetings are depicted using pink boxes, which allows to schedule a meeting by defining its duration, and frequency and also allocating relevant positions to it. A formal meeting notice is sent to all the participating positions before the commencement of the meeting. Based on the degree of formalization of the company, and their other engagements. the positions either choose to ignore the meeting or attend them. If the meeting is attended by the position, then the primary tasks of the positions might somewhat be compromised to attend the meeting and if the positions choose not to attend meetings, this implies that there may be a high chance that the errors may occur in the execution due to missed information.

Similarly, the direct interactions are also mimicked through reporting links. Exception-reporting in particular is majorly influenced by the reporting links between different positions. When the exceptions are encountered, based on their urgency and also the centralization of the team, the position has to either make decisions themselves or delegate the exceptions to the project manager through team leaders. If the project manager is highly backlogged due to the excessive demands for decisions, the Project manager may not be able to respond to the exceptions in the required time which results in the ignorance of decisions which reduces the quality of the product (ePM, 2005).

The interaction between positions and the activities generally takes place in terms of primary and secondary task assignment links. Both the task links delegate positions with the responsibilities to execute activities in the project. All the activities must have only one primary assignment but can have multiple secondary assignments however, on the other hand, a position can be designated with multiple primary assignments. The difference between primary and secondary assignment links is that the position with the primary task assignment link is the main one in charge to handle exceptions arising in the process.

Indirect interactions on the other hand generally occur due to communication and rework links, informal meetings, and noise. Communication links are generally established where there are activity interdependencies involved among tasks. The interdependencies often lead to the formation of interfaces that require information exchange to occur between multiple positions to successfully execute the tasks. Communication links generally refer to the fact that the positions are interacting and exchanging information to make compatible decisions. The amount of information that is exchanged through these links is determined by information exchange probability which is a pragmatic value.

The rework link demonstrates the task dependencies. The rework link connects two tasks in which the predecessor task may undergo rework due to the exceptions generated in the successor task. Rework link is also a pragmatic value and its strength can be established as an absolute volume of rework or in the percentage of rework that the dependent task will have to go through.

Informal communications are the ones that are automatically simulated in SimVision®. Based on the degree of formalization, the software produces informal coordination requests. The Matrix strength also plays a major role in determining of the informal meeting will be attended by the participants or not. A team with low matrix strength is likely to engage in attending formal meetings and vice-versa.

And finally, noise models the interaction of positions with other projects or outside organizations being performed and attended to at the same time. Noise models any communication that is not part of a project under consideration. Noise is represented using a Noise probability which is also a pragmatic value.

Stochasticity

Stochastic processes can be defined as the ones which are primarily based on the usage of pseudorandom numbers as an input to display variability in the outcomes (Grimm et al., 2010). Agent-based models might involve several concepts where the idea of stochasticity is used. This section of ODD is used to define those concepts.

SimVision® being a probabilistic tool uses the Monte Carlo approach to predict both production and coordination work (Jin & Levitt, 1996). By default, the number of simulations is set to 25 and the software displays the average result of all the simulations (ePM, 2005). Additionally, the software uses four main probabilities to model different concepts in Agent-based modeling. These probabilities are explained as follows:

1. Information exchange probability: Information exchange probability is used to measure the volume of information being exchanged between the tasks linked with the communication link. The communication volume is determined by taking into account the number of communication links, duration of tasks, and the information exchange probability.

2. Noise Probability: As also explained before, noise probability is used to take into account the distractions and interruptions that the positions may face in their day-to-day work life which may require them to spend their time in activities away from their main task. Noise probability has a direct influence on the duration of the project.

3. Functional error probability: Functional error probability is used to induce variability in the execution of the tasks. Irrespective of the usage of rework lines, the functional error probability produces localized exceptions in the tasks. The concept is primarily used to depict functional error observations in projects which can be identified through self-checks, peer review, or supervisor review. The identified exception in a task is sent to the concerned position and based upon the centralization of the organization, the exception request is either forwarded to the supervisors or the position can choose to either perform rework, implement a quick fix or ignore the exception.

4. Project error probability: Somewhat similar to the information exchange probability, the project error probability is used to measure the amount of rework generated in the dependent tasks connected through rework links. Contrasting to

functional error probability, the project error probability only generates rework in the tasks connected through rework links.

The probabilities used for the model constructed in this research can be found in the modeling plan (Appendix C). The initialization covered in the ODD methodology describes the procedure for determining these probabilities.

Collectives

Collectives can be defined as the aggregation of agents in the agent-based model such as social groups etc. which are characterized by the properties of the entire group but behave like a unique entity (Grimm et al., 2020a).

SimVision® defines collectives as discreet positions which can be characterized by a name, role (PM, ST, SL), Full-Time Equivalents (FTEs), application experience, etc. As also explained before, one of the key challenges in Agent-based modeling is to choose the right level of abstraction so that the model fulfills its functional objective without adding unnecessary details to it. This concept holds for the organization structure as well.

The model created for this study aggregates the team members who are on a similar layer of hierarchy and are assumed to have similar skill-set. The full-time equivalent represents the number of full-time employees working in the project team. For aggregated positions, the number of FTEs is also equivalent to the number of full-time aggregated employees. It should be noted that the FTE of positions can also be represented as infractions. For example, the full-time equivalent of a part-time employee will be 0.5.

The collectives formed for this research can be found in Appendix-E.

Observation

Observation is intended to emphasize the method of information retrieval and analysis from the outputs of the model (Grimm et al., 2010, 2020a). Once the model is constructed and running, it is essential to identify valuable outcomes and relate them to the problem for which the model was initially intended (Grimm et al., 2020a).

As also mentioned before, this study mainly focuses on the duration of the project. SimVision® calculates the duration of the project in terms of primary production work, coordination work, rework, and decision wait. By allocating different organizational structures and team compositions motivated by contracts, the outcomes will be compared based on durations and their mentioned splits.

Moreover, the duration of a project is also influenced by the cultural properties of the organization, for example, team composition, matrix strength, centralization, formalization, information exchange probability, and noise probability. These factors are further tested for their robustness in the modeling process and the most influential factors have been highlighted.

Initialization

Initialization intends to stepwise elaborate the setup of the model in such a way that the model becomes reproducible for any further research (Grimm et al., 2010, 2020a, 2020b). Initialization discusses the methodology of exactly how the baseline is constructed and how the initialization varies across different scenarios (Grimm et al., 2020a).

The initialization of an agent-based model begins with the acquisition of relevant data. As also explained before, the data collected for the model constructed in the present study is mainly through the official plans (both schedules and organization chart) of Omaxe and several semi-structured interviews conducted with the Assistant manager (MIS and coordination) working on the project. The schematic of data and the acquisition methods is depicted below:

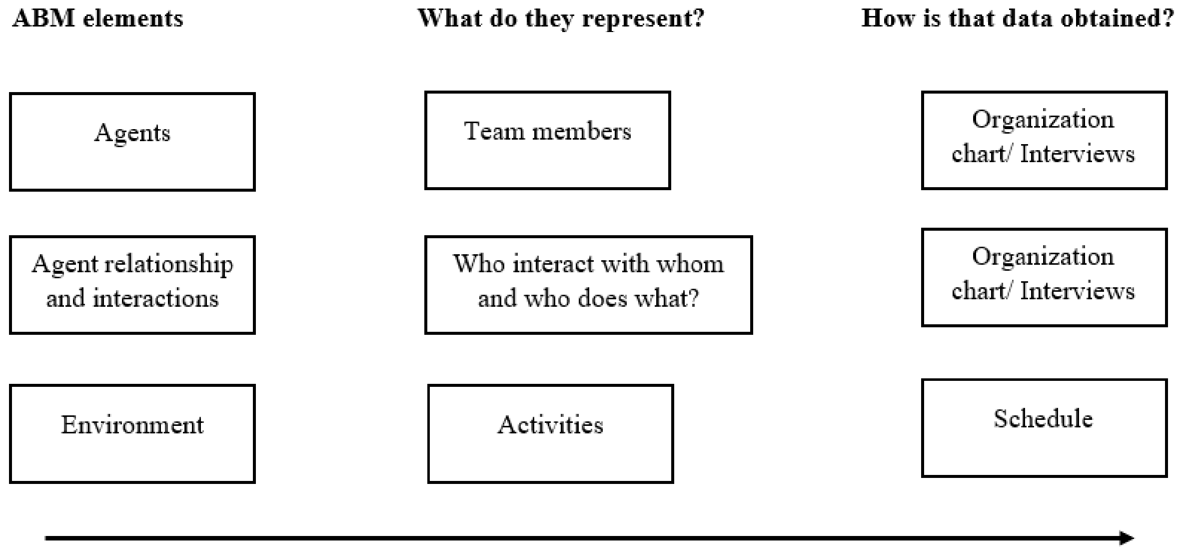


Figure 37: Data acquisition schematic

The construction of the baseline model which is also referred to as the initialization of the model follows an iterative path in the current study with the help of three distinct models. For convenience, these models will be called model 1, model 2, and model 3.

The construction of model 1 starts with determining the main elements that play a role in the process being modeled. Which in simple terms means to identify the main aggregated activities and people responsible for executing those activities.

The first step is to identify the major milestones of the process and determine their dependencies. SimVision® allows adding milestones on the modeling canvas using blue-diamond boxes in the tools which can be populated with the planned date to demonstrate the anticipated time on which the milestone is expected to be achieved. The idea of identifying milestones first is to start on a zoomed-out lens and further add details to it as per the requirements and purpose of the model.

Depending upon the required level of abstraction, these milestones are extended with activities that are required to be executed to reach the milestone. SimVision® model's activities with the help of yellow rectangular boxes which can be populated with a different name, duration type, complexities, etc. (Appendix-F) and joined together either with other activities or milestones using successor links. It should be noted that SimVision® requires at least two milestones (Start and Finish) to demarcate the beginning and end of a process. The additional milestones serve for better understanding and convenience of the user. For this study, 3 major milestones are determined which are further elaborated using 16 aggregated activities (Appendix B).

SimVision® allows characterizing tasks with different types of duration. In the present study, work volumes, work durations, and supervisory tasks are used to demonstrate this. Work duration is generally used to model tasks whose duration is independent of the number of people working on them. For example, if a certain certificate has to be obtained before the commissioning of the project and its nominal time is 14 days, adding more people to the task will not affect the duration of the task. On the other hand, work volume is used to model tasks and activities that are influenced by the addition of people. For example, the laying of rebar for a floor; the Addition of more people is more likely to expedite the process. And lastly, the supervisory tasks try to model the supervisory relationship of certain positions with activities. It might be possible that a certain position is responsible for supervising the directly linked positions without actually being involved in the execution. The supervisory tasks are directly modeled with the use of FTE. The total amount of time that a position spends doing the supervision can be directly translated in terms of FTE and be used as an input to model that task.

It should be noted that work duration does not equate to the calendar days between two activates but is rather the total task duration in simulated days not taking into account the weekends, nights, and non-working time, in general. Work volume on the other hand is calculated by taking a product of task duration, FTE assigned to the task, and their allocation. It should be noted that a certain position can be allocated to various activities. Allocation allows to input the percentage of a certain position on the specified task. For convenience, SimVision® also offers a tool called work-volume calculator which calculates the volume of a task based on the input of start and end date of activity, allocation, FTE, the number of working days in a week, and the number of working hours in a day. A list of activities and their durations for this study can be found in Appendix F.

The next step to create model 1 is to identify the relevant people and their chain of hierarchy. SimVison® is extremely efficient in determining how organizational characteristics influence the markers of a project's success. Therefore, the levels of hierarchy and the reporting system should be carefully understood. It should be noted that the principle of aggregation also holds for people working on the project. As also mentioned in the collectives, the people holding almost similar skills and designations can be clustered together using positions. SimVision® models positions with the help of a green person-like figure which can be populated using different position names, roles, application experience, color, etc (Appendix G.2). To establish the chain of hierarchy and reporting system between different positions, the reporting links are used. In doing so, a sketch of the aggregated organizational team is prepared. For this research, 20 distinct positions are identified (Appendix – G.2).

The main differentiating factor between model 1 and the other two models is that of activity dates and duration. Activities in model 1 are populated using the planned dates retrieved from the schedules of Omaxe. On the other hand, model 2 is merely a replica of model 1 but with actual dates of the activities which are determined through the interviews conducted with the assistant manager (MIS and Coordination). It should be noted that both model 1 and model 2 are uninfluenced by any system settings such as the strength of rework links, the strength of communication links, probabilities, etc. which differentiates them from model 3. Taking model 1 as the basis, the system settings are iteratively introduced till the activity and project duration of model 1 resemble that of model 2. The system settings give an idea of how the team's culture is affecting the entire working process. Model 3, therefore, represents the baseline of the modeling process.

Since this research intends to study the impact of different team composition and organization structures, the initialization of comparative scenarios is highly dependent upon how the organization structure of the comparative scenario is to be modeled. For example, an organizational structure motivated by the EPC contract type is likely to reduce the responsibilities and involvement of the client however at the same time might add a decision layer.

Input data

Input data refers to the additional data supplied to the model during its execution to represent change over time (Grimm et al., 2010, 2020a). Input ta is not implemented in the current model to represent time-varying processes.

Sub-models

This section is intended to explain the construction of a complex model by elaborating on the sub-models that substantiate the main model (Grimm et al., 2010, 2020a).

The model created in this study focuses on the MEP and Finishing phase of the project. This allows the bifurcation of the main model into three sub-models depending upon the task being performed. These three models represent the finishing, MEP, and the creation of a façade for the project that is modeled. A representation of this sub-model can be found in Appendix B. The main reason for the segregation of the model is due to the supervisory tasks that are modeled for the process. Since the supervision of finishing, MEP and façade are done by three distinct positions, for a better understanding of the work process and model, the segregation of the sub-model is done.

Appendix – K

Single-agent verification

S.no	Changes in state variables	Predictions	Status
	Working crew	**Application experience directly affects the processing speed of the positions; Increasing the experience decreases the duration of the project** (ePM, 2005)	
1.	Changed the application experience of finishing crew to High	Finishing works executed drastically early.	**Confirmed**
2.	Changed the application experience of facade crew to High	Facade works executed drastically early.	**Confirmed**
3.	Changed the application experience of MEP crew to High	MEP works executed drastically early.	**Confirmed**
4.	Changed the application experience of construction crew to High	Construction work executed drastically early.	**Confirmed**
5.	Changed the application experience of finishing crew to Medium	Finishing works executed considerably early. Finishes work are exectured earlier than the baseline model but finishes later than the case when application experience is High.	**Confirmed**
6.	Changed the application experience of facade crew to Medium	Facade works executed considerably early. Façade works are executed earlier than the baseline model but finishes later than the case when application experience is High.	**Confirmed**
7.	Changed the application experience of MEP crew to Medium	MEP works executed considerably early. MEP works are executed earlier than the baseline model but finishes later than the case when application experience is High.	**Confirmed**
8.	Changed the application experience of construction crew to Medium	Construction works executed considerably early. Construction works are executed earlier than the baseline model but finishes later than the case when application experience is High.	**Confirmed**
9.	Changed the application experience of facade crew to Low	The façade activities finish considerably later than the baseline case.	**Confirmed**
	Discipline heads		
10.	Changed the application experience of finishing head to Medium	Coordination time of finishing activities increases but the durations remain almost the same.	**Confirmed**
11.	Changed the application experience of MEP head to Medium	Coordination time of MEP activities increases but the durations remain almost the same.	**Confirmed**
12.	Changed the application experience of construction head to Medium	Coordination time of construction activities increases but the durations remain almost the same.	**Confirmed**
13.	Changed the application experience of finishing head to Low	Coordination time of finishing activities increases but the durations remain almost the same.	**Confirmed**

14.	Changed the application experience of MEP head to Low	Coordination time of MEP activities increases but the durations remain almost the same.	**Confirmed**
15.	Changed the application experience of construction head to Low	Coordination time of construction activities increases but the durations remain almost the same.	**Confirmed**
16.	Changed the role of all discipline heads to SL	Increased rework and coordination (ePM, 2005).	**Confirmed**
17.	Changed the role of all discipline heads to PM	Drastic increase in rework and hence duration (ePM, 2005)	**Confirmed**

Appendix – L.1

Meeting participants (Model 1)

Meeting Participant	Allocation	Connected From	Connected To
1	100	Project Controller	Weekly progress meeting
2	100	Finishing head	Weekly progress meeting
3	100	Construction head HAZ. MINI	Weekly progress meeting
4	100	MEP head	Weekly progress meeting
5	100	Construction Manager HAZ. MINI	Weekly progress meeting
6	100	MEP Manager	Weekly progress meeting
7	100	Project Owner	Var. meetings
8	100	Project Manager	Var. meetings
9	100	Project Controller	Var. meetings
10	100	Admins	Var. meetings
11	100	Stakeholder(s)	Var. meetings
12	100	Finishing Manager	Weekly progress meeting
13	100	Finishing Manager	Daily meetings
14	100	Construction Manager HAZ. MINI	Daily meetings
15	100	MEP Manager	Daily meetings
16	100	Finishing Supervisors	Daily meetings
17	100	Construction supervisors HAZ. MINI	Daily meetings
18	100	MEP supervisors	Daily meetings

Appendix – L.2

Meeting participants (Model 3)

Meeting Participant	Allocation	Connected From	Connected To
1	100	Project Controller	Weekly progress meeting
2	100	Finishing head	Weekly progress meeting
3	100	Construction head HAZ. MINI	Weekly progress meeting
4	100	MEP head	Weekly progress meeting
5	100	Construction Manager HAZ. MINI	Weekly progress meeting
6	100	MEP Manager	Weekly progress meeting
7	100	Project Owner	Var. meetings
8	100	Project Manager	Var. meetings
9	100	Project Controller	Var. meetings
10	100	Admins	Var. meetings
11	100	Stakeholder(s)	Var. meetings
12	100	Finishing Manager	Weekly progress meeting
13	100	Finishing Manager	Daily meetings
14	100	Construction Manager HAZ. MINI	Daily meetings
15	100	MEP Manager	Daily meetings
16	100	Finishing Supervisors	Daily meetings
17	100	Construction supervisors HAZ. MINI	Daily meetings
18	100	MEP supervisors	Daily meetings
19	100	Finishing Manager	Daily meetings for other projects in the portfolio
20	100	Construction Manager HAZ. MINI	Daily meetings for other projects in the portfolio
21	100	MEP Manager	Daily meetings for other projects in the portfolio
22	100	Finishing Manager	Weekly meetings for other projects in the portfolio
23	100	Construction Manager HAZ. MINI	Weekly meetings for other projects in the portfolio
24	100	MEP Manager	Weekly meetings for other projects in the portfolio
25	100	Finishing head	Weekly meetings for other projects in the portfolio
26	100	Construction head HAZ. MINI	Weekly meetings for other projects in the portfolio
27	100	MEP head	Weekly meetings for other projects in the portfolio
28	100	Project Controller	Weekly meetings for other projects in the portfolio
29	100	Finishing head	Daily meetings for other projects in the portfolio
30	100	Construction head HAZ. MINI	Daily meetings for other projects in the portfolio
31	100	MEP head	Daily meetings for other projects in the portfolio
32	100	Admins	Weekly meetings for other projects in the portfolio

Appendix – L.3

Meeting participants (Model EPC)

1	100	Construction Supervisor	'Var. meetings
2	100	Finishing Supervisor	'Var. meetings
3	100	MEP Representative	Quality Audits, Progress meeting and change control <Haz. mini
4	100	Construction Representativ	Quality Audits, Progress meeting and change control <Haz. mini
5	100	Finishing Representative	Quality Audits, Progress meeting and change control <Haz. mini
6	100	Owner Engineer	Quality Audits, Progress meeting and change control <Haz. mini
7	100	Senior Manager	Quality Audits, Progress meeting and change control <Haz. mini
8	100	Admins and staff	Quality Audits, Progress meeting and change control <Haz. mini
9	100	Project Manager (Client)	Quality Audits, Progress meeting and change control <Haz. mini
10	100	Owner	Quality Audits, Progress meeting and change control <Haz. mini
11	100	Owner	Quality audtis and progress of other projects in the portfolio
12	100	Project Manager (Client)	Quality audtis and progress of other projects in the portfolio
13	100	Owner Engineer	Quality audtis and progress of other projects in the portfolio
14	100	Senior Manager	Quality audtis and progress of other projects in the portfolio
15	100	Admins and staff	Quality audtis and progress of other projects in the portfolio
16	100	MEP Representative	Quality audtis and progress of other projects in the portfolio
17	100	Construction Representativ	Quality audtis and progress of other projects in the portfolio
18	100	Finishing Representative	Quality audtis and progress of other projects in the portfolio
19	100	Project Manager (contractor)	Quality audtis and progress of other projects in the portfolio
20	100	MEP Manager	Quality audtis and progress of other projects in the portfolio
21	100	Construction Manager	Quality audtis and progress of other projects in the portfolio
22	100	Finishing Managers	Quality audtis and progress of other projects in the portfolio
23	100	MEP Supervisor	Quality audtis and progress of other projects in the portfolio
24	100	Construction Supervisor	Quality audtis and progress of other projects in the portfolio
25	100	Finishing Supervisor	Quality audtis and progress of other projects in the portfolio
26	100	MEP Manager	Daily Meetings of other projects in the portfolio
27	100	Construction Manager	Daily Meetings of other projects in the portfolio
28	100	Finishing Managers	Daily Meetings of other projects in the portfolio
29	100	MEP Supervisor	Daily Meetings of other projects in the portfolio
30	100	Construction Supervisor	Daily Meetings of other projects in the portfolio
31	100	Finishing Supervisor	Daily Meetings of other projects in the portfolio
32	100	MEP Representative	BI-Weekly Meetings of other projects in the portfolio
33	100	Construction Representativ	BI-Weekly Meetings of other projects in the portfolio
34	100	Finishing Representative	BI-Weekly Meetings of other projects in the portfolio
35	100	Project Manager (contractor)	BI-Weekly Meetings of other projects in the portfolio
36	100	MEP Manager	BI-Weekly Meetings of other projects in the portfolio
37	100	Construction Manager	BI-Weekly Meetings of other projects in the portfolio
38	100	Finishing Managers	BI-Weekly Meetings of other projects in the portfolio
39	100	MEP Supervisor	BI-Weekly Meetings of other projects in the portfolio
40	100	Construction Supervisor	BI-Weekly Meetings of other projects in the portfolio
41	100	Finishing Supervisor	BI-Weekly Meetings of other projects in the portfolio
42	100	MEP Supervisor	Quality Audits, Progress meeting and change control <Haz. mini
43	100	Construction Supervisor	Quality Audits, Progress meeting and change control <Haz. mini
44	100	Finishing Supervisor	Quality Audits, Progress meeting and change control <Haz. mini
45	100	MEP Manager	Quality Audits, Progress meeting and change control <Haz. mini
46	100	Construction Manager	Quality Audits, Progress meeting and change control <Haz. mini
47	100	Finishing Managers	Quality Audits, Progress meeting and change control <Haz. mini
48	100	Project Manager (contractor)	Quality Audits, Progress meeting and change control <Haz. mini
49	100	MEP Representative	Bi-Weekly Progress
50	100	Construction Representativ	Bi-Weekly Progress
51	100	Finishing Representative	Bi-Weekly Progress
52	100	MEP Supervisor	Bi-Weekly Progress
53	100	Construction Supervisor	Bi-Weekly Progress
54	100	Finishing Supervisor	Bi-Weekly Progress
55	100	MEP Manager	Bi-Weekly Progress
56	100	Construction Manager	Bi-Weekly Progress
57	100	Finishing Managers	Bi-Weekly Progress
58	100	Project Manager (contractor)	Bi-Weekly Progress
59	100	MEP Supervisor	Daily Meeting
60	100	Construction Supervisor	Daily Meeting
61	100	Finishing Supervisor	Daily Meeting
62	100	MEP Manager	Daily Meeting
63	100	Construction Manager	Daily Meeting
64	100	Finishing Managers	Daily Meeting

Table 41: Meeting participants (Experimental case)