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UNDERSTANDING IMPROVISATION IN CONSTRUCTION THROUGH AGENT-BASED MODELING

by
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AN ABSTRACT OF THE THESIS OF

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Improvisation is a spontaneous, impulsive, but rational decision-making process. Although unpopular, as it indicates deviation from plans, improvisation is unavoidable in construction as it helps address emerging non-standard issues or problems related to unforeseen uncertainties. Therefore, a construction project will benefit from applying an adaptive planning system that employs improvisation and reacts rapidly to unplanned incidents. This research study aims at advancing the knowledge of improvisation in construction through better understanding its dynamics. The study's contribution to the industry lies in guiding construction planners and decision-makers to better manage the problems of unexpected uncertainty through enhancing the overall improvisational performance in a construction project.

Agent-based modeling is used to develop a simulation model that depicts the improvisation practices at the level of planners working and interacting together in a construction project. The simulation model illustrates planner, project, and problem-related parameters that highly influence how each planner improvises. Moreover, the model considers different types of interactions that might shape the ongoing improvisational practices. Also, it identifies how different variations of improvisational parameters, related to the planners' assortment and types of construction projects, influence the emergent improvisational outcome.

Thereafter, Analytical Hierarchy Process survey is conducted among a group of construction experts to quantify certain behaviors and rules related to the model's components. Also, the inputs of the developed model are validated while considering data from five large-size projects, located in a metropolitan capital. In addition, simulation experiments are conducted to develop linear regression models that anticipate the outcomes of the improvisational practices in a certain project from a given distribution or combination of improvisers. The established classification of improvisers in this study has proven to be a significant quantitative predictor for the emergent improvisational performance in a project. Finally, several practical implications and recommendations are made to better enhance the performance of improvisation in construction.

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ABBREVIATIONS

CHAPTER 1
INTRODUCTION

1.1 Introduction

Planning in construction is an indispensable process that spans throughout the project's life cycle and aims to achieve the project's objectives related to time, cost, quality, and safety. Planners and schedulers have always highlighted the importance of planning for organizing work, reducing risk, facilitating communication, maintaining good control, as well as reaching their desired objectives (Akrani, 2012). Unfortunately, traditional planning practices cannot develop plans and procedures for all possible scenarios and eventualities (Woods and Hollnagel, 2006). Therefore, improvisation may appear as the final resort for addressing the issues of uncertainty, dynamism, and complexity (Trotter et al., 2013).

Organizations and management studies have recently increased their interest in improvisation as it helps address unplanned or emergent circumstances in a highly dynamic environment. Numerous organizations have employed improvisation aiming to cope with unplanned interruptions, as well as to compensate for the shortcomings of traditional planning, improper management, and human errors (Cunha, 2005; Mendonca and Wallace, 2007; Chelariu et al., 2002). Therefore, the need to understand improvisation has become essential to survive in dynamic, complex, and/or uncertain environments. Accordingly, researchers have demonstrated the practices of improvisation in different organizational settings and looked at different fields of application to understand the process.

In the context of construction industry, a prevailing reason behind the high failure rate of construction projects is misestimating the level of uncertainty and risk

(Hwang et al., 2014). The increasing level of complexity of construction projects has led to interrelating types of uncertainties for which traditional management methods cannot respond (Fang et al., 2012; Gagarina et al., 2015; Marle, 2015). Accordingly, construction literature has introduced new procedures into planning to efficiently reduce the problems of uncertainty and variability. The Last Planner System (LPS) is developed to manage foreseen or expected uncertainties. It emphasizes the gradual removal of constraints by planning in greater detail as execution is approached (Hamzeh et al., 2015). However, deviations from existing plans and standard procedures cannot be fully avoided during which performance variation is required to manage unplanned or uncertain circumstances (Chelariu et al., 2002). Improvisation is one form of performance variation through which organizations tend to change its standard practices and plans in order to adapt to the newly emerged or unexpected work (Woods and Hollnagel, 2006; Grotan et al., 2008). As a matter of fact, every organization is bound to face issues or problems related to dynamism, complexity, and uncertainty, rendering improvisation as an inevitable practice to cope with such type of problems (Cunha et al., 1999; Woods and Hollnagel, 2006; Trotter et al., 2013).

Improvisation is an intentional but extemporaneous, rational decision-making skill. It usually helps under time pressure and in the absence of the optimal information or resources (Ciborra, 1999). Improvisation has been studied in various fields of application. Initially, jazz theorists have adopted the interpretation of improvisation. Then, typologies have been developed elucidating its different types and attributes in multiple organizational settings such as new product development (Moorman and Miner, 1998), crisis management (Roux-Dufort and Vidaillet, 2003), team work (Vera and Crossan, 2005), and restructuring performance (Bergh and Lim, 2008), just to name a few. Musical theorists have adopted the earliest interpretation of improvisation. Later, typologies have been developed for improvisation in organizations elucidating its different types and attributes. Unfortunately, although the construction field is known to face numerous uncertain, dynamic, and highly variable circumstances, very few researches have attempted to tackle this phenomenon in construction.

Particular to construction, improvisation is perceived as an interesting practice to cater for the dynamism and glitches resulting from unexpected uncertainty. However, few contributions are made in the literature to explain improvisation in the context of construction operations. The aim of this study is to better manage the unforeseen uncertainties in construction through analyzing the process of improvisation at the level of different planners within a certain construction endeavor and identifying the linkages between the overall improvisational outcome and different types of influencing factors. This research employs agent-based modeling to develop a simulation model that depicts the improvisational practices within a construction project. The contribution of this study lies in guiding construction planners and decision-makers to better manage the problems of unexpected uncertainties through enhancing their overall improvisational performance.

1.2 Research process

A research process is designed to set a plan of work from the beginning of this study until completion. It serves as a planned strategy to identify problems and research gaps in the area of study, formulate a set of research questions, and achieve the aimed objectives through a well-developed research methodology. The primary step of the research process includes a review of the available literature on improvisational practices in several fields of application including construction. Also, assessment of a previous exploratory studies related to improvisation in construction has been performed. Then, problems and research gaps related to improvisation in the construction field are identified. Accordingly, they form the motivation of this study and assist in developing the research objectives. Afterwards, specific research questions are set and used as a guidance for the design of the research methodology. Based on the methodology, agent-based modeling and data collection are performed. Validation of inputs and simulation experiments are presented, analyzed, and discussed. Conclusions and recommendations of this research are finally put forth.

1.3 Organization of the thesis

The organization of the thesis is summarized in Figure 1. Chapter 2 provides a research background on the topics covered in this study as well as summarizes previous exploratory studies related to improvisation in construction. Musical improvisation, improvisation in the field of organizational management, improvisational practices and methods for managing uncertainties in construction, as well as simulation and agent-based modeling are reviewed in this chapter. Chapter 3 highlights the problematic areas and gaps in the current research and accordingly presents the research objectives and questions. Chapter 4 explains the developed research methodologies as well as the employed methods. Conceptual and agent-based simulation modeling are explained in Chapter 5. Chapter 6 illustrates different applications of the developed model: 1) Analytical Hierarchy Process (AHP) survey, 2) input validation, and 3) simulation experiments. Results of the input validation and simulation experiments are presented, analyzed, and discussed in Chapter 7. Chapter 8 concludes with the research work, limitations of the current study, recommendations for industry and future research.

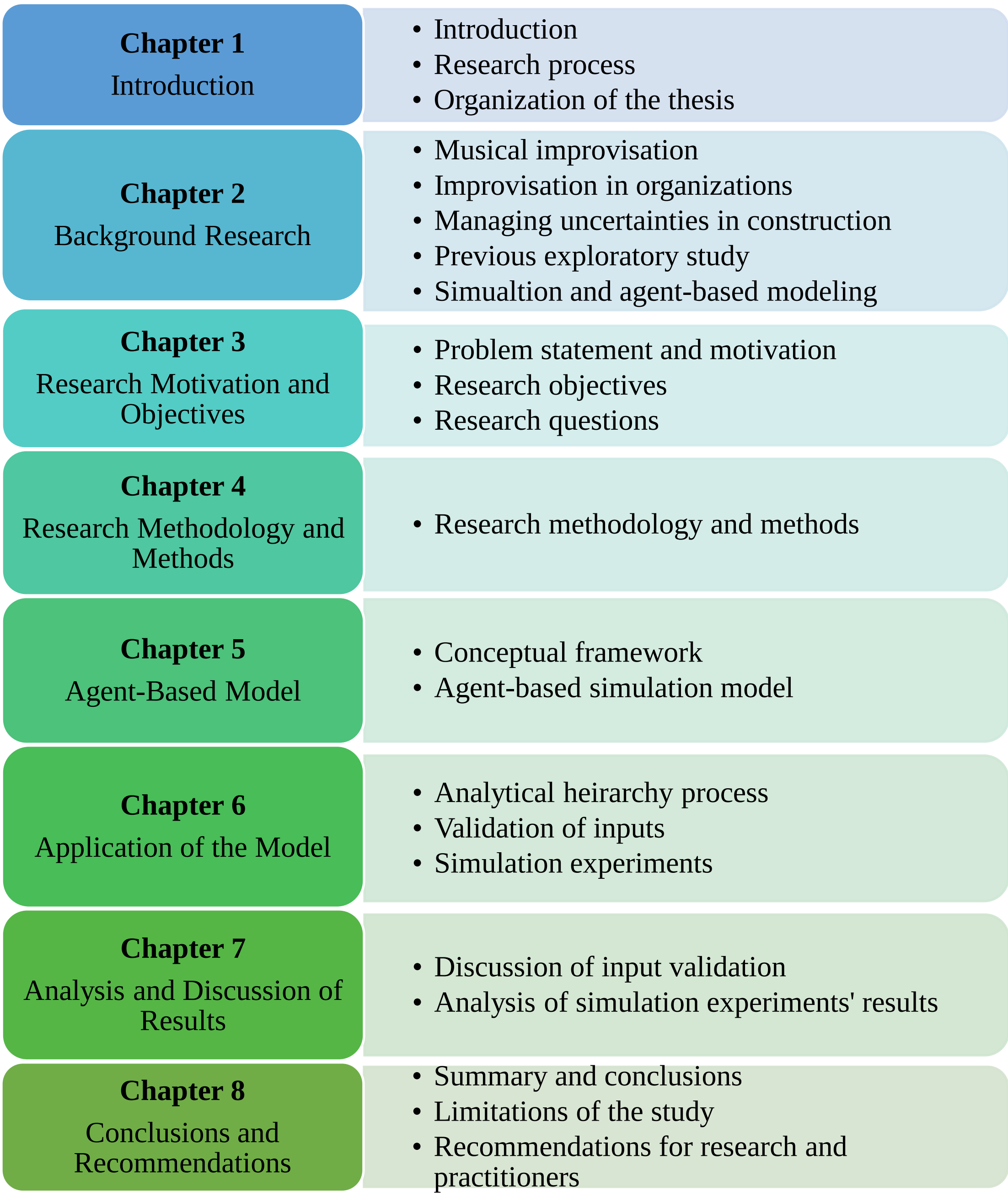

Figure 1 – Organization of the thesis

CHAPTER 2

BACKGROUND RESEARCH

2.1 Musical Improvisation

Early definitions of improvisation are influenced by jazz theory which was devised to explain the way great musicians play improvised music (Levine, 1995). While "ninety-nine percent" of playing a great improvised music can be attributed to the explainable, analyzable and doable, a remaining "one percent" can be referred to as magic. Accordingly, the "ninety nine percent" can be explained by musician's experience and practice, while the remaining "one percent" can only be described by the magic of improvisation that cannot be reached without the fundamental "ninety-nine percent". In an attempt to understand the basics of musical improvisation, Pressing's model is influential in viewing improvisation as a set of generation, selection, and execution of novel melodic processes (Pressing, 1988; 2001). Moreover, the model propounds the powerful impact of experience on the improvised tones where improvisational fluency of musicians is seen as a result of their expertise that automates some attentional cognitive processes.

2.2 Improvisation in Organizations

Organizational improvisation can be performed either by an organization as a whole or by one or more of its members (Hadida et al., 2015). For individuals, improvisation appears as an act of surpassing the standard routines to come up with a novel solution to the problem under consideration (Hadida et al., 2015). Organizations were used to consider improvisation as a deviation from normal plans, a potential source of risk, and something that should be avoided or controlled. However, the role of improvisation has continued to resolve problems and help organizations co-evolve with their changing environments (Hollnagel et al., 2006; Hadida et al., 2015). Therefore, numerous research studies in organizations have been performed to study different attributes and influencing factors of improvisation, and accordingly enhance its performance.

Researches related to organizational management have demonstrated the practices of improvisation by looking at different aspects and accordingly ending up with various definitions. After analyzing different definitions of improvisation presented in the literature, four main criteria describing improvisation are concluded to reach a comprehensive understanding. First, some scholars defined improvisation by referring to the “method” used to improvise. For instance, improvising is to generate new combinations and solutions under wicked conditions (Ciborra, 1999). Second, other scholars have explained improvisation as the action of formulating and implementing solutions simultaneously (Perry, 1991), thus emphasizing on the “time” aspect of improvisation. Third, the “spontaneity” of improvisation has been the interest of many scholars who have elucidated improvisation as extemporaneous and deliberate organizational actions (Cunha et al., 1999). Finally, some studies linked the improvised actions with the “innovation”, therefore relating improvisation to the creativity and ingenuity (Magni et al., 2009).

For a comprehensive understanding of organizational improvisation, Cunha et al. (1999) have developed a general definition that explains improvisation as “the conception of action as it unfolds, by an organization and/or one of its members drawing on available material, cognitive, affective and social resources”. The authors have distinguished four different resources in this definition. Material resources include all resources except the individuals and the external social system. As for the cognitive resources, they comprise the expertise and the learning earned by the entire organization. On the other hand, affective resources incorporate the emotional state of the improvisers. Last of all, social resources include all the formal and informal communication within an organization (Cunha et al., 1999).

Although traditional management theorists have always preferred planning and resourcing where they can rely on routine, repetitious, and automatic processes (Weick, 1993; 1999), the role of improvisation continued to resolve problems and help organizations co-evolve with their changing environments (Cunha, 2005). The importance of improvisation in organizational management has been constantly manifested in several research studies. According to Brown & Eisenhardt (1997), improvisation is the most robust practice that effectively copes with rapidly changing environments. A further emphasis has been made by Chelariu et al. (2002) that planning can lead to complications, and such complications would require improvisational efforts to resolve them. Similarly, advocating the role of improvisation, a study have showed that only one out of hundred respondents didn't support the use of improvisation in organizations (Leybourne, 2006).

Numerous research studies have been performed to study the attributes and the influencing factors of a sound organizational improvisation. There are many attributes that describe improvisation such as novelty, degree of improvisation, and time pressure. In most of literature, the degree of improvisation is framed as a continuum that starts by interpretation, embellishment, variation, and at the upper limit improvisation (Cunha et al., 1999). Interpretation refers to situations where plans are strictly followed. While in embellishment, small variations are introduced into the original plans that remain recognizable. Variation involves introducing new procedures into the plans, and finally improvisation refers to following a radical departure from the original plan. Hence, actions that alter, revise, create, and discover are more improvisational than those that shift, switch, or add (Weick, 1998; Trotter et al., 2013). Time pressure and speed are considered major characteristics of improvisation. When information is shared with a wider group of individuals, improvisation is expected to be of low speed and associated with more powerful forms of information generation. However, high speed improvisation may successfully cope with the uncertainty of the dynamic environment (Chelariu et al., 2002).

In addition, researches have shown a wide range of influencing factors that can affect the way people improvise in an organization. These factors include: 1) *Experience* starting with the ability to recognize an undesired situation, the ability to identify and use leverage points, and finally the ability to generate alternatives (Trotter et al., 2013), 2) *Training* which can improve persons' ability to mentally simulate the results of their actions and hence the ability to practice sound improvisation (Klein, 2007), 3) *Education* that enables employees to learn high-level concepts in their field, 4) *Situation awareness* that accurately evaluates the current setting, 5) *Teamwork* where an improved trust and collaboration between the employees can enhance their improvisational capabilities (Vera & Crossan, 2005), 6) *Information flow* that allows immediate feedback of improvisational outcomes, thus enabling the improvisers to build on or correct the course of their actions, 7) *Minimal structures* or organizational role system since the lack of role definition causes confusion in emergent settings, 8) *Organizational memory* where employees rely on a wider database of past experience and learning so they can practice better improvisation (Mendonca & Wallace, 2007), 9)

Organizational culture related to how employees are empowered to experiment, the way managers track errors, and how they deal with blame (Vera & Crossan, 2005), and 10) *Authority mitigation* in terms of switching the roles and deviating from the standard procedures (Størseth et al., 2010).

Unfortunately, a dark side of improvisation, as a performance variation, is the possibility to generate considerable accidents at operational work. This can be due to lack of a safety culture, time pressure, lack of control and resources, and/or presence of a blame policy (Amorim and Pereira, 2015). Nevertheless, proper practices of improvisation have continued to manage problems related to rapidly changing and uncertain work environments (Hollnagel et al., 2006; Hadida et al., 2015). In addition to the usefulness of improvisation in managing uncertainty in organizations, competition among organizations and institutional pressure to respond rapidly for emergent and continuously changing conditions are important drivers to consider improvisation as an inevitable management tool (Miles et al., 2007). Therefore, in order to gain a competitive edge, an organization needs to cultivate the strategic thinking related to improvisation and encourage their employees to be “at the spot”, hence to properly practice improvisation (Cohen and Prusak, 2001). Aiming to study the role of improvisation in competing with other organizations, Cunha et al. (2012) indicated that improvisation may be considered as a “real time foresight” in the process-based competition, although it is a minor practice or occurrence in the structural competition (Cunha et al., 2012). In addition, in order to support the use of improvisation as a system phenomenon, Trotter et al. (2014) has proven the appropriateness of Rasmussen’s (1997) Risk Management Framework and Accimap methodology for examining the factors influencing improvisation in critical safety situations. Therefore, organizations can practice appropriate and effective improvisation through predicting and understanding the corresponding influencing factors (Trotter et al., 2014).

2.3 Managing Uncertainties in Construction

Aiming to better manage uncertainties associated with the construction environment, Abdelhamid et al. (2009) suggested the use of the OODA (observe, orient, decide, and act) loop along with the Last Planner® as a viable option that aids self-managed construction teams to face unexpected situations (Abdelhamid et al., 2009). Moreover, Desai & Abdelhamid (2012) proposed the input control method to manage uncertainties in construction projects such as building capabilities and securing enough experience and knowledge (Desai & Abdelhamid, 2012).

In an attempt to understand the construction workers' daily disruptions and decisions, an ecological momentary assessment showed that every disruption requires a worker's improvisational skill to continue working (Menches & Chen, 2013). Moreover, a diary study highlighted a group-level positive correlation between disruptions and improvised decisions or actions (Menches & Chen, 2014). Other studies have addressed the possible employment of improvisation to complement the lookahead planning in construction projects. Exploratory results show that an organization's culture may prevent blue collar employees from creating new improvised procedures even when the plans fail to address emergent situations. Hamzeh et al. (2012) have grouped planning failures (i.e., failure to execute tasks on time) into three categories as shown in Figure 2. The first category involves failures in executing planned tasks due to deficiencies in identifying constraints and removing them on time. The second category includes failures due to lack of proper planning and anticipation. Finally, the third group includes failures caused by uncertainties that cannot be foreseen or planned for. Managers usually focus on improving planning procedures in order to eliminate the first two categories of failures. But to deal with the third category of unavoidable failures, planners are advised to improve their improvisational skills (Hamzeh et al., 2012). While some studies have addressed improvisation in construction, none seems to provide a deep understanding of different types of improvisation employed in construction, its behaviors, and the quality of the resulting improvised actions. Therefore, a profound study of improvisation is required before condoning it as a necessary companion to construction planning.

Figure 2 – Failures in planning (Hamzeh et al., 2012)

For managing the first two categories of planning failures, the Last Planner System is found to be a robust practice that aims to enhance the reliability of planning. It focuses on the quality criteria prior to execution of tasks so that one could guarantee a successful and complete execution (Ballard, 2000a). The LPS is segmented into four main stages: 1) “Master scheduling” where long term plans, goals, and means of the entire project are defined, 2) “Phase scheduling” during which the project is divided into smaller packages, and general tasks are more defined and sequenced, 3) “Look-ahead planning” where bi-weekly planning is achieved while considering the constraints of each task, and 4) "Weekly work plans" at which planners start executing the tasks coming from the look-ahead plans, remove constraints prior to execution, and match the available resources with the required assignments. In this case, potential problems of uncertainty and planning deficiencies are minimally reduced. Last planners play a vital role in maintaining proper implementation of the LPS. They are the ones responsible for overlooking the activities mentioned in the weekly work plans. They have multiple commitments such as: 1) breaking down the phase schedule into smaller tasks while considering the available resources, 2) sequencing the tasks that were defined previously and performing "first run studies" to understand and improve the method of execution, and 3) identifying prerequisites and removing constraints prior to execution. The mere aim of the last planners is to approach execution with minimal problems. However, unexpected problems or unplanned incidents might still occur. Therefore, alternative solutions are required to complement planning and proceed with the execution successfully.

2.4 Improvisation in construction: previous exploratory studies

A previous research study has modeled improvisation in construction as a decision-making process and explained its different stages (Hamzeh et al., 2018). Also, another study has defined improvisation in construction as a deliberate decision-making process that is usually used when: 1) speed is required to meet a deadline, 2) planned procedures fail to meet the requirements, 3) pre-planned strategies fail to manage a sudden problem, and 4) standardized procedures fail to catch up with daily ameliorations and progress (Hamzeh et al., 2018). Statistical analyses of this study have highlighted the frequent types of problems initiating improvisation and showed the effect of some personal and organizational characteristics on the outcomes of improvisation. The study concluded that “failure in execution” and “seeing opportunities to improve ready and sound tasks” are the most frequent triggers of improvisation in construction. However, the degree of novelty along with the level of complexity are distinguished as criteria to assess the significance of the associated problems initiating improvisation. Moreover, the outcome of individual improvisation is measured through two outcome indices which are: the level of emerging waste and the task completion status. Emerging waste is defined as an activity or action that doesn’t create any value to the final task’s completion or the planned product (Jasti & Kodali 2015). On the other hand, task completion represents the extent to which planner has completed or solved the task under consideration via improvisation (Hamzeh et al., 2018).

Results of the study showed that personal traits such as high experience, reacting well to time pressure, taking risks, and communicating with others have a significant impact on the level of emerging waste and the task completion status when employing improvisation. Furthermore, Organizations that empower employees, keep good records, and give levels of authority to experienced employees in the field have higher chances of sound improvisations (Hamzeh et al., 2018).

While causes and some influencing factors of improvisation in construction have been examined in previous studies, the overall behavior of several improvisers working together on a single construction project hasn’t been tackled yet. Indeed, different improvisational capabilities of planners who work in different trades within a construction project, as well as the level of the unexpected uncertainty associated with that project highly influence the emergent improvisational outcome. Therefore, a focused research study about how the improvisational behaviors of different planners and the type of the construction project affect the overall improvisational outcome is required to guide construction professionals and the industry to better enhance their improvisational performance and staff planners accordingly.

2.5 Simulation and agent-based modeling (ABM)

Modeling is the act of projecting or imagining a certain occurrence, situation, or incident in individual’s mind and then formulating it explicitly (Epstein, 2008). For explaining and representing these models, different approaches are used such as mathematical modeling that leads to analytical solutions for the perceived models. Mathematical modeling is mostly pertained to models or systems of which components and relationships can be expressed through mathematical equations (Law,2014). However, most of the real-life occurrences and social systems are very complicated so they require computer simulation to be analyzed instead of the analytical approaches. According to Ingalls (2002), simulation is “the process of designing a dynamic model of an actual dynamic system for the purpose either of understanding the behavior of the system or of evaluating various strategies for the operation of a system”. Simulation is employed to mimic the operation of a real-life system by creating a simplified surrogate model representing that system. Systems are mainly simulated for measuring their performance, improving their operation, and/or testing the effect of a change or newly proposed practices (Kelton et al., 2010).

Simulation models are classified into different types in accordance to several dimensions such as time and randomness. The following are the most common classifications along with their explanations (Kelton et al., 2010):

- *Continuous vs. Discrete*: events or changes occur at specific points in time in discrete simulation models, while changes are continuous in continuous models
- *Dynamic vs. Static*: unlike static systems, time is a significant factor in dynamic simulation models.
- *Stochastic vs Deterministic*: inputs are random in stochastic modeling, while they are exact in deterministic models.

Another classification of simulation models is based on the type of analysis and the level of abstraction involved in the simulation model. As shown in Figure 3, *discrete-event* modeling is a process-based and mostly used to model manufacturing processes. It requires medium level of abstraction and a tactic level of analysis. However, system dynamics modeling involves a high abstraction level and strategic analysis with minimum details. It is usually employed to simulate the changes in a country's economy and other global phenomenon or problems. As for the agent-based modeling, it entails low abstraction level during which micro details are taken into consideration. It is employed to model the behaviors, relationships, and interactions among a set of entities in a certain system (Macal & North, 2010).

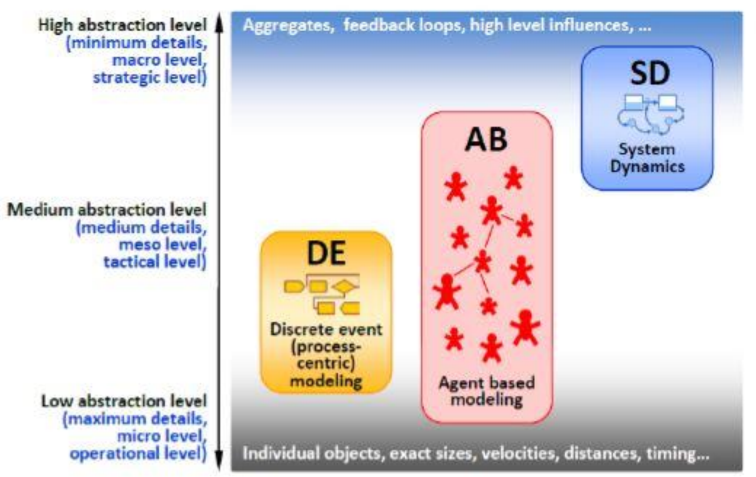

Figure 3- Simulation modeling methods (Ilya, 2014)

Agent based modeling (ABM) is a recent approach used to model complex systems for the purpose of understanding, explaining, or analyzing how they do work. "Agents" are considered the main constituents of these systems; they are autonomous and interacting among each other and with their environment. Agents can be people, time, space, asset, a controlling element, or even a collection of elements. A set of static and/or dynamic attributes usually distinguishes them. Dynamic attributes are deemed important during simulation since they change according to the agents' interactions. Agents with different dynamic attributes behave differently, however; the overall behavior of the system cannot be predicted. Hence, simulation is required to conclude the inclusive emergent behavior of the existing system (Macal & North, 2010). On the other hand, static attributes are fixed and unchangeable during simulation. They are usually used to distinguish between different agents.

Numerous researches have used agent-based modeling to mimic different systems in various fields of application. This approach of modeling has been employed to analyze organizational behaviors, transportation, economic, social, ecological, and robotic systems (Davidsson et al., 2006). Also, it has been used in different healthcare applications and medical issues. For instance, an agent-based model was developed to assess the increase in the demand for emergency care services (Taboada et al., 2012). Not only this, but also the use of ABM has been extended to solve complex issues in aerospace engineering. For instance, Schumann et al. (2012) have identified the critical parameters to optimize the design of an aircraft using ABM (Schumann et al., 2012). In addition, Yu et al. (2012) have developed agent-based model to assess the impact of different regulations, concerned with sea turtles' protection, on Hawaii's logline fisheries and on spatial-temporal distribution of the fishing efforts (Yu et al., 2012).

Moreover, agent-based modeling has been employed to analyze the spread of epidemic diseases. Considering an example, Khalil et al. (2012) have simulated the spread of influenza in Egypt through analyzing the features of the disease, its transmissions, as well as its different preventing and controlling methods (Khalil et al., 2012)

In the field of construction, agent-based modeling has grabbed the interest of several researchers since construction operations are inherently complex and non-linear (Gilbert & Troitzsch, 2005). For instance, in order to provide an accurate cost estimation of a project during early stages, Bernhardt et al. (2011) have developed a cost model that requires a set of inputs and provides a nearly precise value (Bernhardt et al., 2011). On the other hand, modelers have always emphasized on enhancing the construction safety, and thus simulated several scenarios for that purpose. For instance, Palaniappan et al. (2004) has modeled the causes of accidents on construction sites and the interactions between different project factors, aiming to enhance the safety performance on sites (Palaniappan et al., 2004). In addition, workers' absenteeism has been studied by modeling their mental processes and individual behaviors, while conceiving the workers as the main agents of the system (Ahn & Lee, 2011).

This study adopts agent-based modeling to analyze and simulate the improvisational practices within a construction project. The simulation model aims to explain how the improvisational process occurs at the level of each construction individual, and it tends to examine how different types of influencing factors related to the project and improvisers themselves shape the overall improvisational performance.

CHAPTER 3

RESEARCH MOTIVATION AND OBJECTIVES

3.1 Problem statement and motivation

Construction planning is deemed a crucial practice that aims to translate the project's goals into executable plans. It emphasizes on breaking down the project into interrelated tasks while considering the constraints of time, cost, quality, and safety. However, one of the main issues that face planners and schedulers is the inability to stay on the pre-planned track during the construction phase. In some cases, such planning failures can be attributed to improper or even insufficient planning practices. However, failing to achieve the prearranged plans is often provoked by unforeseen or uncertain conditions, which are deemed companions to any construction project. Planners have tried hard to manage uncertainties in construction; however, unexpected uncertainties continue to exist during execution. Therefore, improvised solutions are usually required under such situations for maintaining full control on construction processes and reducing the potential induced losses and delays. Unfortunately, very few researches have tried to enhance the understanding of improvisation in construction, though it is an unavoidable practice in numerous construction operations. While the outcomes of improvisation are usually understandable, the process employs creativity, intuition, collaboration, and time compression. Thus, analyzing the improvisational practices on a certain construction project and assessing the impacts of different influencing factors are essential to enhance the improvisational performance at the level of that project and successfully manage the problems of unforeseen uncertainties.

3.2 Research Objectives

Objective 1: *Understand the dynamics of improvisational practices within a group of different construction planners.*

The need to understand and improve the improvisational practices in construction is essential to properly deal with unplanned work. Improvisation as a decision-making process has different types of influencing factors that contribute in shaping the improvised decision or action. Different personal, organizational, and project-related factors highly impact the way a construction planner improvises. Also, problems that triggers improvisation are unlike each other and accordingly require different improvisational efforts. Therefore, as shown in Figure 4, the improvisational process which one may pass through has different influences and initiatives, and thus different levels of outcomes in construction. Thus, improvisational practices within a group of different planners who work together and interact with each other are necessary to be analyzed and comprehended.

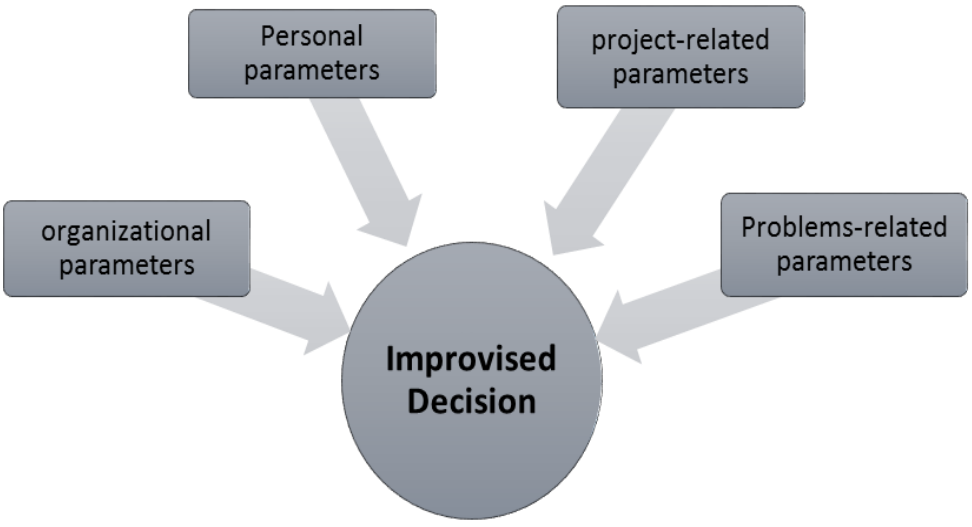

Figure 4 – Improvised decision

Objective 2: *Fathom how different variations of improvisational parameters, related to the planners' assortment and type of construction projects, influence the overall improvisational performance.*

Construction projects usually comprise numerous planners who are responsible for executing certain assignments in different trades. However, those planners usually don't belong to the same contracting company or don't have the same organizational background. So, planners who might practice improvisation have unlike organizational backgrounds as well as different personal attributes which highly affect their behaviors. On the other hand, each construction project is characterized by a certain level of unexpected uncertainty of which problems are distributed differently among trades. Therefore, this study aims to analyze how different combinations of improvisers and various types of construction projects influence the emergent improvisational performance. The latter is the accumulation of the outcomes of all individual improvisational practices; these practices can either lead to successful completion of the task in hands, or they can induce further wasteful efforts.

3.3 Research Questions

The following questions serve as a guiding roadmap throughout this research for attaining the aforementioned objectives:

Q1. What are the main dynamics and drivers of improvisational practices within a group of different planners?

Q2. How do different variations of improvisational parameters, related to the planners' assortment and type of a construction project, influence the emergent improvisational outcome in that project?

CHAPTER 4

RESEARCH METHODOLOGY AND METHODS

To answer the aforementioned research questions, a stepwise research methodology, summarized in Figure 5, is designed to comprise the following major tasks: 1) knowledge acquisition and background research, 2) Development of a conceptual framework, 3) Agent-based simulation modeling, 4) Application of the model, 5)Verification and validation, 6) Model experiments and analysis.

4.1 Knowledge Acquisition and Background Research

A meticulous review on previous studies that addressed the topic of improvisation is required to understand the phenomenon. Accordingly, a thorough review is conducted to aggregate different types and characteristics of improvisational practices occurring in different organizational settings. Thus, a deep understanding of the process, its features, its initiatives, and its influencing factors is attained. Then, a review on major contributions that aim to manage and reduce uncertainty or unplanned work in construction is performed. Few studies that tackle the possible employment of improvisation within construction planning are well considered and analyzed. Also, a previous exploratory study addressing improvisational practices in construction is examined so that necessary data analysis and statistical outcomes are assessed and considered to be used further in this research. As a result, research gaps have been identified, and the contribution of the thesis in enhancing the practices of improvisation in construction has been set accordingly.

4.2 Development of a conceptual framework

A conceptual framework is developed to explain the process of improvisation at the level of different individuals working together and interacting with one another within the same construction project. The framework incorporates the main dynamics and drivers of improvisational practices in construction. Building the components of such framework is mainly based on the statistical findings of a previous research study as well as the available literature.

4.3 Agent-based simulation modeling

A computer simulation model is built for the improvisation process. AnyLogic 7.3.1 (university edition/educational version) is used as the simulation platform to build the model and run the required scenarios in order to address the established research objectives. Agent-based modeling is used to mimic the behaviors of the improvisers. ABM model is developed while identifying the main environment, agents, influencing factors and parameters, as well as agents' behaviors and rules of interaction between agents and environment and among agents themselves. Modeling the improvisation process could be considered as continuous loop that any planner could pass through. This loop starts with a problem from a given environment initiating the interaction between improvisers and the environment; this interaction is modeled using ABM. Then, agents improvise by passing through a well-defined process where behaviors and rules of interactions are set. Finally, the improvised solution is reached, and the level of success is determined accordingly; this is also modeled using ABM.

4.4 Application of the model

After developing an agent-based simulation model, an application of the model is performed where essential behavioral rules are quantified. For this purpose, Analytical Hierarchy Process (AHP) is used. AHP is an effective tool that aids decision makers to set priorities, rank alternatives, and/or make the best decision. It is a measurement methodology based on pair-wise comparisons that depends on judgment to derive priority scales (Saaty, 1980). In this study, an AHP survey has been developed for the purpose of quantifying certain behavioral rules or decision-related rules in the model. Initially, a pilot survey among a small group of construction professionals is conducted to evaluate the efficiency of the survey questions. Then, several adjustments are introduced to improve the clarity of the questions and to avoid biased or inconsistent responses. Afterwards, construction experts are kindly asked to fill the AHP survey. A total of 20 construction experts have participated in this survey where around 60% had more than 10 years of experience in construction management. Pair wise comparison scale, proposed by Saaty (1980), is adopted to rank the importance of one element over the other in the survey.

4.5 Verification and Validation

After analyzing the results of AHP and inserting the computed factors into the model, model's verification is performed where a group of experts are consulted to check the rationality of the model. To verify the developed model and answer the question "Did we build the model right?", some procedures are carried out, such as assessing the model's aim and scope, as well as checking if the model's logic agree with the available data analysis and theories. On the other hand, input validation for the developed model has been performed via the use of data gathered from 10 construction projects, located in a metropolitan capital. A detailed explanation of the input validation is presented in Chapter 6.

4.6 Model Runs and Analysis of Results

After developing the computational model, several scenarios involving different combinations of improvisers and project-related parameters are simulated. Results are analyzed and compared to end up with conclusions about the emergent behavior of several improvisers working on the same projects.

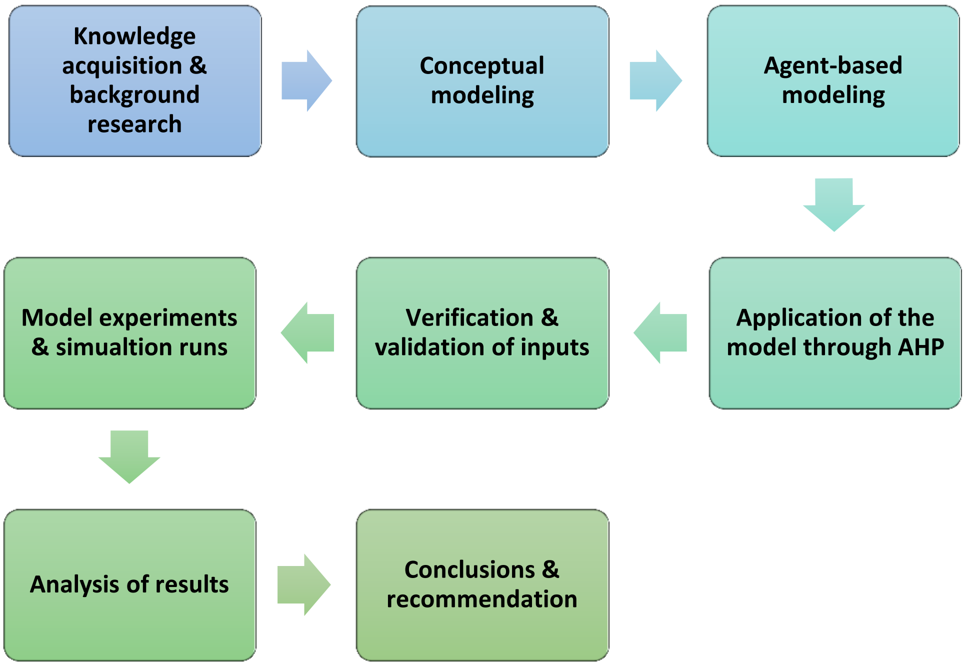

Figure 5 – Research Methodology

CHAPTER 5

AGENT-BASED MODEL

5.1 Conceptual framework

A conceptual framework is developed for elucidating the process of improvisation at the level of different individuals working together and interacting with one another within the same construction project. Also, this framework aims at depicting the impact of different improviser and project-related factors on the overall improvisational performance. The contribution of the developed model lies in providing a better understanding of the dynamics of the improvisational practices within a group of construction individuals as well as guiding construction professionals and planners to properly practice improvisation and make use of it under unexpected or unplanned circumstances.

Similar to any organizational setting, improvisation in construction is usually observed in case of emergent, unplanned, and/or unexpected situations. Individuals who are in charge of executing, supervising, or planning for construction tasks are those who may face unexpected or unplanned work and eventually may end up improvising to solve the problem in hand. In other words, improvisation in construction mainly occurs while individuals are trying to execute a certain task or endeavour. In this study, those individuals are called "planners" since they always have to plan even if they execute or supervise the work. Therefore, in this context, planners are potential improvisers. In case they decide to improvise, they will either succeed to solve the problem under consideration or not, depending on different influencing factors which are addressed in this framework.

Different types of influencing factors significantly affect the way individuals improvise in construction and accordingly shape their improvisational outcomes. Construction planners usually improvise as they have to manage unplanned or unexpected events or situations through taking a decision or performing an action swiftly. However, problems initiating improvisation are different in nature so that they require varying levels of improvisational efforts to be resolved. According to previous research studies, causes of improvisation in construction are most likely to be: 1) missing pre-requisites, 2) inadequate definition of task, 3) opportunities to improve sound tasks, and/or 4) new circumstances during execution (Hamzeh et al., 2018). However, each type of these problems is characterized by certain factors that determine the corresponding required degree of improvisation. These problem-related factors should be considered while analyzing the process of improvisation rather than exploring different types or instances. The level of complexity and the degree of novelty are significant factors to identify the required degree of improvisation and accordingly classify problems based on their improvisational requirements (Hamzeh et al., 2018). However, in the context of construction, there are other problem-related factors which can influence individual improvisational practices such as the number of trades on which a problem depends and the availability of the time duration to solve such problem. Table 1 provides definitions for the aforementioned problem-related factors, which can highly impact one's improvisational outcome in construction.

Furthermore, another type of influencing factors of improvisation in construction is related to the improvisers themselves. Improvisers have varying levels of personal criteria that highly shape their improvisational practices and accordingly influence their improvisational decisions or actions. For a given problem initiating improvisation, improvisers are expected to end up with different outcomes depending on their personal criteria or traits. Previous statistical analyses and hypotheses testing show that work experience, reacting to time pressure, taking risk, ability to communicate with others are significant influencing factors while studying improvisation in construction. Improvisers who have high work experience, react well to time pressure, properly assess risk, and highly communicate with others are those who are capable of generating successful improvised decisions or actions (Hamzeh et al., 2018). In addition, the organizational background of improvisers significantly influences the extent to which they improvise. Improvisers belonging to companies that empower its employees, encourage innovative decisions and solutions, and permit certain levels of improvisation absolutely have higher chances to properly practice improvisation. However, those who belong to traditional firms where adherence to plans and traditional control methods dominate, are less likely to generate successful improvised decisions. Table 2 summarizes the improviser-related influencing factors of improvisation in construction.

On the other hand, the construction project in which improvisation is being analyzed plays a vital role in shaping the dynamics of the improvisational processes. First, the level of unforeseen uncertainty in a certain project determines the extent to which improvisation is required in that project. It is translated as a set of problems with varying criteria that determines their improvisational significance. Therefore, each of these problems imposes varying levels of improvisational efforts. Second, the distribution of improvisers among different trades as well as the way problems initiating improvisation are dispersed among the trades highly impact the overall improvisational performance in a certain project. Table 3 presents different project-related factors that can influence the entire improvisational process in a certain construction project.

After identifying each of the problem, improviser, and project-related factors, improvisers pass through a decision-making process and generate their improvised decisions or actions accordingly. The success of the improvised decision or action is comprehended in this framework through two outcome indices: 1) Level of emergent waste: how much waste is produced due to improvisation, and 2) Task completion status: how much the improvised decision or action has completed the task in hands or solved the problem. Therefore, improvisers might end up with one of the following outcomes: 1) Task completion without waste (TC), 3) Task completion with waste (TCWW), and 3) Task incompletion (TNC). Figure 6 summarizes the conceptual framework, showing the main dynamics of the improvisation process in construction.

While analyzing improvisation at the level of individuals in construction, their improvisational experience should be tracked with time and studied. Improvisational experience simply means how much the individual is used to improvise or know about how to properly improvise. Primarily, each improviser has a certain initial experience in generating an improvised decision or action depending on his personal criteria and organizational background. However, such initial experience won't be constant for improvisers who are facing new improvisational instances with time as well as interacting with other improvisers within the same project. Therefore, the initial experience of each improviser might increase with time differently as he/she passes through considerable number of different improvisational tasks. Moreover, improvisers, working within the same team, might enhance their improvisational experience as they learn from each other and interact upon every improvisational instance.

Table 1 – Problem-related factors

Problem-related Factors	Definition
Level of complexity	Extent to which the goals associated with a given problem are undefined or unclear, and the degree to which the required methods to resolve the problem via improvisation are complex or hard.
Degree of novelty	Degree to which the problem in hands is totally new and novel
Trade interdependence	Number of trades on which a given problem depends
Time Availability	Available time to generate an improvised action or decision in order to resolve a given problem

Table 2 – Improviser-related factors

Improviser-related Factors	Definition
Work experience	Years of experience in construction works
Reaction to time pressure	Decision-making or behavior under time pressure
Risk Assessment	Extent of proper assessment of risk
Communication	Communicating and coordinating with team members
Organizational background	Type of companies to which improvisers belong

Table 3 – Project-related factors

Project-related Factors	Definition
Distribution of problems	Distribution or proportions of different problems inducing varying degrees of improvisational requirements
Distribution of improvisers	Distribution or proportions of improvisers who have varying personal criteria
Distribution of problems and improvisers among trades	How different problems initiating improvisation as well as improvisers are distributed among different trades in a given project

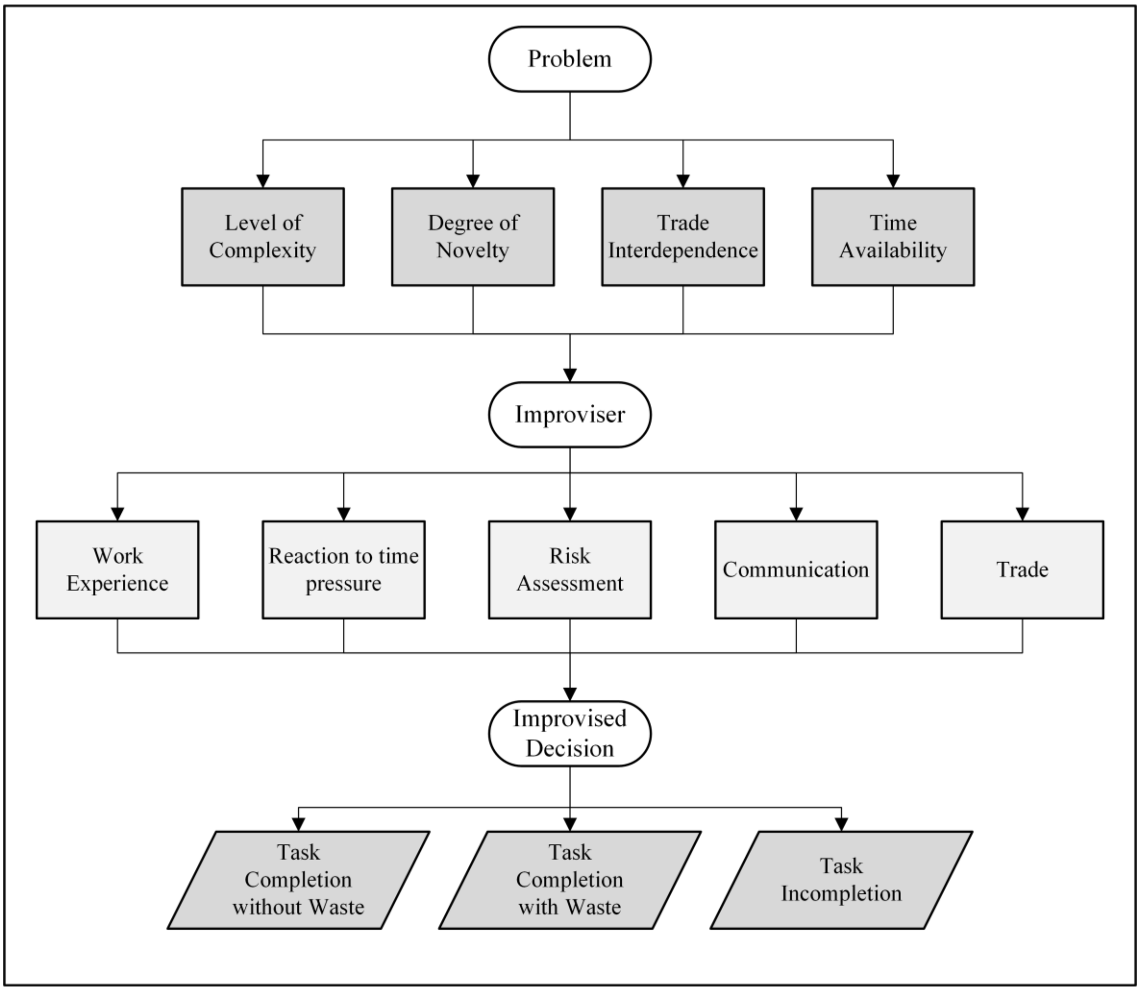

Figure 6 – Conceptual framework

5.2 Agent-based Simulation Model

After developing a conceptual framework, the dynamics of improvisation among a group of individuals in construction is modeled through agent-based simulation. Since the improvisation process and interactions are too complex, non-linear, and hard to be modeled through regular analytical mathematics, agent-based modeling (ABM) is adopted for this purpose. While agent-based modeling uses the reductionist approach to converts the real-world processes or phenomena into simplified and understandable models, it allows to identify the emergent behavior resulting from multiple individual behaviors. In this study, the overall improvisational outcome in a certain construction project is the aggregation of all individual ones within that project.

The environment considered in this study is the construction project, where groups of planners belonging to different trades work and interact together. The environment mainly consists of two types of agents: (1) the planner who is a potential improviser and (2) the problem initiating improvisation. The first type of agent is called "improviser", its size is predetermined depending on the project's size. However, the "problem" agent is created upon every problem-event that triggers an improvisational instance in the project. Interactions between improvisers (agents) and construction project (environment), between improvisers (agents) and problems (agents), and among improvisers (agents) themselves are considered in the developed agent-based model.

AnyLogic, a simulation tool that performs discrete-event simulation, system dynamics, and agent-based modeling, is used as a platform in this study to develop an agent-based simulation model for understanding and analyzing the improvisation process in construction projects. First, the "Main" environment is where all agent groups and types exist. In reference to our study, the main environment is the construction project where construction individuals perform their work. The sub-level of the main environment is the agent population or known as agent group. Construction individuals named as "improvisers" along with "problems" initiating improvisation represent two agent populations in the main environment. Each of the agent population consists of different single agents. Thus, the agent-based model consists of different levels, starting from the macro level which is the main environment and ending up with the micro level which is the single agent.

To setup the ABM model, agent groups are first created in the main environment, then interactions and connections are defined among them. In order to collect output metrics for the entire project level, improvisational outcome metrics are defined in the main environment. Second, the size of the agent groups, their mechanisms and communication channels are set. Third, the behavioral states of each of the agent groups as well as the rules and conditions for transitioning are defined. In addition, rules and conditions of interactions among agents are marked out. Note that the following sub-sections explains each of the model components.

5.2.1 Agent Group: *Improvisers*

As mentioned earlier, construction planners who improvise while performing their works represent a main agent group or population in the developed model. They are called "improvisers" and always present in the main environment which is the construction project. According to the conceptual framework, different personal influencing factors affect the improvised outcomes of improvisers, which are: experience, reaction to time pressure, risk assessment, communication, and organizational background. The aforementioned influencing factors are considered as criteria for classifying the improvisers. Classification of improvisers is made to distinguish between their different behaviors. They are classified as Good (G), Medium (M), and Not Good (NG) improvisers based on their collective score on all the aforementioned criteria. In order to quantify these criteria, a Likert scale is adopted ranging from 1 to 5. Rank 1 is the lowest score, while rank 5 is the highest. Therefore, knowing the rank of an individual on each of the criteria, which basically represent the personal capabilities related to improvisation, allows to classify this individual as a G, M, or NG improviser and accordingly analyze his/her outcome upon future improvisational tasks. Assuming that each criterion contributes equally to one's personal improvisational capability, tables 4 and 5 explain the classification of the improvisers into Good, Medium, and Not Good. Each of the criteria, except for the organizational background, is divided into 3 levels: high, medium, and low. For instance: describing an improvisers' time reaction, he/she might react very well to time pressure, thus scoring high on this criterion; above 3.5 out of 5. Alternatively, he/she might react moderately to time pressure, scoring between 1.5 and 3.5 over 5, or he/she might not react well to time pressure, thus scoring low on this criterion, less than 1.5. Note that for the organizational backgrounds, belonging to an empowering organization scores greater than 3.5, while belonging to traditional one scores less than 1.5. An average organization's score is between 1.5 and 3.5. To sum up, classifying improvisers based on their total scores on five personal criteria allows to distinguish among improvisers and differentiate between their improvised outcomes.

Table 4 – Improvisers' Criteria & Classification

Scores	Experience	Time Reaction	Risk Reaction	Communication	Organizational Background
>3.5	High (>10 years)	High	High	High	Empowering
1.5-3.5	Medium (5-10 years)	Medium	Medium	Medium	Average
<1.5	Low (< 5 years)	Low	Low	Low	Traditional

Table 5 – Improvisers' Classification

Improvisers/Agents	G	M	NG
Total Score	>17.5	7.5-17.5	<7.5

Therefore, within the population of improvisers, three sub-groups exist based on the established classification, each of which share the same improvisational capabilities and thus the same expected improvised outcome. After identifying the distribution of improvisers based on their improvisational identity, hence determining the proportions of each of Good, Medium, and Not Good improvisers, their distribution related to the trades of the project is identified. This model assumes that there are three different trades within a typical project, named as A, B, and C. Accordingly, an improviser might belong to trade A, B, or C. Alternatively, improvisers might be working within the three trades. For instance, the site engineer and the project manager are involved in all the trades of the project. In brief, an improviser might be either working in a single trade or working within all trades. Figure 7 summarizes the groups within the population of improvisers in this model.

After identifying the sub-group to which each improviser belongs, the corresponding behavioral states during improvisation are to be determined. Each improviser passes through a decision-making process to generate an improvised outcome once a problem requiring improvisational efforts is faced. The process starts by scanning the need of improvisation, during which planners may acknowledge the need of improvisation or not. Then, in case the need of improvisation is acknowledged, preparing for improvisation takes place to analyze the current situation and come up with an improvised outcome (Hamzeh et al., 2018).

The next step is defining the improvisers' behavioral states in AnyLogic. In accordance to the improvisational decision-making process (Hamzeh et al., 2018), the states and the in-between transitions are defined for improvisers. Figure 8 shows the state chart of improvisers in the simulation model. Initially, improvisers are in a “working” state, during which they are performing the work as planned. Then, a “message” transition allows them to move into a state of “identifying the problem”, during which they analyze the problem in hands. Based on their analysis, they either identify the need to improvise and thus start “preparing for an improvised decision” to solve the problem, or they fail to identify the need to improvise and thus go back again to the “working” state. After preparing for improvisation, improvisers’ decisions or actions may solve the problem either with or without producing waste, or even they may not solve the problem at all. Thus, they may end up with one of the following states: 1) “Task Completed” (TC), 2) “Task not completed” (TNC), and 3) “Task completed with waste”. Finally, once improvisers finish the improvisation process and reach one of the outcome states, they move back to their “working state” via a “message” transition. Improvisers pass through the state chart, shown in Figure 8, whenever they face a problem initiating the need of improvisation. Note that this simulation model only considers the problems that really need improvisational efforts to be resolved, but with varying degrees of significance. A detailed explanation of “problems” as an agent group is discussed in the next section.

Regarding the transitions between the states, improvisers move from the state of “Identify problem” through a “condition” transition. This transition imposes a probabilistic path that allows moving into one of the subsequent states. However, the value of the probability depends on the classification of the improviser passing through this state, whether he/she is a G, M, or NG improviser. As mentioned earlier, the model only accounts for problems that require improvisational solutions to be resolved. However, the ability of improvisers to identify the need of improvisation depends on their personal improvisational capabilities. Therefore, the model allocates the probability of moving from the state of “Identify problem” into the state of “Preparing to improvise” to be the highest for Good improvisers, and the least for Not Good improvisers. Table 6 shows the probability for each sub-group of improvisers, where $P(Improvise)_G$ is greater than $P(Improvise)_M$, and $P(Improvise)_M$ is greater than $P(Improvise)_{NG}$. Regarding the transition from the state of “Preparing to improvise” into outcome states which are TC, TCWW, and TNC, the conditioned probability doesn’t depend only on the improviser’s type but also on the type of the faced problem. This transition is explained in detail after depicting the problem-agent group.

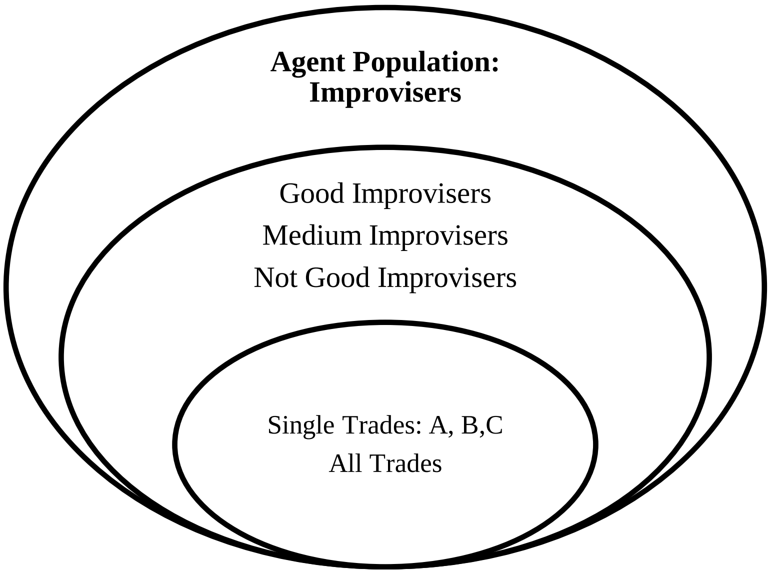

Figure 7 – Improvisers’ groups

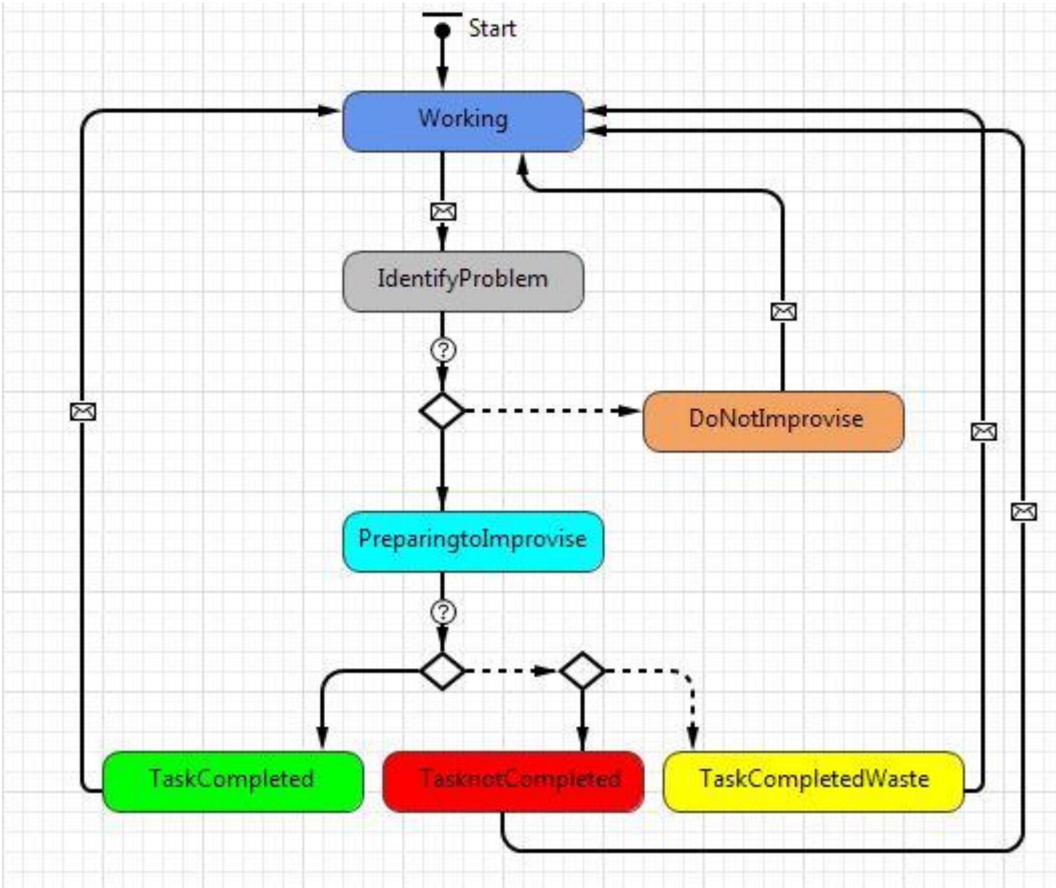

Figure 8 – Behavioral states of improvisers

Table 6 - Identifying the need of improvisation

Improvisers	Probability of identifying the need of improvisation
Good	P(Improvise)$_G$
Medium	P(Improvise)$_M$
Not Good	P(Improvise)$_{NG}$

After defining the sub-groups of improvisers along with their behavioral states, the next step is to define the effect of interactions among improvisers as well as the progress of each improviser's experience throughout the project. Improvisational experience is an essential parameter that affects the behaviors of improvisers with time.

Initially, each agent or improviser has a certain initial experience according to his type (G, M, or NG). However, this initial experience won't be constant as the agents are experiencing new improvisational tasks as well as interacting with other improvisers within the same project. Therefore, the initial experience of improvisers increases with time differently as they pass through different improvisational tasks and accordingly learn from them. Also, it increases as improvisers interact and learn from others upon different improvisational instance. The following explains how each component of improvisational experience is considered in the agent-based model.

<u>Initial Experience:</u>

Each improviser has a certain score of initial experience which is related to his past improvisational practices or knowledge. This score depends only on the type of the improviser; whether Good, Medium, or Not Good. For the purpose of modeling, this initial experience takes a range from 0 to 5; 0 reflects no improvisational experience, and 5 represents very high improvisational experience. This range is divided equally into 3 sub-ranges, each of which corresponds to one group of improvisers (G, M, NG). As shown in Table 7, Good improvisers' initial score of experience is greater than 3.5; medium improvisers' score ranges between 1.5 and 3.5; Not Good improvisers have a score ranging from 0 to 1.4. Therefore, once the type of each improviser is determined in the model, his/her initial score is randomly selected from the corresponding specific sub-range.

Table 7 – Improvisers' initial experience

Improvisers	Initial Score
Good	3.6 – 5
Medium	1.5 - 3.5
Not Good	0 - 1.4

Self-Experience:

Self-experience reflects the part of improvisational experience that's attained by the improviser himself. Thus, it depends on how much the improviser faces problems that require improvisational efforts. Also, this level of attained experience depends on past improvisational outcomes, hence whether an improviser has completed several improvisational tasks without producing waste (TC), completed tasks with waste (TCWW), or couldn't complete improvisational tasks at all (TNC). However, TC, TCWW, and TNC have different influences or weighing factors in shaping the self-experience of the improvisers. TC contributes mostly to enhancing the self-experience, while TNC has minimal contribution in increasing the self-experience. Also, the change in the score of the self-experience differs whether the improviser is Good, Not-Good, or Medium. Definitely, Not Good improvisers have the highest potential to learn more since they already lack the required improvisational knowledge; however, Good improvisers learn the least among their groups since they already have their valuable improvisational experience. Accordingly, in this model, formulas are established to reflect such change in the initial experience score due to self-learning or attainment. The change relies on the type of improvisers as well as on the number of their past improvised outcomes (TC, TCWW, & TNC). Table 8 depicts the formulas of how the experience changes according to the type and the number of past improvisational outcomes. Note that the score of the self-experience increases with time but up to a certain limit. This is due to the fact that it's impossible for the improvisational experience to increase infinitely with time. Also, as the experience of an improviser increases, the number of improvisational instances required to cause a specific change in his experience becomes higher than before. Therefore, the rate of increase in the score of the self-experience should decrease with time and eventually reach zero. However, in this model, the rate doesn't change since it's already very small, so its decrease with time is minimal. Another reason for considering a constant rate is that this model depicts the process at the level of a single construction project, thus within a short time frame during which the saturation in self-experience won't be attained for most improvisers. Note that how the values of the decimal coefficients (G1-G3; M1-M3; NG1-NG3) in the formulas along with the upper limits are set in the model is explained in Chapter 6.

Table 8 – Improvisers' self-experience

Improvisers	Formula of Self-Score	Upper Limit
Good	G1*TC + G2*TCWW + G3*TNC	G-Limit
Medium	M1*TC + M2*TCWW + M3*TNC	M-Limit
Not-Good	NG1*TC + NG2*TCWW + NG3*TNC	NG-Limit

<u>Interaction among improvisers:</u>

As mentioned previously, improvisers working together can attain experience through interacting with or learning from each other. This model covers only the interaction between improvisers who belong to the same trade, assuming interaction across trades to be minimal for improvisation. The interaction of improvisers is modeled as one-to-one learning relation. Therefore, an interaction score of a certain improviser would increase as he interacts with another random improviser in the same trade, called the "interactor". The increase in the interaction-score depends on both: 1) type of the improviser who interacts with another improviser (interactor), and 2) type of the selected interactor. As interaction occurs, the improviser's interaction score increases by a certain decimal increment depending on the type of the improviser himself and that of the interactor. The model assumes that the most beneficial interaction is when a Not Good improviser interacts with a Good one; however, it becomes the least beneficial when a Good improviser chooses a Not Good as interactor. Table 9 summarizes different types of interaction and presents their corresponding factors which are decimal numbers (X1-X3; Y1-Y3; Z1-Z3). The values of the factors in the model are set in the Chapter 6. This type of interaction occurs for each improviser in the model at a certain Poisson rate, where the score of interaction increases by one of the presented factor depending on the type of interaction.

Table 9 – Improvisers' Interaction

Interactor / Agent	Good	Medium	Not Good
Good	X1	Y1	Z1
Medium	X2	Y2	Z2
Not Good	X3	Y3	Z3

<u>Effect of change in experience on improviser's behavior:</u>

The increase in self-experience and interaction score would increase the total experience of improvisers. This increase induces enhancement in the behavior of an improviser as such: increase in the probability of ending up with TC, and accordingly decrease in the probabilities of ending up with TCWW and TNC. In this model, the probabilities change by a decimal factor, which is less than 1, called "K". This factor is calculated based on an exponential equation to account for the exponential learning effect. An exponential learning equation which has been derived analytically by several researchers such Esters (1950) is used in this model. It is one of the standard equations that describes improvements in the performance of tasks with practice (Heathcote et al., 2000; Ritter & Schooler, 2001). Accordingly, factor "K" highly depends on the total experience which is the sum of the initial score, self-score, and interaction score. As the experience increases, the factor k increases exponentially. Therefore, the rate of its increase decreases with time and reaches an upper asymptotic limit "E". This limit is set as the maximum factor by which the probabilities can change. The following is the equation of factor "K".

$$K = E^*(1-e^{-\text{Total Experience}})$$

Equation 1- Exponential equation of factor "K"

Improviser's Parameters & Variables in AnyLogic:

After explaining the classification, behavioral states, and interaction of improvisers, identifying their parameters and variables in AnyLogic is essential for the rationale of the model. Type of an improviser, trade on which an improviser work, and the initial experience are three main static parameters for the "improviser" agent. Type of an improviser can be Good (G), Medium (M), or Not Good (NG), while the trade of an improviser can be: 1) Trade A, 2) Trade B or 3) Trade C, or 4) "Common" in case the improviser work on more than two trades. As for the initial experience, once the type of the improviser is defined, it takes a random value from the corresponding pre-defined score range.

As for the variables, score of self-experience, interaction score, total experience (sum of initial experience, self-score and interaction score), number of faced problems, number of TC, number of TCWW, number of TNC, as well as the factor "k" are either integer or decimal-type variables for improvisers. Also, the "interactor" is an improviser-type (agent-type) variable. It is selected randomly by each improviser at a certain Poisson rate.

Variables related to improvisers are continuously updated in the simulation model through timeout-triggered and rate-triggered events. Timeout triggered event is used when an update for a variable is needed at some particular moment of time. Such an event occurs exactly in timeout time after it is started; it is of cyclic mode. However, a rate-triggered event models a stream of independent events based on Poisson distribution. It is used to update a variable periodically with time intervals distributed exponentially with a parameter rate (lambda). The interaction score is updated through an event called "Update Interaction Score"; it is a rate-triggered event that initiates the interaction of an improviser with another improviser at a certain rate (lambda). Once this event is triggered, an "interactor" for an improviser, working on the same trade, is randomly selected, and the interaction score is updated accordingly. On the other hand, the scores of self-experience and total experience, along with the factor "K" are updated through cyclic events called "Update self-score" and "Update variables" respectively. Data sets are created to track how the variables related to the experience of an improviser change during the time of simulation. "Self-Score", "Interaction", "Total Experience", and "Learning Value" data sets are used to regularly store the changing variables: 1) Self-Score, 2) Interaction Score, 3) Total Experience, 3) K. Figure 9 shows the AnyLogic parameters, variables, state-chart, events, and data sets related to improvisers. To sum up the improviser-related components, Table 10 presents the parameters, variables, and related events along with their types and initial values in the simulation model.

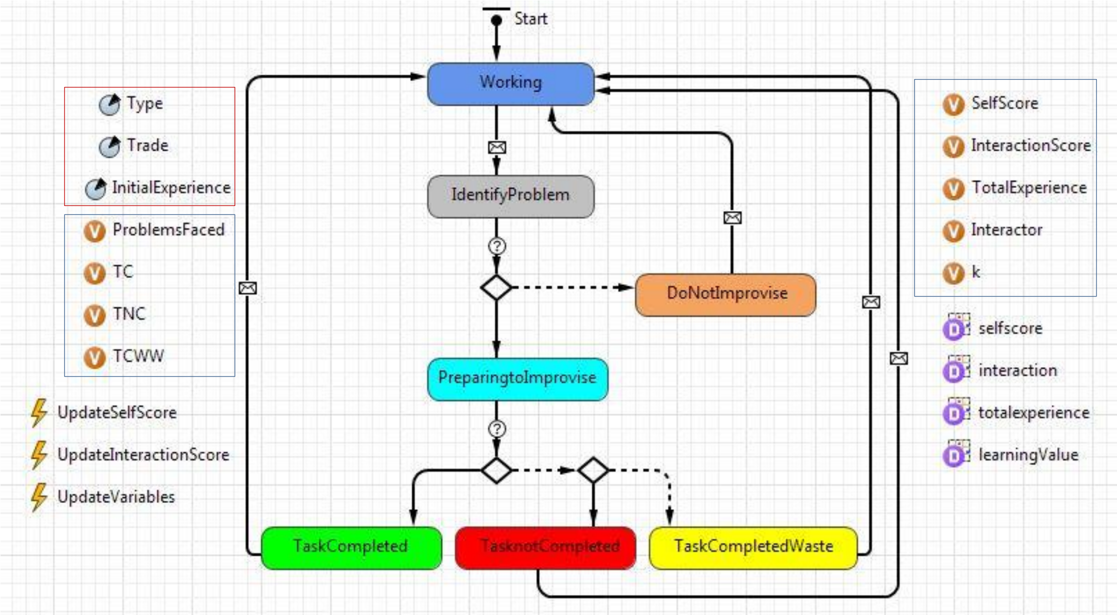

Figure 9 – AnyLogic components of improvisers as agent group

Table 10 – Summary of improvisers' parameters, variables & related events

Properties	Name	Type	Initial Value
Parameters	Improviser's Type	String	G, M, NG
	Trade	String	A, B, C, Common
	Initial Experience	Double	0-5
Variables	Self-Score	Double	0
	Interaction Score	Double	0
	Total Experience	Double	Initial Experience
	Interactor	Agent	-
	K	Double	0
	Problems Faced	Integer	0
	TC	Integer	0
	TNC	Integer	0
	TCWW	Integer	0
Events	Update Self-Score	Cyclic Event	-
	Update Interaction Score	Rate-triggered Event	-
	Update Variables	Cyclic Event	-

5.2.2 Agent Group: Problems

In this model, problems that require improvisational efforts to be resolved in a construction project are modeled as agents, and they form an agent group or population. In reference to the conceptual model, such problems have a set of criteria that determines its significance or complication. These criteria are the level of complexity, degree of novelty, trade interdependence, and time availability. Analysis of the time needed for an improviser to solve different types of problems is out of the study's scope. Hence, the model doesn't consider the "time availability" as a parameter for a problem that requires improvisation. Instead, the model assumes that all problems impose the same time pressure on improvisers to come up with a solution. The author considers the degree of novelty and level of complexity as classification criteria to differentiate between different types of problems. For the degree of novelty, problems that never happened before are classified as "New", however; in case where similar problems or instances happened during past operations, problems are considered to be "Repetitive". As for the level of complexity, problems are categorized in the model into either "Simple" or "Complex". Therefore, according to such classification, the possible types of problems, shown in Figure 10, are New and Complex (NC), New but Simple (NS), Repetitive but complex (RC), and Repetitive and Simple (RS).

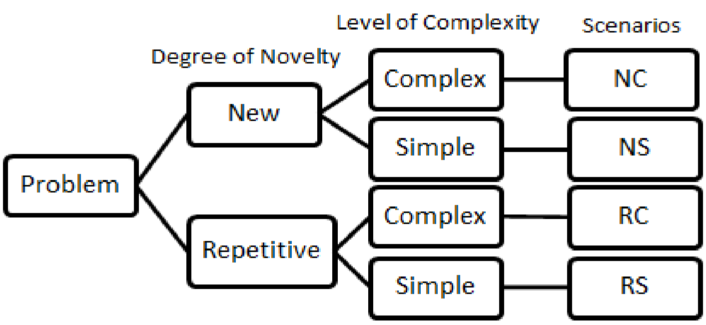

Figure 10 – Classification of problems

In addition to the type of the problems, another related parameter is the type of trade in which a problem occurs. A problem might occur in a single trade, hence in Trade A, B, or C, or it might be related to more than one trade and thus known as a "common" problem. Each project is characterized by a certain distribution of different types of problems. In the ABM model, the proportions of each type of problems (NC, NS, RC, RS) as well as the proportions of each type of problems' trades (A, B, C, Common) are defined through custom probability distributions which describe the probability of each possible type of problem.

In the ABM model, problems are created as agents upon an event called "Problem Initiator". This event occurs at a certain Poisson rate and uses the probability distributions related to the problem type and trade type to generate a certain problem. Upon generation of a problem, it directly becomes in the state of "Detected". Then, an improviser working on a trade, which is similar to that of the generated problem, is selected randomly to solve the problem. Consequently, the selected improviser passes through a decision-making cycle and generates an outcome. Once the outcome of the improviser is identified, a message is sent to the "problem" in order to move into one of the subsequent states depending on the improviser's outcome. As shown in Table 11, the states of the problems are determined based on the outcome which the selected improviser has ended up with. Figure 11 shows the state-chart and the parameter of the problem in AnyLogic.

Table 11 – Problem's state & Improviser's behavior

Problem's State	Improviser's Behavior
Resolved	An improviser has ended up with TC
Not Resolved	An improviser has ended up with TNC
Resolved with waste	An improviser has ended up with TCWW

Ignored	An improviser didn't identify the need of improvisation

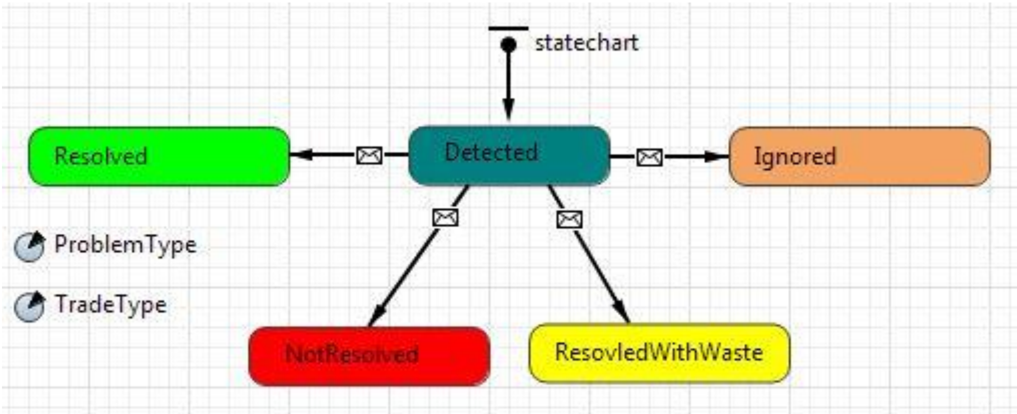

Figure 11 – Problems' state-chart & parameters

After a problem has moved into one of the possible final states, it remains in its state till the end of the simulation. It will be neither removed nor sent to another improviser in the model. Note that the problems' generation is independent and unbiased; it doesn't depend on the types of problems that have been previously generated in the model. Therefore, the problem-improviser interaction is based on one-to-one basis. One problem causes one improviser to improvise and accordingly reach a certain outcome (TC; TNC; TCWW); afterwards, it remains in its corresponding outcome state (Resolved; Resolved with Waste; Not Resolved; Ignored). As mentioned earlier, problems are generated through an event's occurrences that are based on a Poisson rate. Therefore, problems are generated and managed on the basis of "one at a time", given that the time needed to solve each problem is not modeled in this study.

5.2.3 Main Environment: Construction Project

The main environment includes the agent groups, variables, parameters, events, collections and plots necessary for the model's rationale and set up. The main environment of this model is the construction project where all improvisers work and interact together, and different types of problems are generated. As shown in Figure 13, two agent groups exist in the window of the main environment: “Improvisers” and “Problems”. The static parameters in the main environment are set to identify the improvisers’ distribution within the construction project. They define the numbers of Good, Medium, and Not Good improvisers in each trade. The values of these parameters depend on the size of the construction project under consideration, the size of each trade within the project, as well as the criteria of improvisers on that project; hence their classification into G, M, and NG improvisers.

Collections are usually used in ABM to store agents or elements sharing a common parameter or behavior. In this model, collections of improvisers are created in the main environment in order to group those who belong to the same trade. Therefore, collections named as “Trade A”, “Trade B”, and “Trade C” consist of improvisers who belong to trades A, B, and C respectively. On the other hand, several events present in the main environment: 1) “Problem Initiator” is a rate-triggered event related to problems’ generation which is discussed in the previous section, 2) “Update Problem” is a cyclic event that updates the values of variables related to the total numbers of problems which have been solved, solved with waste, not solved, and ignored, 3) “End” is a condition-triggered event that stops the simulation as the project’s duration ends.

Moreover, important variables related to the improvisers’ behavioral state-chart are defined in the main environment since they depend on both agent groups (improvisers and problems). These variables are as follows:

- PImprovise: probability of an improviser to identify the need of improvisation, hence the probability to move from “Identify Problem” state to “Preparing to Improvise” state
- PCompleted: probability of an improviser to solve a problem without producing wastes, hence probability to move from “Preparing to Improvise” state to “Task Completed” state
- PNotCompleted: probability of an improviser not to solve a problem, hence probability to move from “Preparing to Improvise” state to “Task not Completed” state
- PWaste: probability of an improviser to solve a problem while producing waste, hence probability to move from “Preparing to Improvise” state to “Task Completed Waste” state

These variables are updated whenever a problem is generated, and an improviser is selected to solve that problem. They depend on the type of generated problem, whether it is New & Complex, New but simple, Repetitive but Complex, or Repetitive and Simple. On the other hand, the type of the selected improviser highly affects these variables, whether a Good, Medium, or Not Good improviser is selected. Therefore, upon every problem’s generation, the probabilities that govern the decision of an improviser change based on the type of the improviser and that of the problem. Table 12 presents the probabilities of outcomes upon different types of problems for Good, Medium, and Not Good improvisers. The model assumes the following: “Good improvisers are the most likely to complete the task without producing waste, while not good improvisers are considered the most waste-producers while improvising”. Note that the values of these probabilities are set in this study using Analytical Hierarchy

Process (AHP) survey as an application to the developed model; it is explained in Chapter 6. Table 13 summarizes the inputs which the model takes before running the simulation and presents the output of the model. The importance of the developed model lies in computing the emergent improvisational outcomes at the level of the entire project.

Table 12 – Probabilities of possible improvisational outcomes

Problems	Task completed without waste	Task completed with waste	Task not completed
New and Complex	P $(TC_{/NC/G})$ P $(TC_{/NC/M})$ P $(TC_{/NC/NG})$	P $(TCWW_{/NC/G})$ P $(TCWW_{/NC/M})$ P $(TCWW_{/NC/NG})$	P $(TNC_{/NC/G})$ P $(TNC_{/NC/M})$ P $(TNC_{/NC/NG})$
New but simple	P $(TC_{/NS/G})$ P $(TC_{/NS/M})$ P $(TC_{/NS/NG})$	P $(TCWW_{/NS/G})$ P $(TCWW_{/NS/M})$ P $(TCWW_{/NS/NG})$	P $(TNC_{/NC/G})$ P $(TNC_{/NC/M})$ P $(TNC_{/NC/NG})$
Repetitive but complex	P $(TC_{/RC/G})$ P $(TC_{/RC/M})$ P $(TC_{/RC/NG})$	P $(TCWW_{/RC/G})$ P $(TCWW_{/RC/M})$ P $(TCWW_{/RC/NG})$	P $(TNC_{/RC/G})$ P $(TNC_{/RC/M})$ P $(TNC_{/RC/NG})$
Repetitive and simple	P $(TC_{/RS/G})$ P $(TC_{/RS/M})$ P $(TC_{/RS/NG})$	P $(TCWW_{/RS/G})$ P $(TCWW_{/RS/G})$ P $(TCWW_{/RS/G})$	P $(TNC_{/RS/G})$ P $(TNC_{/RS/M})$ P $(TNC_{/RS/NG})$

Table 13 – Model's inputs & outputs

Inputs	**Output**
Project's duration	Total percentage of TC
Rate of problem's occurrence	Total percentage of TNC
Size of improvisers' population	Total percentage of TCWW
Percentage of Good improvisers per trade	Improvisational profile of
Percentage of Medium improvisers per trade	improvisers
Percentage of Not Good improvisers per trade	
Problem-Type probability distribution	

Problem-Trade probability distribution

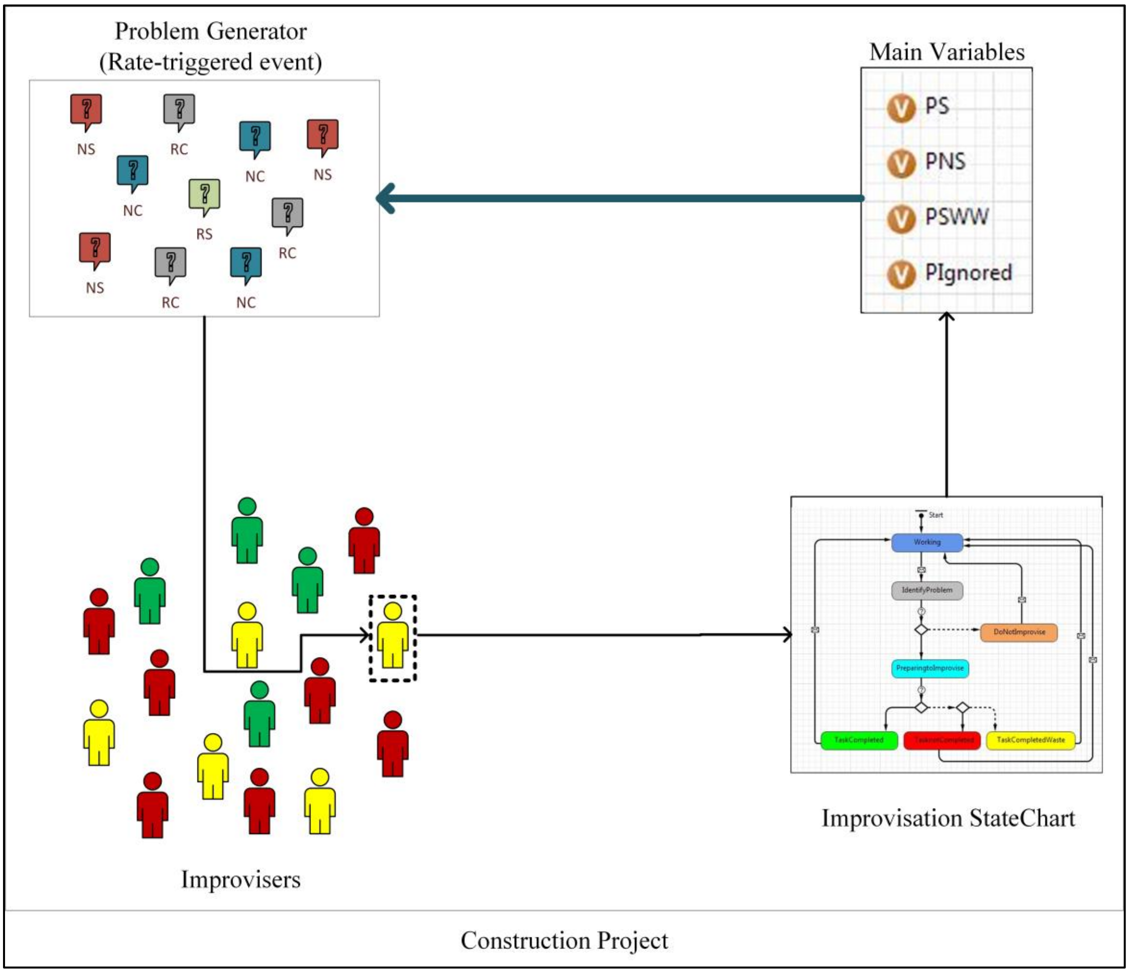

Figure 12 – Flow of the model

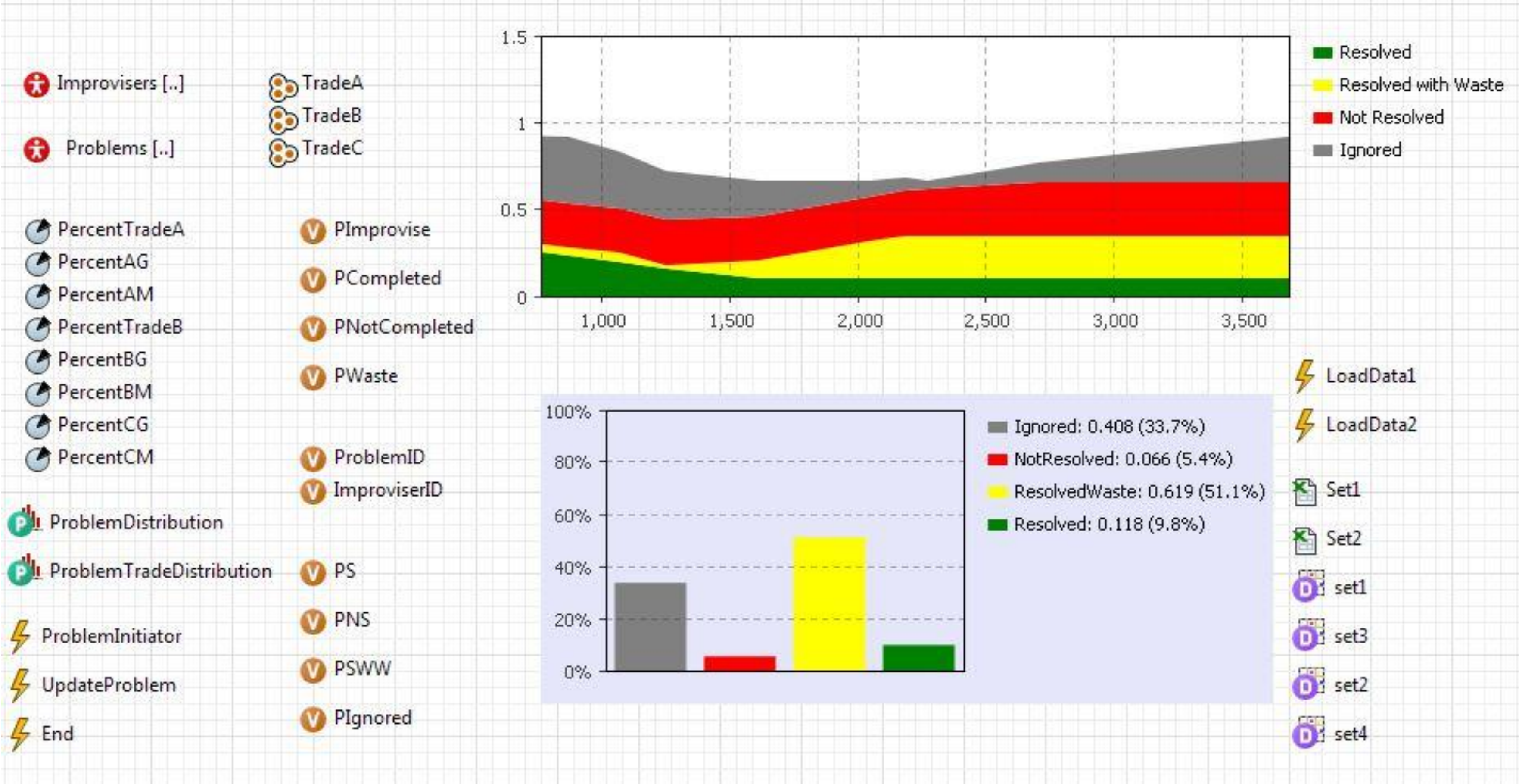

Figure 13 – Main Environment

CHAPTER 6

APPLICATION OF THE MODEL

After developing the agent-based model, different applications are performed in order to: 1) quantify certain behaviors and rules related to improvisers through conducting an Analytical Hierarchy Process, 2) validate the inputs of the developed model using data from five large-size construction projects, and 3) conduct and analyze several simulation experiments. For better clarification, Figure 14 summarizes the major milestones of this research. After conducting a thoughtful literature review, a conceptual framework is built to pave the way for the development of an agent-based model. As the model is set, Analytical Hierarchy Process survey is conducted for the purpose of quantifying certain factors so that the model is calibrated and ready for runs. Afterwards, model runs are performed for validating the inputs of the model as well as conducting simulation experiments. The following sections present a detailed explanation of what have been done regarding the AHP survey and input validation.

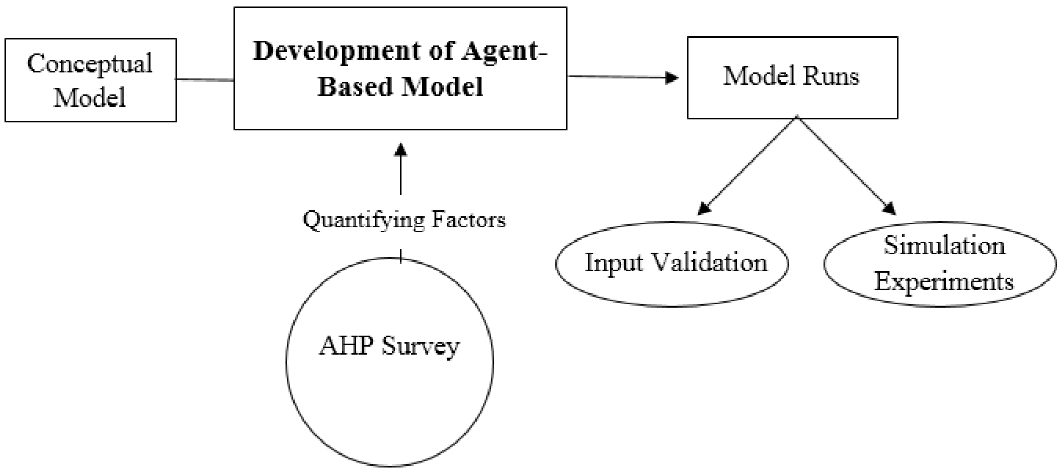

Figure 14 – Major Milestones

6.1 Analytical Hierarchy Process (AHP) Survey

6.1.1 AHP Definition

The Analytical Hierarchy Process is usually used to assign weights or scales for multiple factors contributing to the same problem, goal, or outcome. It is a method of measurement that is based on pair-wise comparisons and dependent on judgments to derive priority weights or scales. During the implementation of the AHP, hierarchies are first constructed, then judgments or measurements on pairs of elements are made with respect to a criterion in order to derive preference scales or weights (Kumar & Maiti, 2012).

The first step of the AHP is to set a goal or a predicted outcome. It is followed by the determination of the key criteria with respect to the goal and the key alternatives or elements with respect to the goal. Then, the key criteria are prioritized relative to the goal, and the consistency of their prioritization is validated. If the consistency is inadequate, the prioritization is iteratively re-performed until the consistency is well validated, else the process is abandoned. Finally, assuming consistency, the key alternatives or elements are prioritized with respect to the goal. Two major assumptions embedded within the concept of AHP are as follows (Kumar & Maiti, 2012; Adamcsek, 2008):

- Decision-making can be modeled in a linear top-to bottom form as a hierarchy
- Dependencies among elements can only be between the levels of the hierarchy

The Analytical Hierarchy Process (AHP) is a flexible and powerful tool since it can generate scores, weights or rankings based on pairwise relative evaluations of criteria. In addition, the computations made by the AHP are always guided by decision makers' experience. Thus, it can be considered as a tool that is able to translate the evaluations, which are both qualitative and quantitative, made by decision makers into a multicriteria ranking.

6.1.2 Implementation of AHP survey

In this study, the aim of using an AHP is divided into two main parts: 1) quantifying the effect of improvisational practices such as TC, TNC, and TCWW on the self-experience score of an improviser; hence determining the coefficients of the equations shown in Table 8, 2) quantifying the probabilities of possible improvisational outcomes, presented in Table 12. Accordingly, an AHP survey is constructed to serve the ascertained aim after a pilot survey has been conducted among a group of ten construction experts in order to evaluate the efficiency of the survey questions and reduce the possibility of inconsistent responses.

The survey is divided into four main sections as shown in Appendix. Prior to the main sections, it starts with a brief introduction about the research topic and defines important terms and concepts to be used throughout the survey. Then, the survey explains the scale system which is adopted from Saaty (1980) and used to answer the survey questions; it also provides an example on how to rank a priority between two criteria. Section 1 of the survey deals with the effect of improvisational practices on an improviser's experience. It consists of 3 main questions, each question is dedicated for one type of improvisational practice (TC, TNC, TCWW). In section 1, the main goal is set to be the "Effect of a certain improvisational practice on the self-experience score of an improviser", and the contributing criteria are the types of improvisers: Good, Medium, and Not Good. In question 1, respondents are asked to compare the "effect of completing an improvisational task successfully without producing any waste" (TC) on the self-experience score for Good, Medium, and Not Good improvisers. On the other hand, question 2 asks to compare the effect of "completing an improvisational task successfully while producing waste" (TCWW) on the self-experience score for Good, Medium, and Not Good improvisers. Finally, question 3 entails comparing the effect of "failing to complete an improvisational task" (TNC) on the self-experience score for Good, Medium, and Not Good improvisers.

As mentioned earlier, in this model, the outcome of improvisation is mainly dependent on the type of the selected improviser and that of the problem under consideration. Sections 2, 3, and 4 of the survey are meant to compare the effect of the improviser's type and the problem's type on the outcome probabilities, shown in Table 12, which are related to the behavior of an improviser upon facing a problem initiating improvisation. Each section is dedicated only for one type of improvisers. Each of the sections 2,3, and 4 is meant for Good, Medium, and Not Good improvisers respectively. In these sections, respondents are asked to compare the impact of different types of problems on the likelihood of three possible outcomes, which are: 1) successfully completing a task without producing any waste (TC), 2) successfully completing a task but producing waste (TCWW), and 3) not completing a task (TNC). The corresponding criteria are the different types of problems, and the goal is "the impact of the problem's type on the likelihood that an improviser of a certain type ends up with one of the possible improvisational outcomes (TC, TCWW, TNC)". Table 15 summarizes the criteria to be compared as well as the specific goal for each question in the survey.

Construction experts are kindly asked to fill the AHP survey through semi-structural interviews during which the interviewer explains the survey's concept as well as necessary terms and assumptions. Also, the consistency of each response is checked so that it can proceed for further analysis. A total of 20 construction experts have participated in this survey where around 60% had more than 10 years of experience in construction management, and 40% had more than 3 years of work experience.

To sum up, the survey is developed to gather experts' judgements which are basically pair-wise comparisons related to improvisers' behaviors in the ABM model. Pair wise comparison scale, proposed by Saaty (1980), is adopted to rank the importance of one element over the other.

Table 14 - Saaty's Scale for AHP

Scale	Definition	Explanation
1 **2**	Equal importance Slightly Equal	Equally-treated criteria
3 **4**	Moderate Importance Moderate plus	Moderately favor one criteria over the other
5 **6**	Strong Importance Strong plus	Strongly favor one criteria over the other
7 **8**	Very Strong Importance Very Strong plus	Very Strongly favor one criteria over the other
9	Absolute Importance	Absolutely favor one criteria over the other

Table 15 – Criteria & Goal for each survey question

Survey's sections	Questions	Criteria to be compared	Goal
1	1	Types of improvisers: Good Medium Not good	Effect of TC on self-experience of an improviser
1	2		Effect of TCWW on Self-experience of an improviser
1	3		Effect of TNC on Self-experience of an improviser
2	4	Types of Problems: Complex & New Complex & Repetitive Simple & New Simple & Repetitive	Effect on the likelihood of a Good improviser to end up with TC
2	5		Effect on the likelihood of a Good improviser to end up with TCWW
2	6		Effect on the likelihood of a Good improviser to end up with TNC
3	7		Effect on the likelihood of a Medium improviser to end up with TC
3	8		Effect on the likelihood of a Medium improviser to end up with TCWW
3	9		Effect on the likelihood of a Medium improviser to end up with TNC
4	10		Effect on the likelihood of a Not Good improviser to end up with TC
4	11		Effect on the likelihood of a Not Good improviser to end up with TCWW
4	12		Effect on the likelihood of a Not Good improviser to end up with TNC

6.1.3 Analysis and results of AHP survey

The data gathered from the responses are basically pair-wise comparisons for multiple criteria. The first step is to combine the individual comparison judgements from 20 participants so that a single comparison matrix is produced. This is achieved by computing a geometric average for each response. Note that the simple arithmetic average won't satisfy the reciprocal relation that may present in the AHP unless all members of the group have the same individual judgments; and in that case, there is no need to combine the judgments. Instead, geometric mean is used to combine the individual judgments which entails multiplying them and then taking the root equal to the number of participants. Afterwards, proper mathematical procedures are implemented to calculate the target weights for each criterion. There are several methods for calculating the weights that quantitively describes the importance of each criterion, relative to the goal. Numerical tools, such as MATLAB and Mathematica, have built-in functions related to the analysis of AHP. In this study, R-studio along with built-in function in excel have been used to undergo the analysis and eventually compute the weights.

After computing the corresponding weights, analysis of these weights has been made to be included in the model's rationale. Regarding section 1which deals with the improvisers' experience, the effect of each of TC, TCWW, and TNC on the experience of different types of improvisers have been quantitively described through considering the computed weights of importance. Table 16 presents the equations related to the experience of improvisers that have been previously established in Table 8. Note that the weights of importance obtained from AHP are embedded in the coefficients of the equations. As for sections 2,3, and 4 of the survey, the weights related to the likelihood of improvisers to end up with TC, TNC, and TCWW are quantified according to the resulted weights of importance for each scenario.

Table 16 – AHP results: Self-Experience

Improvisers	Formula of self-experience score
Good	0.0015*TC + 0.0025*TCWW + 0.0045*TNC
Medium	0.0025*TC + 0.0035*TCWW + 0.003*TNC
Not-Good	0.006*TC + 0.004*TCWW + 0.0025*TNC

The analysis related to section 1 in the AHP survey have led to numerous inferences. As shown in Table 16, Good improvisers learn the most from the tasks which they've failed to complete it through improvisation and the least from the tasks that they've successfully completed it through improvisation; the coefficient corresponding to TNC is the highest and that for TC is the lowest for Good improvisers. This can be explained that Good improvisers are well-knowledgeable and experts in improvisation, so their experience won't be considerably enhanced unless they really fail to properly improvise and therefore learn from their mistakes. On the other hand, Not Good improvisers ultimately benefit or learn the most from the tasks that they have completed successfully through improvisation. As for medium improvisers, they will gain more or less the same experience from the three possible outcomes (TC, TCWW, TNC).

Table 17 – AHP results: Good improvisers' behavior

Problems	Task completed without waste	Task completed with waste	Task not completed
New and Complex	0.75	0.1	0.15
New but simple	0.85	0.1	0.05
Repetitive but complex	0.8	0.1	0.1
Repetitive and simple	0.95	0.05	0

Table 18 - AHP results: Medium improvisers' behavior

Problems	Task completed without waste	Task completed with waste	Task not completed
New and Complex	0.35	0.35	0.3
New but simple	0.5	0.25	0.25
Repetitive but complex	0.5	0.25	0.25
Repetitive and simple	0.8	0.1	0.1

Table 19 - AHP results: Not Good improvisers' behavior

Problems	Task completed without waste	Task completed with waste	Task not completed
New and Complex	0.1	0.15	0.75
New but simple	0.1	0.1	0.8
Repetitive but complex	0.05	0.1	0.85
Repetitive and simple	0.5	0.25	0.25

6.2 Validation of inputs

For investigating the practices of improvisation on real-life projects as well as validating the inputs of the developed model, data related to improvisation on five large-size construction projects are used in this study. Data is acquired from a previous research study where an extensive survey has been carried out among construction employees on different construction projects to explore the dynamics of improvisation in construction (Faek, 2015). In our study, large-size projects are selected to validate the inputs of the developed model. A project is considered to be large in size whenever it incorporates more than hundred working employees and comprises standard planning practices and procedures. Note that there is no correlation between improvisation and large-size projects, but this selection is made to guarantee that a considerable number of improvisational instances exits within each project.

The collected data is mainly about the personal criteria and organizational backgrounds of the main improvisers on each project. Respondents have scored the given personal criteria and organizational characteristics using a Likert scale ranging from 1 to 5 based on the degree of agreement with each statement: 1 being strongly disagree and 5 being strongly agree. Accordingly, improvisers are classified into Good (G), Medium (M) and Not Good (NG) based on the scores of their improvisation-related criteria. Therefore, the distribution of improvisers' types in each project is used as input for one model-run. In addition, the analysis of data related to the distribution of the types of problems have revealed that the previously mentioned types of problems are more or less equally distributed for all projects except for the healthcare project (Project 5), where the likelihood of occurrence of New and Complex problems is around 0.5. Therefore, the problem-type distribution has been inputted accordingly for each project. Regarding the inputs related to the problem-trade and improviser-trade distributions in each project, the available data haven't considered the effect of the trades in the analysis of improvisation. Therefore, the author didn't differentiate between trades while running the model for each project scenario. Table 21 presents the main inputs of the model in each project as well as their corresponding outputs. The output represents the overall percent of TC and TCWW in each project after passing 1 year of work, with a passion-based rate of 1 problem per day.

6.3 Simulation Experiments

For further analysis, three main simulation experiments are designed and implemented on the ABM model. These experiments aim at studying the effect of changing the distribution of improvisers' types on the overall improvisational outcomes. Accordingly, experiments 1, 2, and 3 focus on changing the percentage of Good, Medium, and Not Good improvisers respectively while keeping other influencing factors intact. This is achieved by changing the percentage of one type of improvisers from 0 to 100 percent by an increment of 10 percent, while keeping the remaining two types equally distributed. For instance, in experiment 1, the percentage of Good improvisers is varied from 0 to 100 while Medium and Not Good improvisers are kept equally distributed accordingly. Note that the distribution of improvisers is the only variable in these experiments where all other input parameters are kept similar and constant throughout the simulation. Types of problems, trades of problems, as well as trades of improvisers are assumed to be equally distributed for all simulation runs. Table 20 summarizes the inputs of the three experiments. Not that each distribution of improvisers is considered a single simulation. A single simulation is repeated 50 times with a new random number seed to account for stochastic nature of the improvisation process in a construction project.

The aim of the three experiments is to investigate the impact of improviser's distribution on improvisational outcomes and examine the potential of developing a significant regression models that predict the expected portions of different improvisational outcomes at the level of the entire construction project. As mentioned earlier, the improvisational outcome is manifested by one of the following: 1) Task completed (TC), 2) Task completed with waste (TCWW), 3) Task not completed (TNC), and 4) Task ignored (I). In these experiments, the percentages of (TC) and (TCWW) are the response variables at interest since construction professionals always prefer to end up with such outcomes rather than failure. Indeed, once the anticipated portions of (TC) and (TCWW) are computed, other portions related to either not completing or ignoring an improvisational task can be inferred.

Table 20 – Inputs of simulation experiments

Inputs	**Experiment 1**	**Experiment 2**	**Experiment 3**
Project's duration	1 year	1 year	1 year
Rate of problem's occurrence	1 per day	1 per day	1 per day
Size of improvisers	15	15	15
%G per trade	Variable	Constant	Constant
%M per trade	Constant	Variable	Constant
%NG per trade	Constant	Constant	Variable
Problem-Type Distribution	Equally Distributed	Equally Distributed	Equally Distributed
Problem-Trade Distribution	Equally Distributed	Equally Distributed	Equally Distributed

Table 21 – Projects' input & Output

Projects	Types	Percent of White-Collar improvisers	Percent of Blue-Collar improvisers	Classification of improvisers	Percent of overall TC & TCWW
1	Residential	60%	40%	70% G 15% M 15% NG	75.3 %TC 7.5% TCWW
2	Residential	80%	20%	50% G 35% M 15% NG	71.56 % TC 11% TCWW
3	Residential	40%	60%	30% G 35% M 35% NG	51.2% TC 11.1% TCWW
4	Residential	90%	10%	83.34% G 8.33% M 8.33% NG	85.7% TC 6% TCWW
5	Healthcare	80%	20%	50% G 35% M 15% NG	40.7 % TC 20.6% TCWW

CHAPTER 7

ANALYSIS AND DISCUSSION OF RESULTS

7.1 Discussion of input validation

As mentioned earlier, the inputs of the model are validated through considering the scenarios of five large-size projects. In each project, improvisers who are responsible for executing the work are classified based on their job titles and improvisational capabilities. Regarding their job titles, each improviser is classified whether he belongs to the blue or white-collar group. Whereas, the second classification is mainly based on the personal criteria related to improvisation; improvisers are classified as Good, Medium, or Not Good.

After running a simulation for each project, several outcomes are reported such as the overall percentage of TC and that of TCWW. As shown in Table 21, in projects 1 and 2, improvisers who belong to the white-collar group is more than those from the blue-collar group. The percentage of Good improvisers in Project 1 is higher than that in Project 2; however, the results related to TC and TCWW isn’t much affected since the change in the types of improvisers occurs only between Good and Medium improvisers, where the portion of Not Good improvisers is the same for the two projects. For project 3, the blue-collar improvisers dominate as the percentage of white-collar improvisers drops to be 40%. The resulted number of TC has considerably decreased since the percentage of Not Good improvisers have increased by an increment of 20, in comparison with Project 2. However, the percentage of overall TCWW in Project 3 remains nearly the same as that in Project 2; this means that the increase in the number of Not Good improvisers has much higher effect on the outcomes of TC rather than TCWW in the developed model.

Regarding project 4, most of the improvisers are white-collar employees as well as Good improvisers. Consequently, around 85% of the improvisational tasks have been completed successfully without producing wastes, and around 6% of the tasks have been completed with waste. Unlike the other projects, project 5 is a healthcare-type project, where the likelihood of occurrence of New & Complex problems initiating improvisation has been reported to be nearly 0.5. Although 80% of improvisers are white-collar employees, and around 50% of improvisers are classified as Good, only 40.7% of improvisational tasks have been successfully accomplished. This is due to the fact of the abundancy of New and Complex problems that my initiate improvisation in projects where special and complicated systems are to be executed. Finally, it is worth mentioning that in cases where white collar employees dominate, the percentage of Good improvisers happens to be higher than that of Not Good and Medium improvisers. Note that this is an observation that have been only based on five projects, hence it cannot be generalized.

7.2 Analysis of simulation experiments' results

After running different scenarios while varying the percentage of each type of improvisers at a time, the percentages of TC, and TCWW are recorded over one year. Then, the end percentages are considered for analysis. Before analyzing any potential regression model, Pearson Correlation factors between the percentage of TC and the percentage of each of Good, Medium, and Not Good improvisers are calculated. Also, similar calculation is performed for the percentage of TCWW. It has been shown that

TC is positively correlated with percent of Good improvisers and negatively correlated with the percent of Not good improvisers. However, poor negative correlation is detected between TC and percent of Medium improvisers. As for the TCWW, percent of Good and Medium improvisers have high negative and positive correlation respectively. Whereas, the percent of Not good and the percent of TCWW have revealed low correlation in-between. Table 22 summarizes the corresponding correlation factors. In order to visualize the calculated correlation factors and identify the potential type of regression between the response variables and predictors, the percent of TC and TCWW are plotted against each of % Good, % Medium, and % Not Good improvisers as shown in Figure 15 and Figure 16.

Table 22 - Pearson Correlation factors

Type of Improvisers	% TC	% TCWW
% Good	0.88	-0.78
% Medium	-0.084	0.84
% Not Good	-0.8	-0.06

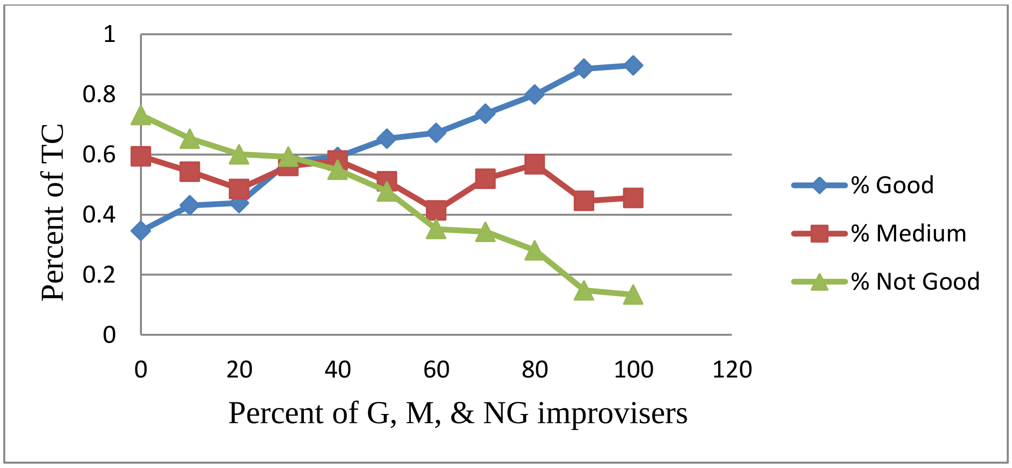

Figure 15 - % TC vs % Good, Medium, & Not Good improvisers

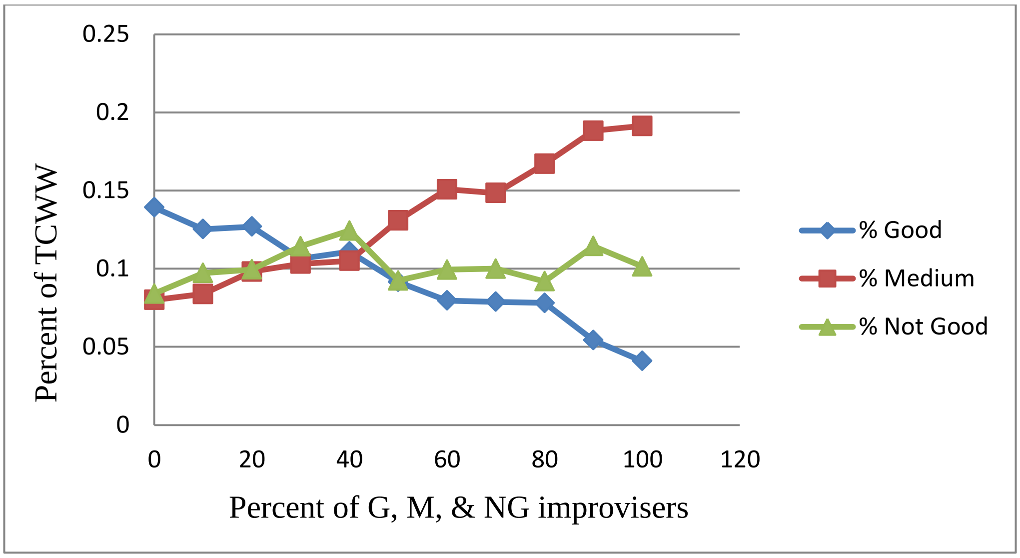

Figure 16- % TC vs % Good, Medium, & Not Good improvisers

After analyzing the plotted graphs, it is inferred that the relation between % Good & %TC, and % Not Good & % TC, as well as the relation between % Good & %TCWW, and %Medium & %TCWW might be modeled through linear regression. The corresponding plots has shown a linear relationship between each of the response variables and the predictors. Therefore, the significance of potential linear regression models and the corresponding hypotheses are tested and analyzed. The following are the tested hypotheses:

Hypothesis 1: Percent of Good and Not Good improvisers on a construction project are significant predictors of the percent of task completed (TC) via improvisation.

Hypothesis 2: Percent of Good and Medium improvisers on a construction project are significant predictors of the percent of Task completed with waste (TCWW) via improvisation.

Note that the null hypothesis is that all of the regression coefficients are equal to zero. After running the regression test, the results show that the F value is significant for both hypotheses 1 and 2 where the corresponding p-values are much less than alpha

(0.05). In addition, the t-tests for the linear regression coefficients are significant with 95% confidence interval. Note that the interaction between predictors has been tested in both hypotheses, but it was not significant. Moreover, after establishing the linear regression models, the residuals and standardized residuals are plotted in order to check the underlying assumptions of linear regression. The plots have shown that residuals are nearly normal, linear, and somehow have constant variance. Also, no high leverage points are observed. To check for any potential multicollinearity problem, the variance inflation factor (VIF) which is the ratio of variance in a model with multiple terms, divided by the variance of a model with one term alone, is computed for each case. VIF quantifies the severity of multicollinearity in ordinary least squares regression analysis; it provides an index that measures how much the variance of an estimated regression coefficients is increased because of collinearity. For both linear regression models, the (VIF) values are less than 2 which ensures that multicollinearity is negligible. The following are the equations of the linear regression models:

$$\%TC = 0.004447*(\%G) - 0.003286*(\%NG) + 0.4932778$$

Equation 2 – Equation predicting the % of TC

$$\%TCWW = -5.851E-4*(\%G) + 7.339E-4*(\%M) + 0.103$$

Equation 3 - Equation predicting the % of TCWW

Considering equation 2, the percent of TC is nearly 50% when all improvisers are of “Medium” type, that’s the percentages of Good and Not Good improvisers are zero. As the percent of Good improvisers increases by an increment of 10 while holding that of Not Good improvisers constant, the percentage of TC is going to increase by around 4.5. On the other hand, for every 10% increment in the population of Not good improvisers, while keeping the proportion of Good improvisers constant, the percent of TC will decrease by an increment of around 3. Therefore, the impact of being Good improvisers is slightly higher than that of being Not Good improvisers.

As for equation 3, the percent of TCWW is nearly 10% when all improvisers are of “Not Good” type, that’s the percentages of Good and Medium improvisers are zero. As the percent of Good improvisers increases by an increment of 10 while keeping that of Medium improvisers constant, the percentage of TC is going to decrease by around 0.6 (0.585). However, for every 10% increase in the population of Medium improvisers, while keeping the proportion of Good improvisers constant, the number of TC will increase by around 0.7 %. As a result, it can be inferred that the effect of improviser’s type is much more intense on the percent of TC than that of TCWW. Thus, considerable changes in the number of good and medium improvisers should be made in order to increase the emergent number of TCWW. However, few increase in the population of Good and Not Good improvisers are capable to considerably change the portion of the emerging TC.

These linear regression models can be later used to anticipate the proportions of the problems requiring improvisational efforts and ending up either successfully solved or solved while producing a certain level of waste. Note that these equations predict the percent of TC and TCWW given that the distribution of improvisers’ type after one year of construction. However, in order to use these two models, an important assumption should be made, and it is that the different types of problems which are classified based on the level of complexity and degree of novelty are equally probable during construction, and equally distributed between different trades. Hence, no specific type of problems has a distinctive weighing factor over the other. This assumption is made to cater for the standard or normal scenario where every problem has same likelihood to occur. If a specific type of problems initiating improvisation has higher likelihood than others, one can change the distribution of type and trade of problems and then re-run the same scenarios and analysis so that the linear regression models will be adjusted accordingly.

CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS

Planning and control methods in construction are substantially essential for enhancing the performance of construction projects and reduce the possible problems related to variability and uncertainty. Unfortunately, problems related to unexpected uncertainty and shortcomings of planning methods are bound to happen in any construction project. In other words, one of the main issues that face construction personnel is sometimes the inability to stay on the pre-planned track during construction due to unexpected uncertainty, unforeseen conditions, or even insufficient or improper planning. As a result, more time and effort are invested to come up with solutions that would overcome such problems. In such cases, improvised solutions are expected to be developed in order to minimize losses and wastes and to maintain full control on the construction process. The aim of this research study is to advance the knowledge of improvisation in construction and better understand its dynamics. This study employs agent-based modeling to develop a simulation model that depicts the improvisational practices within a construction project. The contribution of this study lies in guiding construction planners and decision-makers to better manage the problems of unexpected uncertainties through enhancing the overall improvisational performance in a construction project.

After identifying the specific research questions, a stepwise research methodology is designed to attain the ascertained objectives of the study. First, the author has conducted a thorough review on improvisation in different fields of application including construction. Then, after attaining a deep understanding of the process based on previous research studies, a conceptual framework is developed; it mainly explains the dynamics of improvisation within a group of construction individuals working and interacting together in a certain construction project. The framework illustrates three types of factors that can influence the individual improvisational outcomes; they are classified as: project-related, improviser-related, and problem-related factors. Also, the outcomes of an individual improvisation are framed as three main possibilities, which are: 1) completing the task via improvisation without producing waste, 2) completing the task via improvisation while producing waste, and 3) failing to complete the task via improvisation. In addition, the developed framework highlights how improvisers in construction can interact together and thus benefit from each other. Improvisers can enhance their experience in generating improvised decisions through interaction with other members in the team or through self-learning upon a work-related improvisational incident.

Accordingly, an agent-based simulation model is developed to study the improvisation process at the level of a group of individuals working on different trades and interacting together within the same project. The simulation model takes into consideration several types of parameters that highly influence the emergent improvisational outcomes of the group. Interactions between improvisers (agents) and construction project (environment), between improvisers (agents) and problems (agents), and among improvisers (agents) themselves are consider in the ABM model. The importance of the developed model lies in depicting the dynamics and drivers of improvisational practices within a group of improvisers, as well as illustrating how different variations of improvisational parameters, related to the planners' assortment and type of construction projects, influence the overall improvisational performance.

After setting out the ABM model, an AHP survey is conducted among construction experts to quantify certain behaviors and rules related to improvisers in the model. Also, the inputs of the developed model are validated while considering data from five large-size projects. Moreover, simulation experiments are conducted, and linear regression modeling is performed for the purpose of anticipating the overall improvisational outcomes in a certain project from a given distribution or combination of improvisers. Linear equations are developed to predict the portions of successful improvisational instances from a given distribution or combination of improvisers, while imposing several assumptions on the given construction project.

This study imposes several practical implications and recommendations that aim to enhance the management of unforeseen uncertainty in a construction project through advancing the practice of improvisation. Planners and decision-makers are advised to consider the improvisational capabilities as well as the expected level of uncertainty for a certain project while predicting its performance. The following are several recommended practices which decision-makers can adopt to better enhance the overall improvisational performance in a project:

- Improvisational capabilities of construction planners in a certain firm shall be recorded and continuously updated, as well as classification of improvisers based on their capabilities (e.g. Good, Medium, Not Good) shall kept in records for future work assignments.
- For construction projects associated with higher potential levels of unforeseen uncertainties, more Good improvisers are expected to be staffed for better improvisational performance.

- Project managers and decision-makers shall avoid random assignment of improvisational capabilities within a team of planners without considering their trades' requirements in a construction project, since it may not necessarily improve the emergent improvisational performance at the level of that project.
- Staffing for a project shall ensure a fair distribution of improvisational capabilities within each team so that the benefits of interaction and one-to-one learning upon improvisational instances are reaped up.

Finally, several limitations of this research study are worth mentioning so that future research work can be recommended. Regarding the developed agent-based model, the major limitation is the use of deterministic probabilities to describe certain behaviors of improvisers (agents). Instead, probability distributions should be used to account for all possible random behaviors. In this study, identifying such probability distribution which requires a separate research study is out of the scope. Moreover, the developed model doesn't take into account the time spent by each improviser (agent) to improvise; time analysis is not included in this study. As for the validation part, the inputs of the model are only validated due to the limitations of the available data. Further data collection and more AHP responses are required to enhance the validity of the developed model.

For future research, this research can be extended to be applied on more case studies to experiment the validity of the output of such model and analyze improvisation in different types of construction projects so that more recommendations for the industry can be achieved. The developed model could be enhanced if probability distributions related to the behaviors of improvisers are identified and plugged into rather than the deterministic approach. Furthermore, future research is recommended to identify other influencing factors related to the improvisational performance of a group of construction planners as well as incorporate the time factor in the developed agent-based model. A future research work would be interesting if it focuses on analyzing the relation between the improvisational outcomes in a construction project and certain corresponding key performance indicators related to time or cost.

APPENDIX

General Survey Introduction

This study tackles the subject of improvisation in the context of construction industry. Improvisational practices are usually employed when: 1) speed is required to meet a deadline, 2) planned procedures fail to meet the requirements, 3) pre-planned strategies fail to manage a sudden problem, and/or 4) standardized procedures fail to catch up with daily ameliorations…etc.

In this research study, improvisers are classified into three groups: good (G), medium (M), and not good (NG). The classification is based on collective score of parameters that have proven to significantly shape the improvisational behaviors and outcomes. Note that this classification is used throughout the survey to distinguish between improvisers having different levels of improvisational capabilities. The following are the parameters on which the classification of improvisers is based.

- Work Experience
- Time Reaction
- Risk Reaction
- Communication Capabilities
- Organizational Background

Note that the term "waste" in this survey represents the wasteful work emerged while improvising. Improviser my produce different types of waste such as increase in cost, resource usage, duration, and/or complexity of task control. Alternatively, wasteful work could be a decrease in quality, productivity, and/or safety performance…etc.

Note that in sections 2,3,4, problems that initiate the process of improvisation are classified according to two major criteria. They are:

- **Degree of novelty**: is related to what extent the problem under consideration is new and novel.
- **Level of complexity**: is related to the degree to which the goals of the problem are vague and poorly-defined. Also, it explains how complex or hard the required methods and means of improvisation are.

Survey Questions

Please adopt the following scale system to answer the questions of the survey. Using the below table, scale the importance between the stated criteria by writing a number representing the importance of 1st criterion over the 2nd. If you feel that the second criterion is more important than the first one, then use the reciprocal of the number.

Scale	Definition	Explanation
1	Equal importance	Equally-treated criteria
2	Slightly Equal	
3	Moderate Importance	Moderately favor one criteria over the other
4	Moderate plus	
5	Strong Importance	Strongly favor one criteria over the other
6	Strong plus	
7	Very Strong Importance	Very Strongly favor one criteria over the other
8	Very Strong plus	
9	Absolute Importance	Absolutely favor one criteria over the other

Source: Saaty (1980)

Throughout the survey, kindly insert a number ranging from 1 to 9 according to the above-mentioned scale to compare between the two stated criteria.

***Illustrative Example**:*

Scale the importance of health versus money.

If health is moderately more important than money; Health vs. Money = 3

If money is moderately more important than health; Health vs. Money = 1/3

Section 1 - Improvisational Experience

Q1. When an improviser has **successfully completed a task without producing any waste** through improvising, compare the consequent increase in the improvisational experience for different types of improvisers.

1. Good (GI) **vs.** Medium (MI) ☐
2. Good (GI) **vs.** Not-Good (NGI) ☐
3. Medium (MI) **vs.** Not-Good (NGI) ☐

Q2. When an improviser has **successfully completed a task but produced waste** through improvising, compare the consequent increase in the improvisational experience for different types of improvisers.

1. Good (GI) **vs.** Medium (MI) ☐
2. Good (GI) **vs.** Not-Good (NGI) ☐
3. Medium (MI) **vs.** Not-Good (NGI) ☐

Q3. When an improviser **couldn't complete a task through improvising**, compare the consequent increase in the improvisational experience for different types of improvisers.

1. Good (GI) **vs.** Medium (MI) ☐
2. Good (GI) **vs.** Not-Good (NGI) ☐
3. Medium (MI) **vs.** Not-Good (NGI) ☐

Section 2 – Improvisational Outcomes for Good Improvisers

Q4. Compare the impact of different types of problems which require improvisational effort on the likelihood of **successfully completing a task without producing any waste** through improvising, given that the improviser is **Good**

1. Complex & New **vs.** Complex & Repetitive ☐
2. Complex & New **vs.** Simple & New ☐
3. Complex & New **vs.** Simple & Repetitive ☐
4. Complex & Repetitive **vs.** Simple & New ☐
5. Complex & Repetitive **vs.** Simple & Repetitive ☐
6. Simple & New **vs.** Simple & Repetitive ☐

Q5. Compare the impact of different types of problems which require improvisational effort on the likelihood of **successfully completing a task but producing waste** through improvising, given that the improviser is **Good**

1. Complex & New **vs.** Complex & Repetitive ☐
2. Complex & New **vs.** Simple & New ☐
3. Complex & New **vs.** Simple & Repetitive ☐
4. Complex & Repetitive **vs**. Simple & New ☐
5. Complex & Repetitive **vs.** Simple & Repetitive ☐
6. Simple & New **vs.** Simple & Repetitive ☐

Q6. Compare the impact of different types of problems which require improvisational effort on the likelihood of **not completing a task** through improvising, given that the improviser is **Good**

1. Complex & New **vs.** Complex & Repetitive ☐
2. Complex & New **vs.** Simple & New ☐
3. Complex & New **vs.** Simple & Repetitive ☐
4. Complex & Repetitive **vs.** Simple & New ☐
5. Complex & Repetitive **vs.** Simple & Repetitive ☐
6. Simple & New **vs.** Simple & Repetitive ☐

Section 3 – Improvisational Outcomes of Medium Improvisers

Q7. Compare the impact of different types of problems which require improvisational effort on the likelihood of **successfully completing a task without producing any waste** through improvising, given that the improviser is **Medium.**

1. Complex & New **vs.** Complex & Repetitive
2. Complex & New **vs.** Simple & New
3. Complex & New **vs.** Simple & Repetitive
4. Complex & Repetitive **vs.** Simple & New
5. Complex & Repetitive **vs.** Simple & Repetitive
6. Simple & New **vs.** Simple & Repetitive

Q8. Compare the impact of different types of problems which require improvisational effort on the likelihood of **successfully completing a task but producing waste** through improvising, given that the improviser is **Medium.**

1. Complex & New **vs.** Complex & Repetitive
2. Complex & New **vs.** Simple & New
3. Complex & New **vs.** Simple & Repetitive
4. Complex & Repetitive **vs.** Simple & New
5. Complex & Repetitive **vs.** Simple & Repetitive
6. Simple & New **vs.** Simple & Repetitive

Q9. Compare the impact of different types of problems which require improvisational effort on the likelihood of **not completing a task** through improvising, given that the improviser is **Medium.**

1. Complex & New **vs.** Complex & Repetitive
2. Complex & New **vs.** Simple & New
3. Complex & New **vs.** Simple & Repetitive
4. Complex & Repetitive **vs.** Simple & New
5. Complex & Repetitive **vs.** Simple & Repetitive
6. Simple & New **vs.** Simple & Repetitive

Section 4 – Improvisational Outcomes of Not Good Improvisers

Q10. Compare the impact of different types of problems which require improvisational effort on the likelihood of **successfully completing a task without producing any waste** through improvising, given that the improviser is **Not Good.**

1. Complex & New **vs.** Complex & Repetitive ☐
2. Complex & New **vs.** Simple & New ☐
3. Complex & New **vs.** Simple & Repetitive ☐
4. Complex & Repetitive **vs.** Simple & New ☐
5. Complex & Repetitive **vs.** Simple & Repetitive ☐
6. Simple & New **vs.** Simple & Repetitive ☐

Q11. Compare the impact of different types of problems which require improvisational effort on the likelihood of **successfully completing a task but producing waste** through improvising, given that the improviser is **Not Good.**

1. Complex & New **vs.** Complex & Repetitive ☐
2. Complex & New **vs.** Simple & New ☐
3. Complex & New **vs.** Simple & Repetitive ☐
4. Complex & Repetitive **vs.** Simple & New ☐
5. Complex & Repetitive **vs.** Simple & Repetitive ☐
6. Simple & New **vs.** Simple & Repetitive ☐

Q12. Compare the impact of different types of problems which require improvisational effort on the likelihood of **not completing a task** through improvising, given that the improviser is **Not Good.**

1. Complex & New **vs.** Complex & Repetitive ☐
2. Complex & New **vs.** Simple & New ☐
3. Complex & New **vs.** Simple & Repetitive ☐
4. Complex & Repetitive **vs.** Simple & New ☐
5. Complex & Repetitive **vs.** Simple & Repetitive ☐
6. Simple & New **vs.** Simple & Repetitive ☐

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