AMERICAN UNIVERSITY OF BEIRUT

STUDYING THE EFFECT OF BIM ON CONSTRUCTION CONFLICTS AND DISPUTES USING AGENT-BASED MODELING

by
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AN ABSTRACT OF THE THESIS OF

Hawraa Ibrahim Aidibi for Master of Engineering
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Title: Studying the Effect of BIM on Construction Conflicts and Disputes Using Agent-Based Modeling

Because of the risks and complexities that are naturally inherent to construction projects, conflicts may inevitably arise and quickly turn into claims and disputes and cause delays if not well managed. In fact, many project managers in different organizations are typically spending 30% to 42% of their work time in managing conflicts, which is time-consuming and uneconomical. This thesis presents work targeted at assessing the benefits of adopting Building Information Modeling (BIM) on projects and its impact in avoiding conflicts and disputes. Although previous research efforts developed efficient models to tackle conflict and dispute resolution, none of these studies modeled the effect of BIM in avoiding and resolving them using Agent Based Modeling (ABM). Based on ABM, a construction project environment can be modeled as an active environment, in which agents interact with each other and their surroundings, thereby creating an adaptive environment open for improvement. The solution to the problem is described in details using a simulation model developed in AnyLogic 7 (Educational Version). In an attempt to compare traditional versus BIM-based environments for conflict management, the model was designed to quantify the time spent in resolving conflicts and the repercussions on the project schedule in each case. The components of the proposed model were created, and results highlighted the potential of using the agent-based modeling paradigm to simulate the effect of BIM on construction conflicts. The results showed that the use of BIM and lean practice can optimize time spent in managing conflicts and minimize delays and the likelihood of conflicts escalating into disputes.

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ABBREVIATIONS

BIM: Building Information Modeling

ABM: Agent Based Model

ADR: Alternative Dispute Resolution

DART: Dispute Avoidance and Resolution Techniques

MEP: Mechanical Electrical Plumping

VO: Variation Order

RFIs: Requirements of Information

TBP: Traditional Based Project

BBP: BIM Based Project

DEDICATION

To my Father…

CHAPTER I

INTRODUCTION

A. **Research Background**

One of the major nuisances that plagues the construction industry is the high cost incurred for the resolutions of arising conflicts and disputes [1, 2].Many researches stated that conflicts within the construction projects are unavoidable and inevitable despite all the preventive measures taken [3]. This is due to many reasons, which manifest themselves in different forms, like the increase of complexity of the projects, or the adversarial competitive relationship between parties involved in the projects, which is further exacerbated by having different views, dissimilar backgrounds, contrasting priorities, hidden agendas to maximize their own interests, etc. As such, many techniques in dispute avoidance and resolution were developed to improve on how to minimize conflicts all together, or at least manage those conflicts from escalating into claims, and preventing them from becoming disputes or lawsuits [4].

Accordingly, when disputes do arise, they significantly affect disputants, developers, contractors, sub-contractors, suppliers, consultants, owners, and future occupiers. Hence, they should be settled with the least harm possible to stakeholders by adopting suitable resolution technique [5]. The disputes in the construction industry can be resolved through different methodologies such as litigation, arbitration, mediation, or negotiation. Arbitration and litigation are effective formal dispute resolution systems for the construction industry [5]. However, these two methods are time consuming and costly; hence, Alternative Dispute Resolution (ADR) mechanisms were developed [8].

In the same context, different concepts and technology innovations have been developed to mitigate and rule out factors affecting the performance of the construction industry. Building Information Modeling (BIM) is one of them, which represents the developmental process and entails the use of a computer-generated model to simulate the planning, design, construction, and operation of a facility in a virtual environment [8]. BIM has a revolutionary and fundamental impact in the world of construction at all levels through providing a new interactive medium between participants. BIM requires high level of collaboration, information sharing, and coordination from the inception of the project until its completion [9]. The firms that have been early adopters of BIM are realizing its benefits and enjoying a competitive advantage as they work to secure and perform new projects in a much more efficient manner. The benefits were evident across all project stages, whether in the conceptual design stage up to project completion, and even later on in the operation and maintenance of the building [9]. Overall BIM has had a significant impact when it comes to working on avoiding disputes in construction, and even leading to the potentiality of a much less dispute ridden projects.

B. **Research Objectives**

Most of the studies concerning this subject show that BIM contributes significantly in reducing the causes that may lead to conflict or dispute. This is mainly due to the collaboration and coordination it creates in the business environments, which are manifested through the easy sharing and flow of information and data, clash detection, and early identification and resolution of errors and omissions [5, 7, 8, 10, 11, 12]. These studies agree that these sophisticated models could reduce potential conflicts each through its own approach and methodology. Accordingly, with the increase in significance of BIM in the construction industry, and based on these recent studies and researches, it is necessary to shed the light more on the role of BIM in reducing the root causes of construction conflicts.

On the other hand, many simulation and modelling tools like Agent-Based Modelling (ABM) have recently received a considerable amount of attention from researchers in several domains of social sciences, economics, and engineering [13]. Its applications have largely increased due to their power of simulating and modelling the behaviours and complex interactions of autonomous agents, with the intention of assessing their impacts on the system. Having said that, construction projects given their complex environment, have been an important medium that were modeled by many researches for different goals and purposes [13].

In the light of the above, this thesis aims at modeling the time-effect of BIM on conflict prevention, detection, and resolution, leading to also assessing the impact on the duration of the design and construction phases of the project. Therefore, the overarching goal of the proposed study consists of developing an integrated model that makes use of of BIM underlying characteristics (like centralized shared data, coordination and collaborative concepts) and simulate its impact on resolution time of conflicts, and consequently on the duration of the whole project. Three specific objectives have been identified in the proposed study:

- Investigate about conflicts, disputes and claims arising on construction projects and current legal practices, and then assess the benefits of BIM in general and as a way to avoid and resolve conflicts in particular.
- Develop a comprehensive model by integrating the principles of BIM in conflict prevention and resolution, and applying Agent-Based Modelling (ABM) paradigm for simulating the effect of BIM on time spent in resolving conflicts.
- Evaluate the effectiveness of the proposed model in conflict management by assessing its performance in both traditional and BIM- based environments using a case study.

C. **Research Methodology**

In order to address and achieve the above stated objectives, this thesis took the required steps, summarized in Fig. 1, by create a simulation model that serves this purpose. As for the research methods, detailed steps were taken to achieve the thesis objectives and are thoroughly described below.

- A comprehensive literature review has been carried out to obtain enhanced information about causes of construction conflicts, dispute resolution mechanisms, BIM and its innovations mainly regarding addressing conflicts, and Agent based simulation modeling.
- Once the interactions between BIM principles and conflicts factors are identified, an ABM model of conflict management is developed using

AnyLogic 7.0 [14] while considering traditional and BIM-based environments.

- Assessing the potential benefits of BIM on time spent dealing with conflicts and the consequent effects on project duration through a case study.

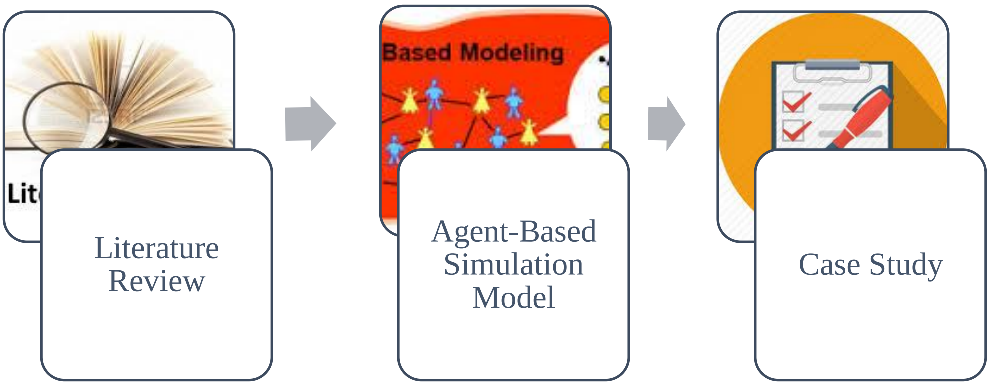


Figure 1 : Research Methodology

D. **Thesis Structure**

This thesis is organized as follows:

- Chapter II, titled "Literature Review", provides an extensive background on issues related to construction conflicts, BIM principles and agent based (ABM) simulation.

- Chapter III, titled “Agent-Based Simulation Model”, would describe in details the assumptions, the conceptual framework and the methodology of building the ABM.
- Chapter IV titled “Results and Discussion” will present the results of running the model with a thorough discussion that validates the thesis objective.
- Chapter V titled “Conclusion and Recommendations” will sum up all the above studies and suggest additional work and further recommendations to improve the results of this study.

CHAPTER II

LITERATURE REVIEW

A. **Introduction**

Due to increasing challenges and complexity in the construction industry, many researches consider disputes as a part of the project lifecycle regardless of all the avoidance and the preventive actions taken [7]. If disputes are not resolved promptly, they tend to drag and escalate which would lead to filing of claims that require litigation proceeding for resolution. This all would ultimately cause project delays. Different concepts and technology innovation have been developed to mitigate and rule out the factors affecting the performance of the construction industry. Building Information Modeling (BIM) is one of them . It has had a revolutionary and fundamental impact in the world of construction on all levels being a new efficient interactive way between participants that requires high level of collaboration, information sharing and coordination, from the time of inception of the project till its completion [7]. Given BIM's substantial effect in minimizing conflicts and resolving conflicts, it promises to yield a much less conflict-ridden environment [8].

Many studies were done in the past to assess the relations between construction conflicts and BIM usage but none tried to quantify this effect through a model. Hence, this study aims at creating a model to quantify the time effect of BIM on resolving conflicts using the Agent Based Modeling (ABM) technique, which is gaining attention nowadays in many domains.

B. **Literature Review**

1. Construction Conflicts and Disputes

a. Definition

In general, conflict is defined as any action or circumstance resulting from incompatible or opposing needs. It results from challenges, disagreements and arguments relating to tasks, roles, processes and functions, which often involves detailed discussion of relevant issues [15]. A claim is a request, by a construction party to another party, for compensation over and above the agreed-upon contract amount. These are due to additional work or damages that may have resulted from events that were not included in the initial contract [16]. However, a dispute is presented as a disagreement that requires a final determination, which is aided by the intervention of a third party [15].In other words, a dispute is defined as a type of conflict, which manifests itself in distinct and justifiable issues. It involves disagreement over issues capable of resolution by negotiation, mediation, or third party adjudication [5].

Thus, project managers should actively focus on preventing the escalation of conflicts by managing them at early stages. Otherwise, these conflicts will lead to disputes or even lawsuits, whereby resolving them will be time consuming and costly to say the least. This is illustrated in Fig.2 and Fig. 3, which validates that conflict, will escalate with time if not managed and resolved early. Moreover, detecting and resolving conflicts at later stage may also cause even further delays. Such occurrences often leads to an added cost to participants, and inevitable adversarial relationship, which will more likely lead to additional disputes and claims in the project [16].

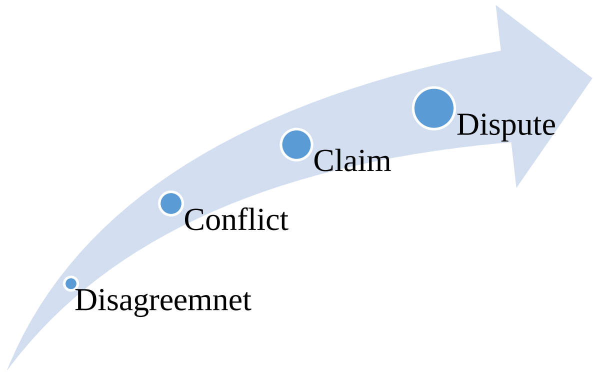


Figure 2 : Escalation of conflict

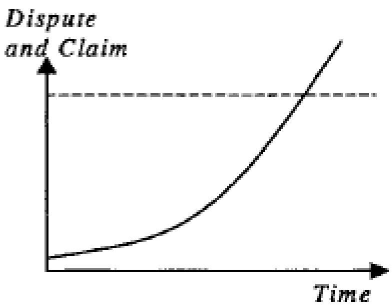


Figure 3: Escaltion of conflict with time [4].

b. Root Causes of Conflicts

To have a deep understanding of the nature of conflicts that may arise in the construction industry, it is essential to examine the root causes of disputes. A considerable number of research efforts was done and reviewed regarding this issue. All studies concurred that disputes are either time, cost or quality dissatisfaction related, and the disturbance caused by disputes on projects is invariably significant [7].

The main causes of conflicts can be classified under the following categories [4,5,7, 17,18, 19, 20,21]:

- Contractual problems: Definition, interpretation, and clarification of the contract are the main sources of conflicts, due to the imperfection and ambiguity language commonly used.
- Lack of coordination: In complex projects, when involving many various specialities of disciplines and trades, coordination is the key. Conflicts often arise because work is not properly coordinated. This inevitably leads to conflicts during installation, which is often costly and time-consuming to resolve.
- Change of scope: Changes of scope are additions, omissions, or changes in the agreed upon steps / implementation of work. Most changes are at the request of the client and may arise because of the client inexperience and requirements, stakeholder's needs, physical location, and the prevailing economic environment.
- Speed of construction and delays: Some items that give rise to dispute in the construction process are failure to plan and schedule adequately. In the case of delays in project, contractors tend to carry out accelerative measures and incur additional costs only to find that the developer refuses to pay, which will inevitably lead to dispute.
- Design errors and deficiencies: They often occur due to the poor knowledge and lack of experience and coordination. When they are

identified late in the construction phase, it will result in delays and cost overruns and become a subject for the dispute.

- Quality of workmanship: Failure to follow a scheduled plan, disagreement over the material which was specified to be utilized, failure to supply adequate manpower, responsibility for the lack of adequate subcontractor manpower, equipment changes that may cause delay, are also main sources for conflicts. Another important issue is that specifications sometimes are not clear and each party has different views on whether the quality meets the requirements or not.
- Behavior and Interaction: The way parties interact with each other is fundamental in terms of having a clear and efficient communication or carrying on a constructive conversation. In addition, it is very crucial that the commitments and goals of each are compatible with one another. Aggressive and strained forms of communication between them can almost assuredly trigger conflict.
- Short tendering periods: The time allowed for analysing the tender documents, preparing an outline program and methodology, carrying out risk assessments, estimating prices involved, and determining profitable commercial outlook for the project is often impossibly short. Mistakes in this process may have an adverse effect on the successful commercial outcome of the project.

Due to the diverse nature of construction industry, conflicts and disputes are inevitable. However, it is very possible to manage potential conflicting issues in better manner, mainly by reducing the probability of disputes occurring from the get go or dealing with them early on [6].Disputes are one of the main factors, which prevent the successful completion of the construction project. Thus, it is important to be aware of the causes of disputes in order to complete the construction project within the desired time, budget, and quality [4].

c. Setting Disputes

As aforementioned, conflicts and disputes, occupy a significant portion of the construction industry. They considerably affect project performance and outcomes and lead to delays and cost overruns. Hence, they should be well managed and settled as early as possible with the least harm to each stakeholder [7]. Fig.4 illustrates the common dispute resolution methods. They start with negotiation, and escalate up to litigation as a final remedy. The more the steps reach higher in the ladder, the more the method becomes costlier and more adversarial [6]. Utilizing the first four steps allows the parties to engage on terms they set, whereas in binding arbitration and litigation, there are already established rules and procedures that need to followed, with associated evidence and documentation required to support arguments. Accordingly, once the conflict escalates further and higher resolution methods in the ladder are adopted, the parties directly involved with the conflict would have less participation, less flexibility, and no real control over the outcome [4].

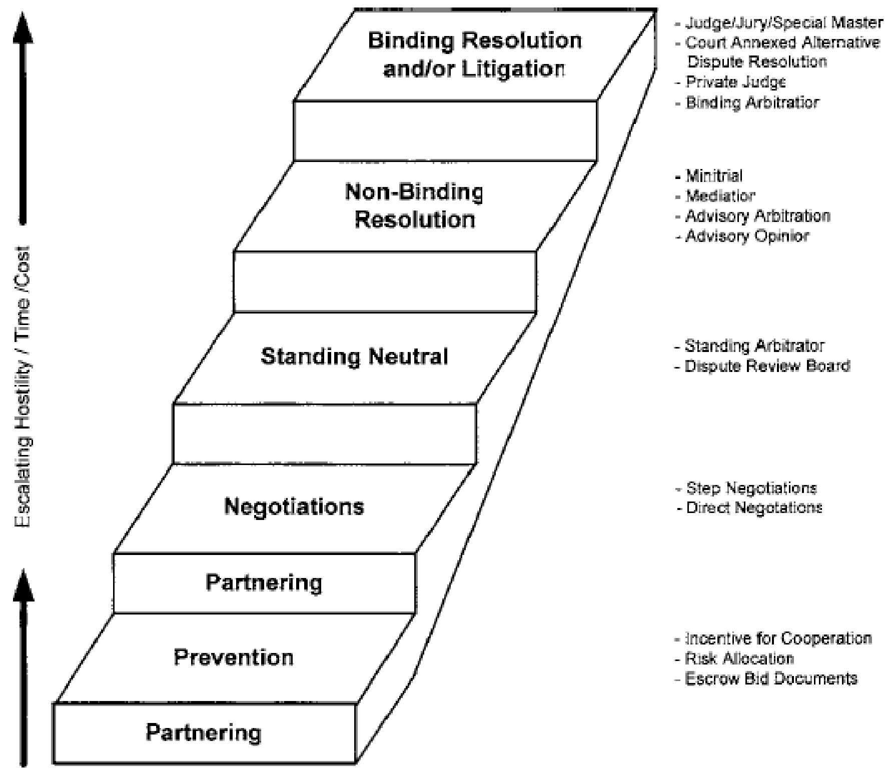


Figure 4: Construction Dispute Resolution Steps [4].

Each step of this ladder is defined as follows [4, 15]:

- *Prevention*: Prevention focuses on minimizing the sources of potential conflict on a project. Some prevention techniques range from constructability analysis and documentation, cost/ schedule controls, to contract implementation.
- *Negotiation*: Negotiation is a process in which parties discuss their differences through meetings and open dialogue in an attempt to resolve their disagreements quickly. This step prepares the parties to manage conflicts and to mitigate pertaining effects should they arise.

- *Standing Neutral*: A neutral third party is selected by party participants. The neutral third party is allowed to observe project activities, evaluate, and resolve disagreements, when and if they arise. The knowledgeable professional aims to provide objective and unbiased feedback in a timely manner to prevent adversarial relationships from growing and hardening. Dispute review boards play a similar role as a standing neutral except they are in the form of a panel.
- *Nonbinding Resolution*: Nonbinding dispute resolution procedures result in a mutually agreeable solution with the aid of a neutral facilitator, who assists in reaching a settlement. Parties can enter into proceedings voluntarily and select the third party by mutual consent; therefore, the facilitator's role is advisory and nonbinding.
- *Binding Resolution*: Arbitration is the most popular form of binding dispute resolution and is defined by the American Arbitration Association to be the "referral of a dispute to one or more impartial persons for final and binding determination. Private and confidential, it is designed for quick, practical, and economical settlements".
- *Litigation*: Litigation tends to be the final step in the dispute resolution ladder. At this step, verdicts are based on monetary compensation whereby one side wins and the other loses; however, even if a dispute proceeds to litigation, there are possible options to improve the situation, including a solid discovery process and an effective presentation.

More pointedly, EC Harris' report Global Construction Disputes 2013 stated that disputes relating to major global construction projects increased in value to, on average,

$32.1 million in 2013, and that disputes are taking longer time to be resolve [22]. In this context, many new Dispute Avoidance and Resolution Techniques (DART) have been developed to improve the prevention, management, and resolution of conflicts in design and construction projects [4]. Here comes the role of the new technology BIM that is being widely implemented nowadays as a tool that can serve the above-mentioned techniques, and must be explored further to serve efficiently in resolving the disputes.

2. Building Information Modeling (BIM)

a. Definition

Many factors confirm that traditional way or simply the current way used in designing and managing construction projects contains many deficiencies and faults [23]. These deficiencies can be represented by the separate drawings and documents developed, where each describes a piece of the project and none describes it all. Moreover, access to documents and any related information exchanged between parties involved in a project is decentralized, which causes the information to be open to many interpretations and accordingly requires clarification [23]. This can be reflected in the fact that the construction industry has great difficulty integrating all separated work steps together.

However, the advancement in technology in providing software and adequate tools makes it possible to have analysis, simulation and digital fabrication in which stakeholders can understand how virtual ideas can be realized and managed. Today, what is called Building information Modeling (BIM) has the potential to create a single model that offers visualization, clash detection, construction phases, materials and testing all integrated together in one system [24]. BIM promises to bring huge improvements to the construction industry. It is a revolutionary technology and process that has quickly transformed the way buildings are conceived, designed, constructed and operated [24]. There can be different perspectives when defining BIM. According to The National Building Information Modeling Standards (NBIMS) committee of USA [24]: “BIM is a 3D digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder.” Unlike two-dimensional computer aided design drawings and blueprints, BIM produces three-dimensional (3-D) computer models using data sets to create objects virtually, and simulate how those objects would be handled physically in the real world. It allows all the information provided by all involved specialists in a construction project to be integrated in one holistic model [24].

As shown in Fig 5, through BIM, the relation and information exchange between stakeholders can be organized in a more structured way. When using BIM, the complete project is structured on a digital platform. All the elements forming a project are embedded in the model inside out. This is done by combining architectural, structural, mechanical, electrical, plumbing, and HVAC designs under a single model via particular software, and under a proper platform. Moreover, the entire information, cost, schedule, resources, progress and more can be supplemented into the model [8].

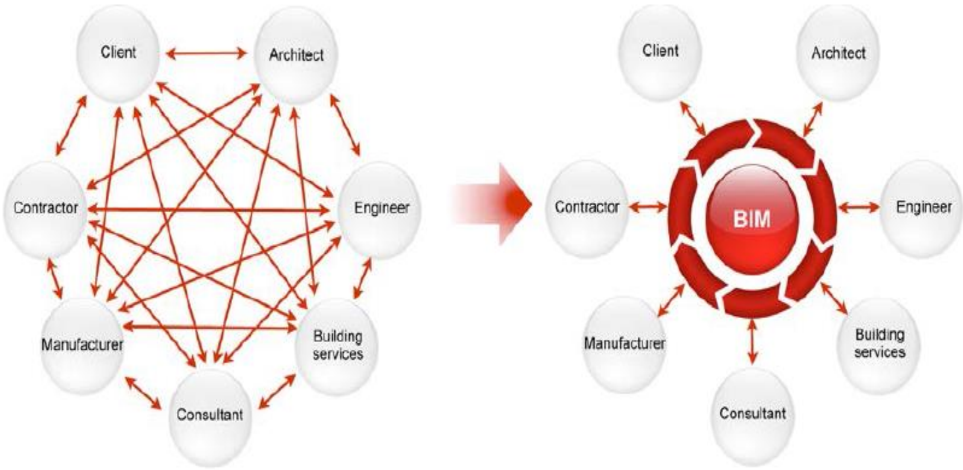


Figure 5:Information Exchange before BIM and with BIM [25]

Furthermore, BIM goes beyond the notion of a model or tool and is considered as one of many lean practices. Lean process is concerned with the overall, simultaneous, and continuous improvement of all phases of a project. The core principles of lean target fundamental issues of collaboration, value creation, transparent communication, reduced rework, avoidance of cost and schedule overruns, as well as eliminating waste of all kinds. In fact, BIM and lean are synergistic practices as BIM embraces lean principles at the core of its process. BIM and lean streamline information exchange, enable real time management, and improve decision making among project teams [26].

b. Applications of BIM

The revolutionary development of BIM in technology is quickly reshaping the Architecture-Engineering-Construction (AEC) industry [8]. This has been reflected in the following major innovations [9, 27]:

- 3D design and visualization: It enables designers and contractors to work together to identify and resolve problems with the help of the model before walking on-site. It allows 3D coordination to reduce RFIs, errors and omissions. Visualization also provides a very useful and successful marketing tool for all those involved in a project. Contractors can also use project visualization to understand how the building will come together.
- 4D design (Time): It is the integration of a 3D (or BIM) model with a construction schedule in order to visualize the sequence of construction that can be created at various levels of detail, from high-level zone analysis during the design phase, to detailed subcontractor coordination during construction. The model can maintained throughout the project based on the updated schedule and the 3D model. In a 4D BIM, you would be notified, for example, that you couldn’t schedule installation of tie-lines until after the delayed cable trays have been installed.
- 5D design (Cost): This includes Automated Quantity Take-Offs and cost estimating, including the tie-ins between quantities, costs, and locations. The model includes information that allows a contractor to accurately, and rapidly generate an array of essential estimating information, such as materials

quantities and costs, size and area estimates, plus productivity projections. As changes are made, estimating information automatically adjusts, allowing greater contractor productivity.

- Collision, conflict and interference detection: This is based on the automated ways for examining spatial and sequential conflicts within BIM. All major systems can be checked, instantly and automatically, for interferences. Consequently, BIM enables potential problems to be identified early in the design phase and resolved before construction begins. Illustrating the advantages of BIM, one project for the General Services Administration in America saw BIM model reviewers find 257 constructability issues and 7,213 conflicts. On the same project, traditional plan reviewers found 6 constructability issues and one conflict [5].
- Engineering analysis: Detailed energy modeling and acoustical analysis can be performed utilizing data already in the model.
- Fabrication/shop drawings: It will be easy, using BIM, to generate shop drawings for various building systems. In addition, the level of construction information in a BIM model means that prefabrication could be utilized with greater assurance that prefabricated components will fit once they are on-site.
- Code reviews: Fire departments and other officials may use these models for their review of building projects.
- Forensic analysis: A building information model can be easily adapted to graphically illustrate potential failures, leaks, evacuation plans, and so forth.

- Construction Operations Building Information Exchange (COBIE): COBIE is an information exchange format that captures the information created during design, construction and commissioning, and allows this information to be passed directly to the building operator. Accordingly, the information could now passed from the model directly into the owner’s facility management program without paying again for the same data.

c. Effects of BIM on the Construction Industry

The above applications have beneficial consequences on the outcome of the overall project and during its whole lifecycle, whereby these can be summarized as follows [25, 45]:

- Faster and more effective processes: Information is more easily shared and can be value-added and reused.
- Better design: Building proposals can be thoroughly analysed, simulations performed quickly, and performance benchmarked, enabling improved and innovative solutions. BIM is also capable of producing construction documents with higher quality compared to 2D CAD software and is suitable for providing better information for downstream use.
- Controlled project costs and environmental data: Project lifecycle costs are better understood and are under control from the beginning through the completion, and the environmental factors / performance is more predictable
- Better production quality: The quality of production developed has high standards since the documentation output is flexible and exploits automation.

- Better customer service: Proposals are better understood through accurate visualization.
- Life-cycle data: Requirements, design, construction, and operational information could be used in facilities management. BIM was able to enhance on several aspects of the pertaining life cycle data like substantial elimination of unbudgeted change, larger cost estimation accuracy, major reduction in time to prepare costs estimates, clash detection leading to savings in contract value, and even considerable reduction is project time.

Due to the above benefits of BIM, many governments encourage construction players to apply BIM to projects because of the huge potential to facilitate solving problems of construction projects [29]. BIM can prevent disputes between construction players, manage the right quantity for each structure, decrease construction cost and avoid project delays [30]. Moreover, the potential effects of BIM especially on resolving and managing conflicts were taken as a subject for many studies that will be discussed in the following section.

3. Potential Effects of BIM on Construction Conflicts

Research efforts proved that BIM models significantly reduce the number of events that might become conflicts and provide new opportunities for significant progress in dispute resolution procedures [7]. For example, by eliminating design and scheduling conflicts, BIM is considered to be an effective tool in reducing conflicts associated with costing and scheduling, whereby these two have been known to be perennial main sources for disputes [11]. In more details, BIM can reduce the source of conflicts, and consequently disputes, directly or indirectly though the following aspects:

a. Collaboration and Coordination

BIM causes a fundamental change in the way participants in a construction project interact with each other. It provides new and significant levels of collaboration, information sharing, and coordination, from the moment of inception of a construction project until its completion [11, 49]. If used correctly, it is suggested that fewer projects will result in disputes due to improved collaboration [32].

b. Early Detection of Errors

BIM greatly reduces conflict issues by integrating all the key systems into the model, whereby internal conflicts will be detected early in the design phase prior to construction, plus conflicts between the models and other imported information could be highlighted [34,5].

c. Visualization and Animation

Resolving disputes on engineering and construction projects can mean dealing with complex issues that are often difficult to comprehend. The use of a BIM model, and the chance to visually present what is being described, would lead to a better and faster understanding of the issues at hand, and makes causation appear more obvious [27]. It is also possible to use animation to illustrate the effect of a variation in terms of how a project looks as-planned or as-built, including portraying the consequences of delay or disruption to a construction project [10].

d. Accurate Data

By using the data in the model, dimensional errors, conflicts, and integration of errors can be avoided or significantly reduced. In addition, the model could be updated with as-built information, allowing accurate prefabrication of custom components. Hence, as a result, more construction work can be performed offsite with lesser cost and in timely manner [30].

e. Flexibility towards Design Changes

Changes happen in different phases from the design leading up to construction. These can be due to inadequacy of details, errors in design, misinterpretations and incompetence in preparing the set of detailed drawings. BIM assists building experts to model and test the constructability of the design within the model prior to setting foot on the project site. BIM is efficient in adopting and propagating changes in the model, editing objects and reloading updated links. This way changes could be easily integrated and the new updated shop drawings can be easily generated [5, 6].

f. Simulation

BIM provides a digital simulation of the facility that can be viewed, tested, designed, constructed, and deconstructed. This promotes iterative design optimization and the ability to "rehearse" construction before ever-moving labor, material, and equipment into the field. Moreover, it would aid in better understanding of the situation and making suitable decisions to choose the best alternative way that meets the set objectives and requirements. Consequently, such a simulation reduces the late variations and changes, which are considered to be persistent source of conflicts [48].

g. Preparation of Claims

It has been identified that one of the key difficulties often faced when resolving disputes is handling, understanding, and interpreting exhaustible amounts of documents and information including the retrieval of information where required [10]. As an integrated digital model of the project, BIM stores all the information of the projects in detail, which ultimately leads to easy claim preparation, avoiding complexity in claim's substantiation and visual representation [7].

h. Project Lifecycle Management

When a model is created by the designer then updated throughout the construction phase, it becomes an 'as built' model. In this case, the model contains all of the specifications, operation and maintenance (O&M) manuals, and warranty information useful for future maintenance. This eliminates the problems that might arise if the O&M manual has been misplaced or is kept at a remote location [5].

The discussion above shows that BIM is a significant tool that could largely assist in conflict avoidance or resolution. However, BIM can face its own challenges related to contractual and technical issues [27, 35, 36, 37].

4. Illustrating the Potential Effects of BIM on VOs and RFIs .

Researchers, based on case studies, confirmed that when projects are appropriately modeled, the decrease in errors reduces the number of RFIs and variation orders due to conflicts, to near zero [38]. The main pillars of BIM/Lean process coordination, communication, collaboration, shared centralized data, as well as flexibility toward changes are all important factors that help prevent errors and speed up the time for resolving any conflict, which would eventually help in saving effort and time [39]. Communication, for example, has a big role to play in conflict management. It has been verified that poor communication always results in misunderstandings and leads to conflicts. Communication must not be done with some members separately, but must be on a common platform so that everyone would share the same information, and this develops productive alignment when dealing with pending or problematic matters [39].

A simple example, illustrated in Fig. 6 and Fig. 7, shows the flexibility when implementing a design change within BIM environment compared to traditional one in the case of variation order.

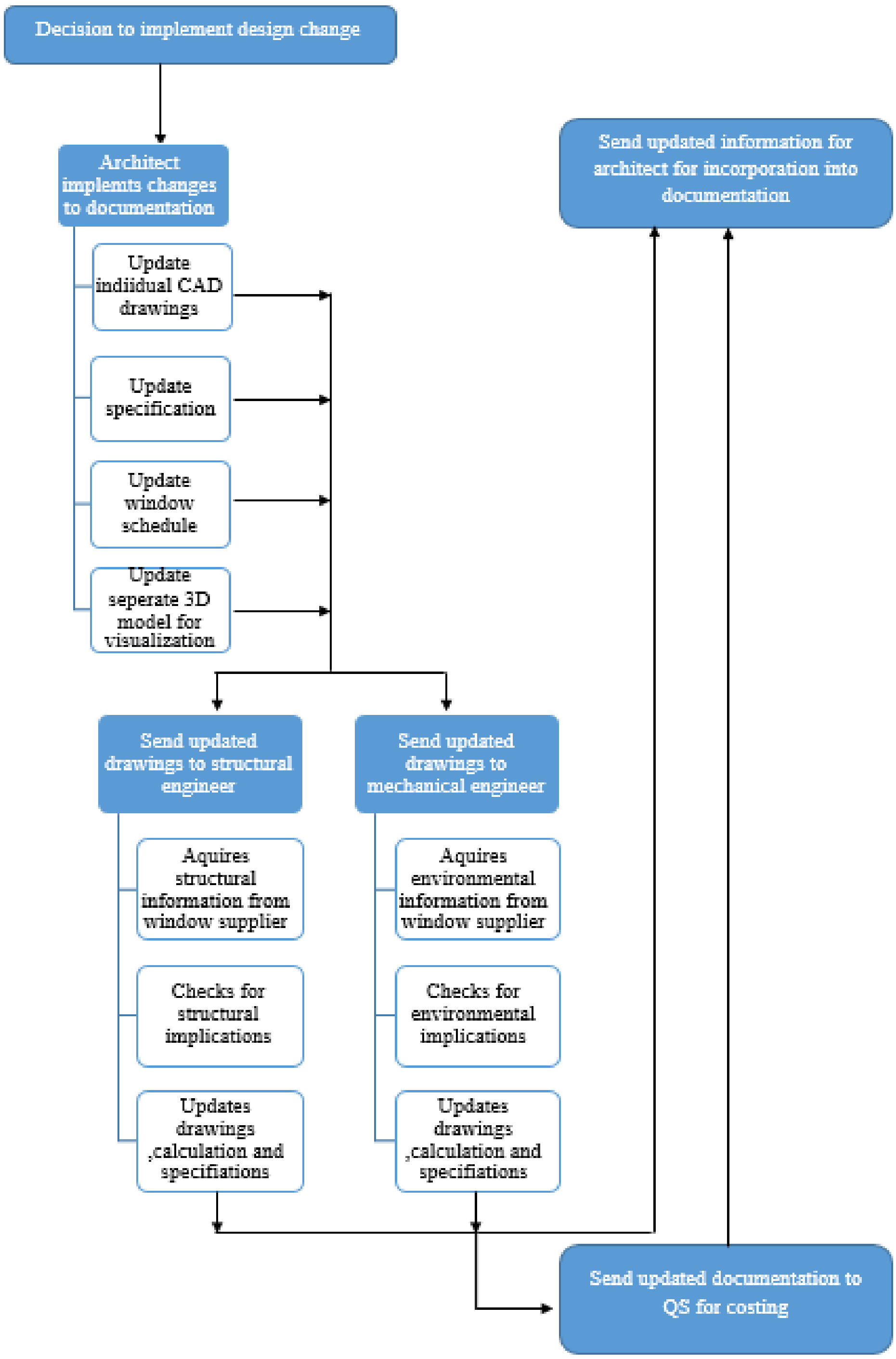


Figure 6: Sequence of events to implement a design change decision in TPB [39]

Fig. 6 illustrates how different stakeholders dependently update their information and return it to different organisations. Almost all tasks are manually achieved given that each task is prone to errors, and each information transfer process may result in a miscommunication [39]. On the other side, Fig. 7 shows that an efficient BIM model with the related components eliminates most of the tasks involved within the decision making process and removes communication errors. When using the full power of BIM all participants have access to the information. The process is significantly more streamlined and the amount of non-value adding tasks is significantly reduced [39].

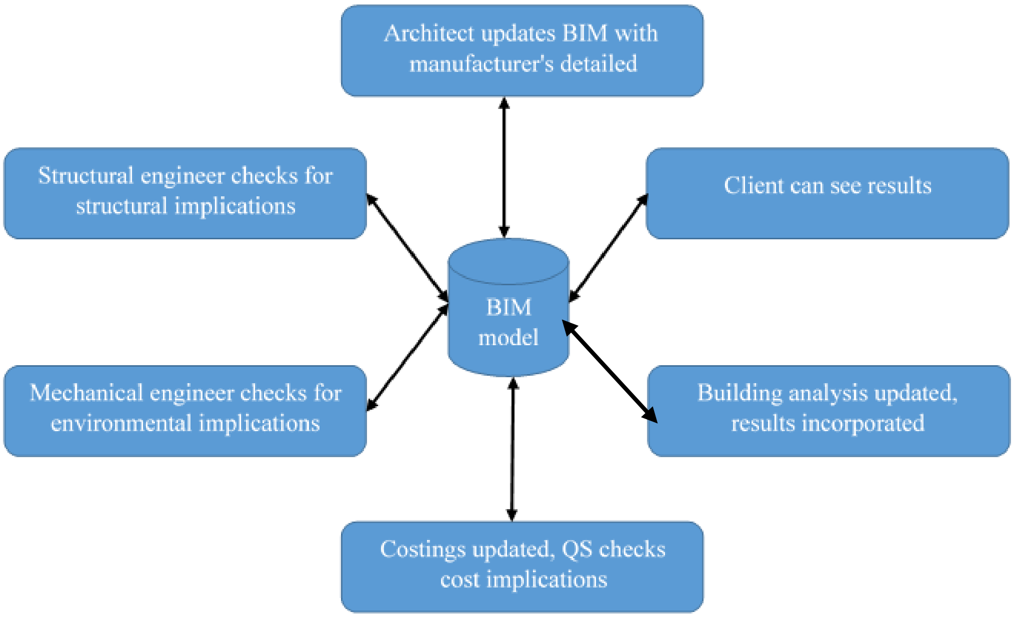


Figure 7: Sequence of events using BIM collaboratively [39].

Another important example that illustrates the effectiveness of BIM in reducing time spent on resolving conflicts is demonstrated in Fig. 8. When BIM is applied, projects will have an average reduction of RFIs (Requirements of Information) and several firms claim that field generated conflict RFIs were reduced to virtually none [38]. A large number of RFIs is an indication that large amount of time had being spent on clarifying design intent rather than performing productive work. Therefore, the coordination factor will reduce conflicts, subsequently rework, plus minimize the idle time, which are all root causes for delays [38].

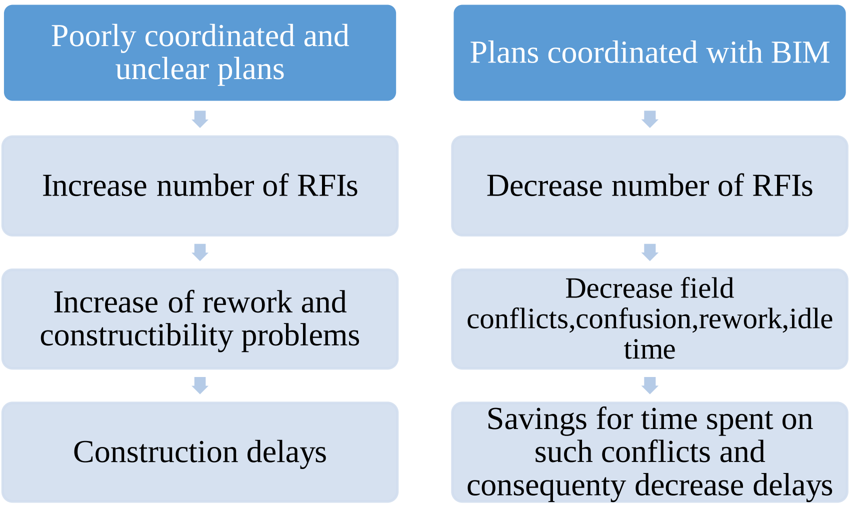


Figure 8: Effect of BIM on Reducing RFIs and Rework [38]

From the above discussion, it becomes obvious that we cannot neglect the effect of BIM in reducing the risk of conflicts and disputes to a certain limit, mainly because of detecting those at an early stage. Therefore, the earlier the conflicts are detected, the better the ability to control and mitigate their negative impact on the projects. In addition, shortening of construction time, eliminating unbudgeted changes, and increasing the quality of work will certainly lead to mitigating the risks of conflicts. Many studies have approved the direct or indirect effects of BIM on reducing the risks of delays and cost overruns, which are considered as main reasons for disputes and claims [38]. By understanding the benefits of BIM and lean principles, the issues and errors that can be sources of conflict could be better tackled, in an attempt to reduce both their incidence and escalation. However, applying BIM alone as a tool and failing to employ it as a lean process does not bring about the desired benefits. On the other hand, the effects of BIM/lean practices on construction conflicts can be studied and visualized using modeling and simulation tools, such as the Agent based Modeling (ABM) paradigm, which is considered to be a powerful tool for studying and illustrating complex interactions between agents and their environment.

5. Modeling and Simulation

Modeling is a way to solve real-world problems. In many cases, we cannot afford to experiment with real objects to find the right solutions so instead, we can build a model that uses a modeling language to represent the real system [40]. Researchers may also develop models in order to understand or illustrate some aspect of a targeted system of interest. Some define a model as follows: "A model is a simplification – smaller, less detailed, less complex, or all of these together – of some other structure or system" [41]. Thus, the model should be less complex than the real system, and must lead to some improved understanding of how the real system functions or might function.

Computer-based approaches to simulation models can help researchers achieve a variety of different objectives. The key advantages of modeling and simulation are that [40]:

- Simulation models help analyse systems and find solutions where methods such as analytic calculations and linear programming fail.
- Models give the ability to animate the system behavior in time, which is useful for demonstrations, verification, and debugging.
- Simulation models are far more convincing than other tools.

Simulation modeling has accumulated a large number of success stories in a wide and diverse range of application areas. As new modeling methods and technologies emerge and computer power grows, you can expect simulation modeling to enter an ever-larger number of professional areas [40]. In this context, different types of simulation exist of which the three most important and commonly used are Discrete Event, System Dynamics and Agent Based. Each method serves a specific range of abstraction levels. In our research, agent-based method was selected.

a. ABM Concept

Agent-based modeling aims to employ agents as the core component units that compose the model. In this sense, agents can be thought of as intelligent and autonomous programs that interact with other components of the system and their environment in order to affect a certain set of programmed goals [41]. ABM is now rapidly gaining attention in many different areas due to its interdisciplinary appeal. This appeal can be attributed to the flexibility in the construction of agent architectures and the fact that some quite complex and interesting model behavior can be generated with this framework, once the basic concepts have been understood. Therefore, the aim of agent-based simulation and modeling is to improve understanding and explanations of aspects of complex systems that are composed of interacting components. Moreover, it is of significant importance to understand the methodological strands of developing a model. This methodological process is more or less the same as any scientific research approach, which can be broken down into several steps that include: (1) abstraction of the studied system to a conceptual model; (2) formalization of the said abstraction using computer modeling; (3) model execution and behavior exploration; (4) integration and analysis of results; and (5) carrying out substantiated conclusions on the original target system [41].

Furthermore, validation of agent-based models is a crucial step that builds trust in the outcome of the model. The validation process usually focuses on qualitative and quantitative approaches. On one hand, the qualitative part consists of comparison of behavior of the model with empirical observations or descriptive accounts drawn from relevant literature and case studies. On the other hand, quantitative validation is provided by comparing the statistical analyses across time-series outputs from the model with empirical data [41].

b. ABM in Construction Industry

ABM has recently received a considerable amount of attention from researchers in several domains of social sciences, economics, and engineering; hence, its application has largely increased. Particularly in civil engineering, ABM has been employed for various purposes [13]. Complexity is one of the major characteristics of the construction industry. In fact, the construction sector witnesses multiple project participants who need to get together to perform various construction activities, especially when coming to resolving conflicts and disputes. Moreover, these construction activities usually involve open, dynamic, and complex problems where the structure of the system itself is capable of changing dynamically. Such a complex interactive environment requires agents to be able to operate together and collaborate with each other [42]. It has been stated that agent systems in the construction industry could provide [42]:

- Effective decomposition of large-scale construction problems
- Improved collaborative and concurrent operations
- Easier and cheaper access to information.

Realizing these benefits, ABM was used in various construction applications such as material management, engineering design, supply chain management, scheduling and control, and negotiations in dispute resolutions. Previous research projects include agent-based integrated building design environment, agent-based design changes system, agent-based resource management system, infrastructure management, construction labor productivity on site, bidding environment, simulation for modeling construction earthmoving operations, models for situational simulations in construction industry, and agent-based project schedule coordination [13].

More specifically, several models have been developed for resolving conflicts and disputes in construction industry. The most worth mentioning are:

- CONVINCER mediating agent-based model [43].
- MASCOT negotiating agent-based model [44].
- MAS-COR a multi-agent system for construction dispute resolution, which uses facts and outcomes of precedent disputes to simulate legal discourse in construction disputes [42].
- A multiagent System for detecting and solving design-time conflicts in civil infrastructure [45].
- A model to value the implementation of a project specific dispute resolution process in construction projects but using system dynamics approach [46].

C. **Limitations of Current Studies**

In light of the above, some research efforts attempted at studying the effect of BIM on construction conflict prevention and resolution [7, 8, 49, 50] but failed to capture all the complexities of this mechanism and its dynamics. This thesis presents an agent-based model that models an active environment in which project participants or agents interact with each other and their surroundings thereby creating an adaptive environment open for improvement and conflict resolution. Despite the considerable attention ABM is gaining in different domains, specifically in the construction industry, as shown in the latter discussion about ABM in section B-5-a, there exists no simulation model that studied the effect of BIM on conflict resolution from a time perspective.

This study acknowledges this mentioned gap and attempts to apply the ABM concept to model the time effect of BIM on resolving conflicts from the instance of their detection until their resolution. This, in a way, would help validate the potential effects of BIM on the time spent resolving conflicts under both traditional and BIM-based environment.

CHAPTER III

AGENT BASED SIMULATION MODEL

A. **Introduction**

Simulation is used to imitate real life processes, operations, situations. The importance of simulation is its ability to help predict outcomes of certain situations based on different scenarios. The flexibility of simulation is very important since the level of detail, speed of simulation, varying parameters, etc. can all be adjusted and are usually selected based on the case modeled and based on the expected and required outcomes. Simulation can be applied to any field with examples such as healthcare, manufacturing, marketing, construction, etc. [14, 40].

Here in our research ABM is selected which is defined, from the viewpoint of practical applications, as an essentially *decentralized*, *individual-centric* (as opposed to system level) approach to model design. When designing an agent based model the modeler identifies the active entities, the *agents* (which can be people, companies, projects, assets, vehicles, cities, animals, ships, products, etc.), defines their behavior (main drivers, reactions, memory, states, ...), puts them in a certain environment, establishes connections, and runs the simulation. The global behavior then emerges as a result of interactions of many individual behaviors [14].

B. **Model Objective**

Time, cost and quality are three main factors that play a significant role in the planning and controlling of construction projects. Moreover, conflicts, when managed professionally and effectively throughout the project, can have a positive effect on these factors. Being the case, this research aims at assessing the benefit of adopting the BIM/lean approach to efficiently manage conflicts using the ABM paradigm. Therefore, the main objective of the proposed ABM model is to measure the effectiveness of BIM in conflict management by quantifying the time spent in resolving conflicts, and the repercussions on the project schedule under both the traditional and BIM-based approaches

C. **Architecture of the Model**

The model architecture is represented in Fig. 9, with an input, process, and output components.

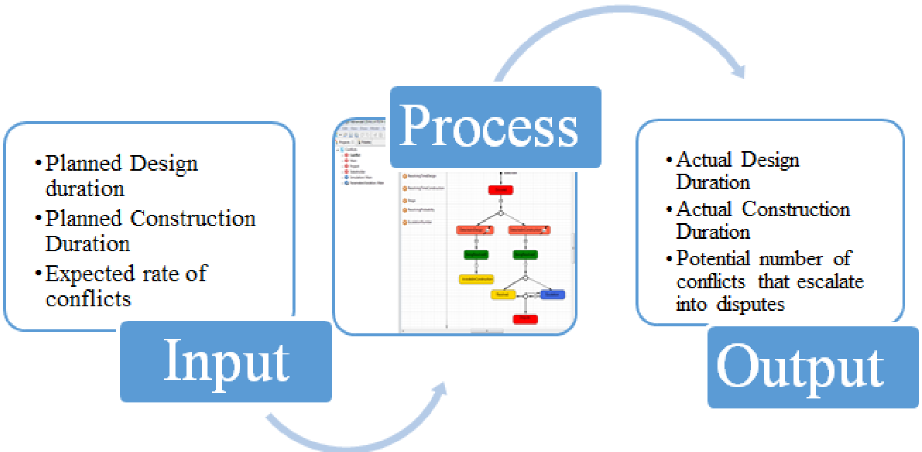


Figure 9 : Schema of General Model Architecture

The input of the model consists of: (1) the planned design duration, (2) the planned construction duration, and (3) the expected rate of conflicts in the two main phases of the project. The latter differs according to the project complexity, nature, and size. On the other hand, the output after running the model comprises of: (1) the actual design duration, (2) the actual construction duration, and (3) the potential number of conflicts that may escalate into disputes. The actual design and construction duration is set to equal the total planned design and construction duration in addition to the time added due to conflicts. Finally, the process component, which is actually the underlying process of the ABM model, is shown in Fig. 10.

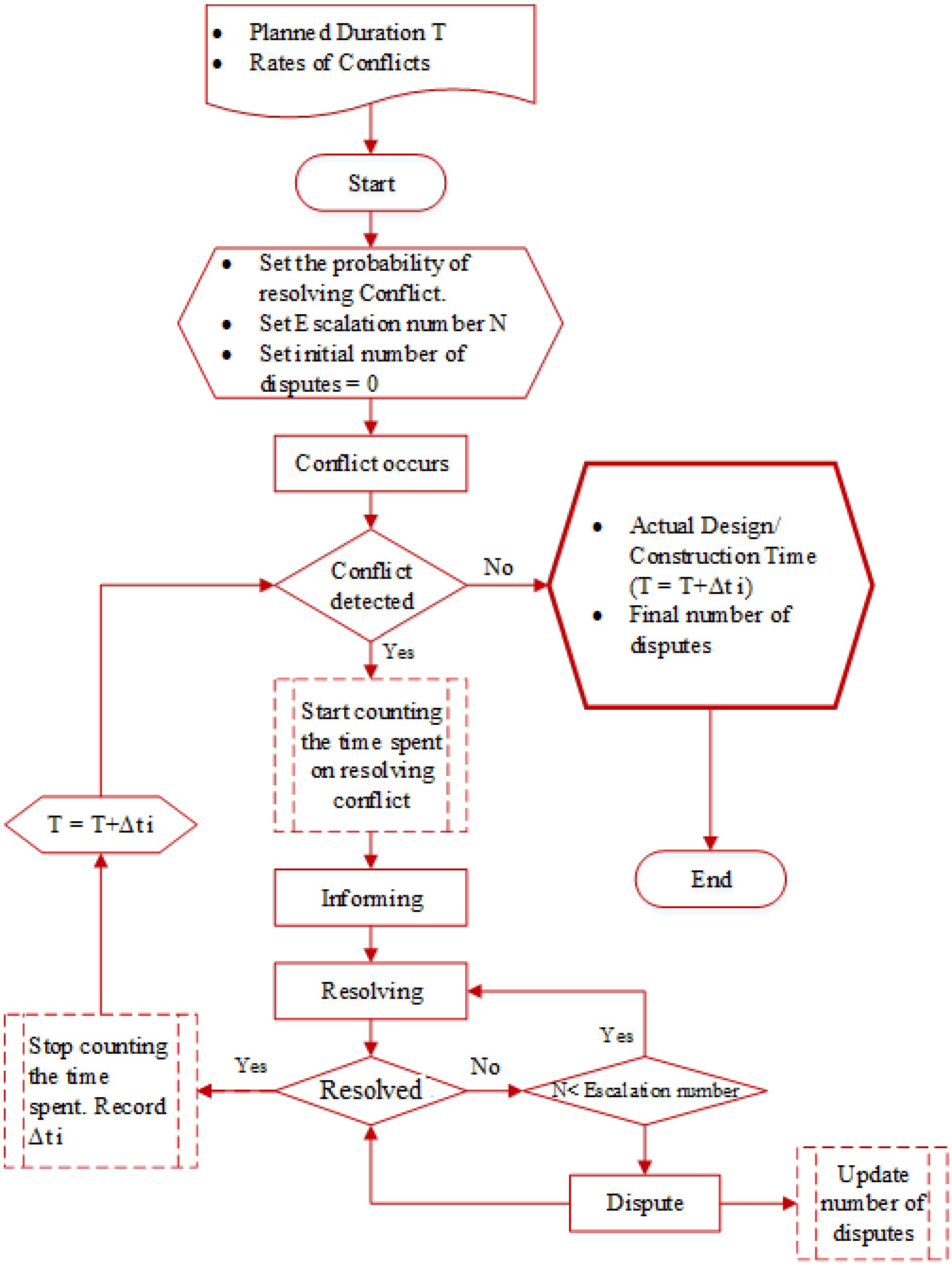


Figure 10: Underlying Process of the ABM Model

The process starts with the user entering the input (model variables), then running the model, and as next step the conflicts are generated at a defined rate. Once a conflict is detected, the model starts counting the time spent on resolving it. After informing all the involved parties about it, the conflict moves to the resolving state where there is a probability of reaching a resolution or failing to do so. If it is resolved, the model stops counting the time spent on resolving this conflict and adds it to the initial duration (T+ΔTi). However, if it is not resolved, it enters an escalation loop, meaning it would take longer time to get resolved. When the time spent on resolving a conflict exceeds a maximum defined by the user (i.e. escalation number), the conflict is considered a dispute. When no more conflicts are detected, and the time is equal to the planned durations entered, the model stops. Here the output of the model, or in other words the actual durations and the potential number of dispute, is obtained. This process is further discussed in Section F.

D. **Model Assumptions**

Prior to presenting the ABM model, it is important to recognize its underlying assumptions.

- The model does not target the dispute resolution process timeline illustrated in Fig.11, but is more concerned with the incremental time added on the total project duration due to conflicts.

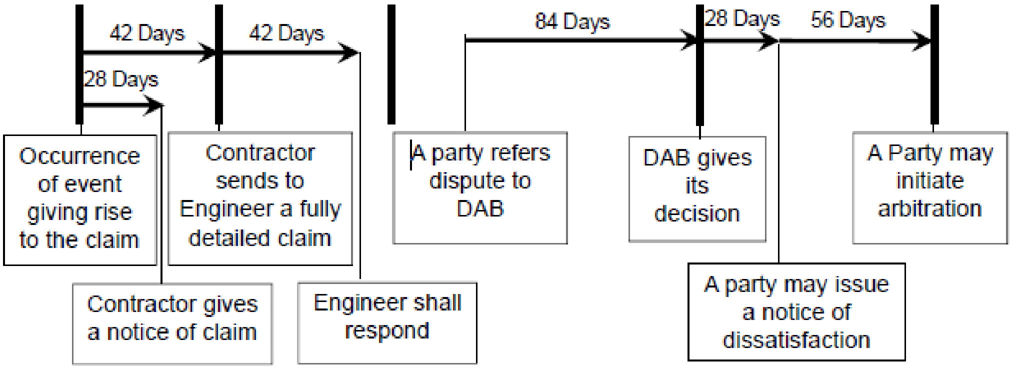


Figure 11: Dispute Resolution Timeline [51]

- The development and the results of the corresponding model are based upon using and implementing BIM as a lean process and not just a CAD tool.

- The type of conflicts taken into consideration in our model are selected in a way only where BIM can contribute to. Examples to these selected conflicts include but are not limited to technical conflicts due to clashes, and conflicts due to design errors, constructability issues, data analysis and interpretation, shop drawings and variation orders, etc.

- The model is set to generate a certain number of conflicts based on a rate value input by the user. This rate is typically estimated based on precedent cases or studies, and usually varies according to the size, complexity and nature of project. The rate of conflicts under the BBP approach is assumed to be less than the rate of conflicts under TBP. In fact, this assumption was acquired from a previous study [47], which shows that the increase of coordination effort decreases the number of conflicts as shown in Fig.12.

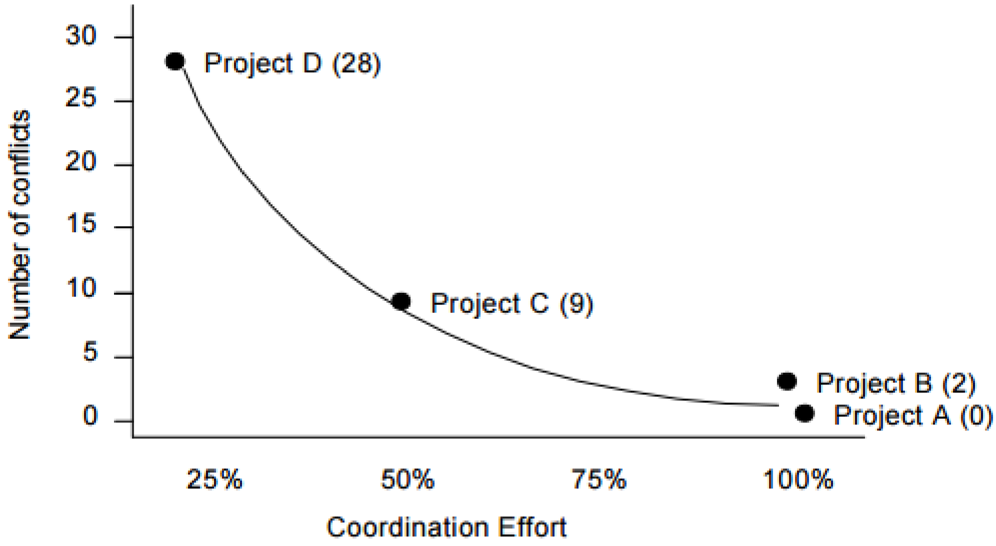


Figure 12: Effect of Coordination Effort on number of Conflicts [47].

- The duration for preventing and resolving conflict in its earliest stage is minimal compared to the duration when conflict is identified at a later stage. In other words, resolving conflicts in the design phase always causes less delay than when detected in the construction stage.

- In both approaches, whether BBP or TBP, delay might occur, when conflicts are detected in the planning or construction phase. However, the main difference is in the magnitude of delays. Therefore, the assumption based on the literature is that the factors affecting the time for detecting and resolving conflicts shrink the delay more under BBP.

- It is considered that conflicts can be of different types and levels, which directly affects the amount of delay. Table 1 shows the levels of conflicts whereby each has a time impact that affects delays differently [48].

Table 1: Level of Conflict [48]

Issues	Description
Level 1	Could be solved in site, not a major impact on the actual construction process
Level 2	Shut down, waiting to be processed by technicians on site
Level 3	Shut down, need to dismantle and reconstruct
Level 4	Shut down, need to dismantle and reconstruct, and change parts of the original design purpose

- It is assumed that the duration required to detect and get informed about any conflict under BBP is shorter due to the shared centralized database, fast and flexible flow of information, and the high levels of coordination and collaboration.
- Under BBP, based on BIM/Lean principles and characteristics, and the graph shown in Fig.13, it is assumed that most potential conflicts occur and are detected early in the design phase, and resolved before construction begins. Conversely, under TBP, the rate at which conflicts are detected is less in the design phase than in the construction phase.

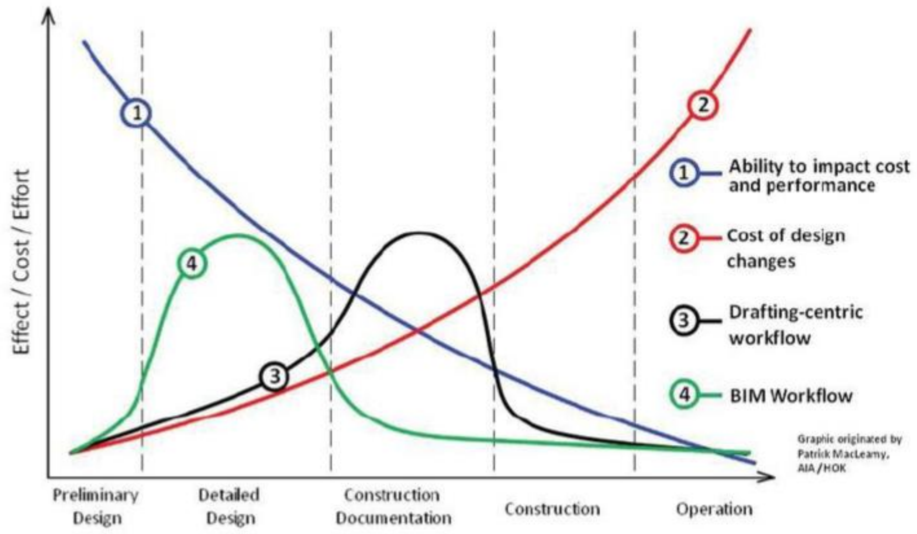


Figure 11: McLeamy curves [5]

- Due to the supporting factors in BBP that help in early detection and resolution of conflicts and which are lacked in TBP, the probability for resolving a conflict early without escalation in BBP is greater than under TBP. Moreover, each time the conflict is not resolved, it is assumed that it will escalate and take a longer time to be resolved.
- The model assumes that most conflicts that occur in the design phase are resolved without escalation while in the construction phase, conflicts can escalate and turn into disputes which are resolved causing thereby delay without any termination of the project.
- In the model, it was also assumed that when conflict occurs, it causes a delay placing it thereby on the critical path of the project schedule. This is actually identified through a Time Impact Analysis (TIA).

E. **Schematic Representation of the ABM Model**

The first step for developing any model is to abstract the studied system to a conceptual framework to better illustrate it. The system under consideration is the conflict resolution system, which is mainly composed of the responsible stakeholders, the conflicts to be resolved, and the duration of the project under consideration. Since it is required to compare two different environments (TBP and BBP), two conceptual frameworks were developed.

Fig. 14 represents the conceptual model for traditional-based projects (TBP). In the *Stakeholders* agent, all the project responsible stakeholders interact using traditional way with sub-optimal communication and coordination. While the *Conflict* agent displays the behavior of conflict from the instance of its occurrence until its resolution. The variables that affect this agent, which are different between the two processes, are factors that affect the time for detecting and resolving conflicts as shown in the framework. Together the *Stakeholders* and *Conflict* agents form the conflict environment, which in turn affect the durations of the main phases of the project represented by a separate agent called *Project* agent.

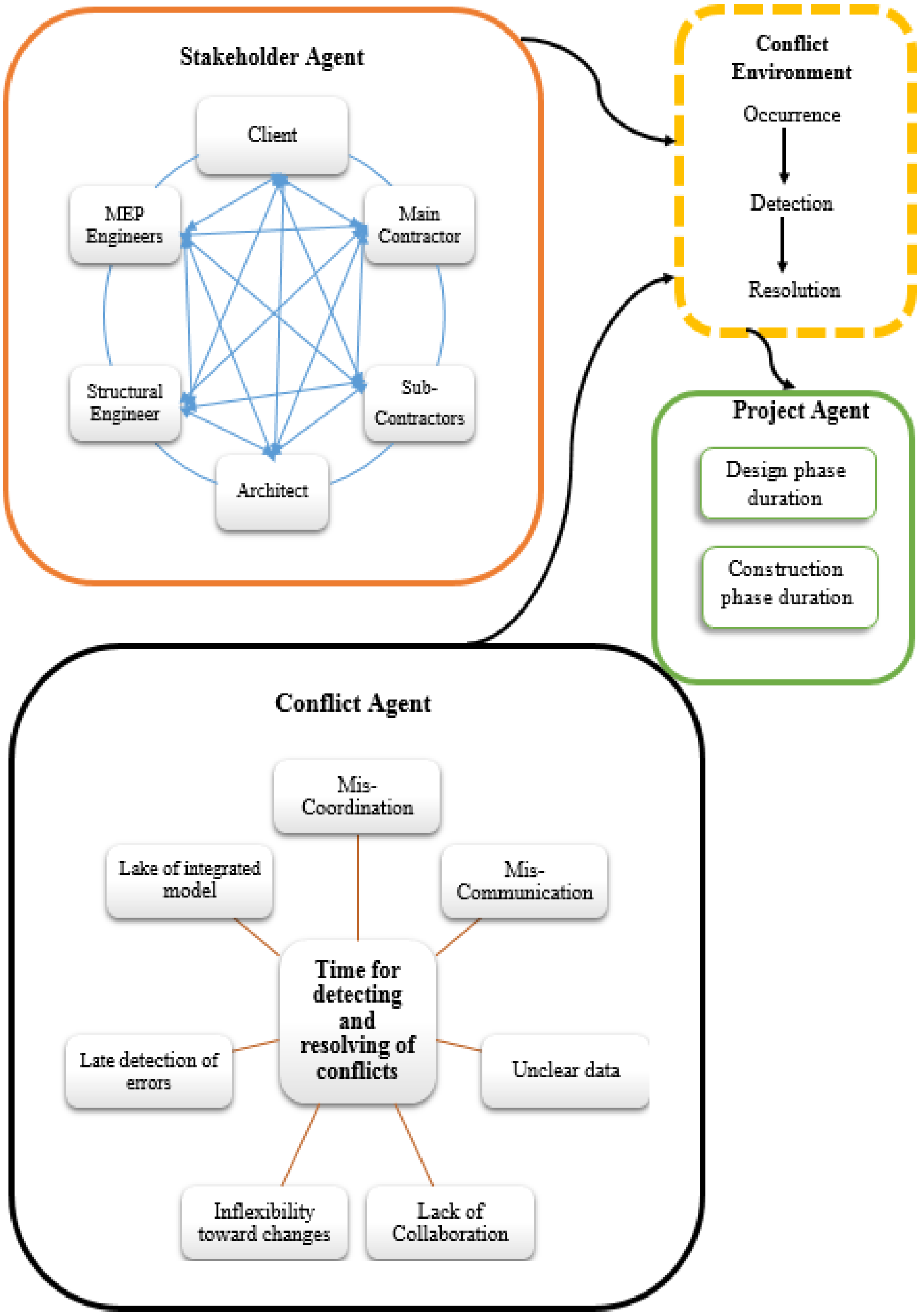


Figure 12: Conceptual Simulation Model for Traditional based Projects

Similarly, the conceptual model for BIM-based projects (BBP) is represented in Fig. 15, but here the stakeholders interact with a high level of coordination, whereby they are connected to a centralized common database forming thereby a more transparent platform.

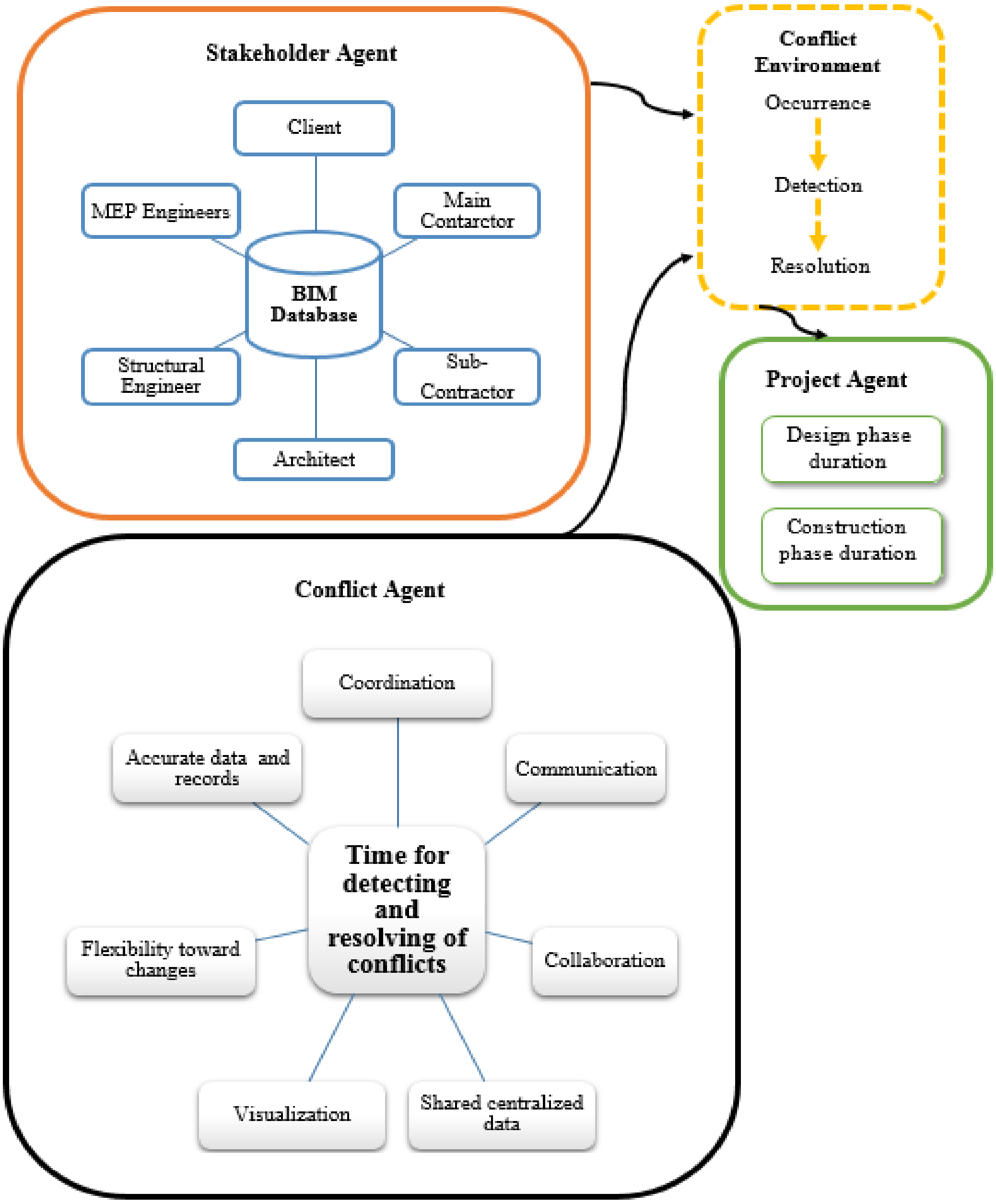


Figure 13: Conceptual Simulation Model for BIM based Projects

In this case, data can be shared continuously among project participants, allowing them to work effectively and efficiently. Moreover, regarding the *Conflict* agent, the time for detecting and resolving conflicts is positively affected due to the underlying BIM/Lean principles that this BBP framework follows.

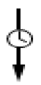
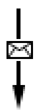
F. **Implementation of the ABM model using ANYLOGIC**

The proposed computerized model is implemented in the AnyLogic software system (Version 7), which is a dynamic simulation tool that allows for agent based modeling. The AnyLogic platform implements Java as a high-level language for defining data types and data transformations. In addition to the built in features for each agent, a Java code is developed to guide the agent behaviour during the model. The development of the model is described below in details [14,40].

1. AnyLogic Components

First, in order to explain how to develop a simulation model using ABM and the characteristic of the agents, it is essential to start by defining all the AnyLogic elements and components needed to develop the model, which are defined in Table 2.

Table 2: Agent Components in AnyLogic

General Library	
Agents	*Agent* is the main building block of AnyLogic models; it can have parameters, variables, ports, events, statecharts and embedded active objects. Agent is the unit of dynamic creation of destruction.
Event	An *event* allows the user to schedule an action to occur based on a condition or at a specific time or in a cyclic manner.
Parameter	A *parameter* is used to model the characteristics of the modeled objects (e.g. speed of vehicles). Parameters are usually static and do not change during a model run.
Variable	A *variable* is also used to model characteristics of a model. However, it usually varies during model execution (e.g. wind speed).
Statecharts	*Statechart* has states and transitions. Transitions may be triggered by timeouts or rates, messages received by the statechart, and conditions. Transition execution may lead to a state change where a new set of transitions becomes active.
State	*State* represents a location of control with a particular set of reactions to conditions and/or events. A state can be either simple or, if it contains other states, composite.
	Event with trigger of type *timeout*. The event occurs exactly in timeout time after it is started. Optionally, the event may be made cylcic and set to occur at startup.
	Statechart transition with trigger of type message. Such transition is executed when the statechart receives a message (integer or Object) that conforms with the transition trigger. If the guard appears to be false when the transition is about to execute, it is not taken and becomes inactive until the next message arrival.
Branch	A *branch* represents a transition branching and/or connection point. Using branches you can create a transition that has more than one destination state, as well as several transitions that merge together to perform a common action.
	Statechart transition with trigger of type rate. Such transition is executed with the timeout distributed exponentially with the parameter rate (counted from the moment the statechart came to the transition's source state)

2. *Agents of the Model*

Project Agent: The role of this agent is to represent the different stages of the project, namely the design and construction phases. It was deemed necessary to create this agent in order to simulate the time effect of the early or late detection of the conflicts in different phases of the projects. The statechart of this agent is represented in Fig. 16 below:

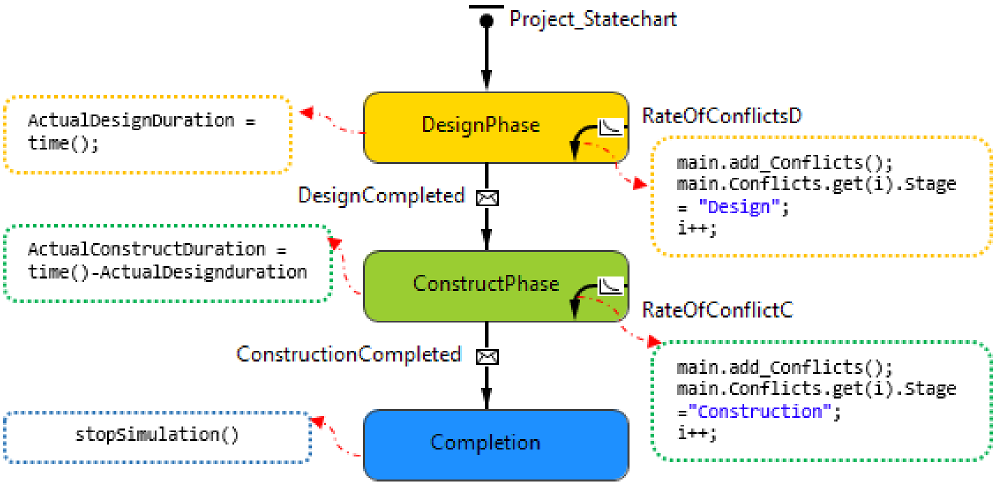


Figure 14: StateChart of Project Agent

Subsequently, because this study is only concerned with the time effect of conflicts on the duration of the project, the variables defined for the project agent are:

– *PlannedDesignDuration*: It is the expected value- added time required for design and entered by the user.
– *PlannedConstructionDuration*: It is the expected value- added time required for construction and entered by the user.
– *ActualDesignDuration*: It is the actual time spent in the design phase.
– *ActualConstructionDuration:* It is the actual time spent in the construction phase.

When running the model, conflicts get generated according to the rate input by the user and time is registered. Once this time becomes equal to the *PlannedDesignDuration,* a message is sent to move to the *ConstructPhase* where similar actions happen before moving to the *Completion*.

Stakeholders agent: The role of this agent is to represent the main stakeholders involved in the project, in this case *Client, Contractor, Architect, Structural Engineer, MEP Engineers, and Sub-Contractors.* The statechart of this agent is shown in Fig 17.

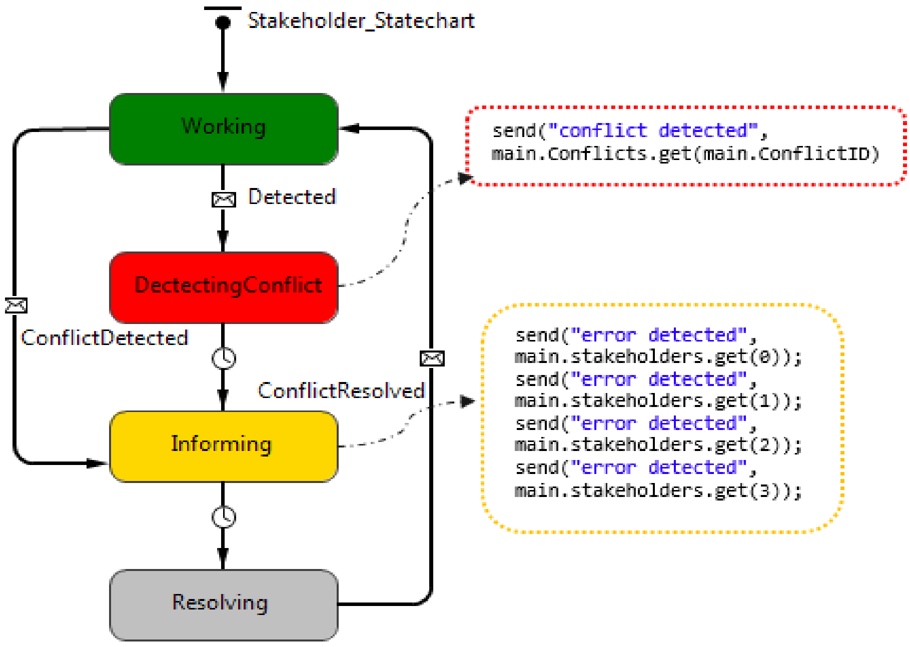


Figure 15: StateChart of Stakeholders Agent

When running the model initially, all the stakeholders are in the *Working* state. The statechart shows that each stakeholder can be in the defined states (i.e. *DetectingConflict*, *Informing*, and *Resolving*) in the case of conflict occurrence. Additionally, a *ConflictDetection* event (Fig. 18) was created to allow detection of conflicts according to a given rate. It sends a random message to one of the stakeholders to announce the detection of a conflict. Once the conflict is detected, the respective stakeholder moves from the *Working* state to the *DetectingConflict* state. A timeout duration is then defined that represents the time needed for other stakeholders to get informed about the conflict; i.e. moving from *Working* state to *Informing* state. From the time the conflict is detected and one of the stakeholders is not working, the model starts counting the time spent on resolving this conflict which is considered in our model a non-value added time to the project. Another timeout was defined which represents the time needed to start resolving a conflict; i.e. being in *Resolving* state. Once the conflict is resolved, a message is sent from the *Conflict* agent to all stakeholders to exit the *Resolving* state, and return to the initial state (*Working* state), until another error is detected.

Figure 16: ConflictDetection Event

The two variables defined for this agent are *TimeToGetInfrormed* and *TimeToGetResolved,* which are expected to be different between traditional based (TBP) and BIM-based projects (BBP).

Conflict Agent: The role of this agent is to represent the flow of a conflict from the state of its occurrence, detection, and finally to its resolution, as it is illustrated in Fig. 19. Since the detection of conflicts at early stage (design phase) or at late stage (construction phase) are assumed to have a different time-effect, it is necessary to study these two phases. So in these two phases there is a rate for detection of conflicts which differs between BBP and TBP, and that are be represented by the variables *RateDetectionConflictsD* and *RateDetectionConflictsC.* Likewise, there will be other variables that define the time required to resolve a conflict, which also differs between BBP and TBP, and are represented by *ResolvingTimeDesign* and *ResolvingTimeConstruction.* In case the conflict occurs in the construction phase, there will be probability of escalation, which also differs between BBP and TBP, and is represented by the variable *ResolvingProbability.* In case conflict is not resolved, it enters an *Escalation* state, which increases the time for resolving this conflict. Therefore, a parameter termed as *EscalationNumbe*r and multiplied by a *TimeFactor*, counts the number of times a conflict enters the escalation loop. When the time spent on resolving a conflict is greater than *ResolvingTimeConstruction* EscalationNumbe*r* *TimeFactor*, then this is considered as a serious conflict, and indicated as *Dispute* in the model.

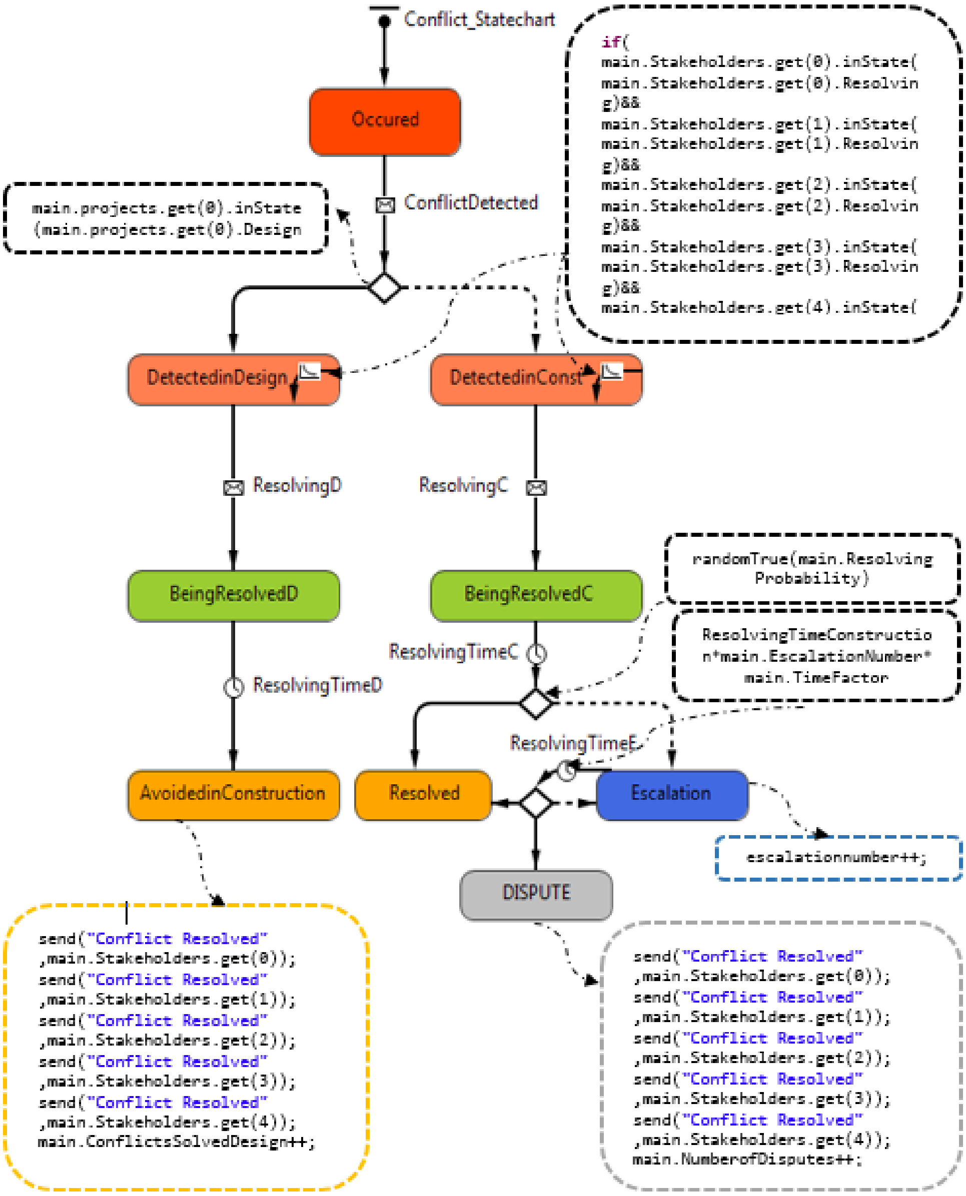


Figure 17: StateChart of Conflict Agent

The above-defined agents and all parameters interact to achieve the model objective, i.e. predict the time spent on resolving conflicts and actual total project duration.

CHAPTER IV

CASE STUDY: RESULTS AND DISCUSSION

A. **Case Study**

1. Project Description

Table 3: Project Description [48].

Project Attributes	Parameters
Site Area	42140 m^2
Location	North District, North Industrial Park, Shanghai
Type	Centralized Information System Data Centre of the State Grid Corporation
Gross Floor Area	28124 m^2
Construction Scale	Underground Construction Area: 7807 m^2 Ground Floor Area: 20317 m^2 Height: 23.950 m (from outdoor ground to roof parapet) Height: 28.650 m (from outdoor ground to roof shutters) Height: 9.1m (Diesel Generator Room) Seismic Fortification Intensity: 7 degrees
Design Time	September 2010

This project, which is described in Table 3, faced many issues, such as the involvement of numerous professionals of diverse expertise, the complexity of the equipment and system involved, a tight schedule, strict requirement on cost control for materials and labour, etc. In particular, the main building contains a large number of pieces of equipment, including air-conditioning devices, electrical devices, water pumps and other devices (1,228 in total). There are very complex electro-mechanical systems, including nine HVAC systems, 12 water supply and drainage systems, and 18 electrical engineering systems. These are all placed in a limited space (each story's height is 5.5

m, the bottom of the beam is 4.53 m from the ground, the design of the ceiling in the corridor is 3 m, the space for pipeline installation is only 1.53 m wide). The actual construction duration of the project only lasted for seven months. As this project was selected as a BIM pilot project by the Shanghai government, the construction company was required to complete the design and planning using a series of both traditional and BIM methods, as well as tentatively applying BIM in the construction phase [48]. There were three implementations of BIM in this project, namely BIM in MEP design review, the 4D simulation of the construction scheme, and BIM-supported materials management and control. The evidence from the case study provides authentic data to explain how the roles of conflict detection, the construction schedule, and materials management and control may affect the time and cost involved. This expands our understanding of how to maximize the outcome of BIM via proposing alternative ideas, methods, and techniques against the traditional methods.

However, this thesis is only concerned with the data related to the application of BIM to design review and conflict detection. Based on the calculation of the above project, the comprehensive application of BIM technology found more than 2,000 errors in the original design. By using the error classification and conflict inspection reports, the 500 most important errors were discovered and eliminated prior to the construction stage, whereby it reduced the reworking, labor, and materials waste. By changing from passive response to active control, BIM ensures the overall control of the time during the process of construction. The time savings due to conflict detection after applying BIM are given in Table 4.

Table 4: MEP design issues and time saving data based on a BIM design review [48].

No.	Items	Issues			Time-saving	
		Issues identified before construction	Issues identified in construction	Total	Time per each issue (day)	Total time-saving (day)
1	Level 1 issues	198	67	265	0.05	13.25
2	Level 2 issues	132	32	164	0.1	16.4
3	Level 3 issues	95	26	121	0.15	18.15
4	Level 4 issues	58	6	64	0.2	12.8
5	prefabrication	-	-	5	-	-
Total		483	131	**614**	-	65.6

Level 1 issues: could be solved in site, not a major impact on the actual construction process
Level 2 issues: shut down, waiting to be processed by technicians on site
Level 3 issues: shut down, need to dismantle and reconstruction
Level 4 issues: shut down, need to dismantle and reconstruction, and will change parts of the original design purpose

Table 5 sums up the required data extracted from the above case study to assist in setting some realistic assumptions necessary to build the model.

Table 5: Data Analysis from case study.

Variable	After BIM Implementation	Without BIM application
Design duration	unknown	unknown
Construction duration	210 days	275 days
Num. of conflicts resolved in design	500 days	unknown
Num. of conflicts resolved in construction	131	614
Rate of conflict in design (per day)	unknown	unknown
Rate of conflict in construction (per day)	0.6	2.2

2. Setting Model Variables

Based on the above data and assumptions discussed in Chapter III-section D, some realistic values for the variables and parameters could be predicted and used to build the presented model. It was obvious there was different input for the variables defined below in the model (Table 6) according to the type of projects (i.e. traditional-based project (TBP) vs. BIM-based project (BBP)).

Table 6: Main Variables of the Model

Variables	**BIM Based Project**	**Traditional Based projects**	**Unit**
ResolvingTimeDesign	[0.01- 0.1]	[0.06- 0.2]	day
ResolvingTimeConstruction	[0.05-0.02]	[0.07-0.25]	day
ResolvingProbability	[0.45-0.7]	[0.45-0.6]	-
EscalationNumber	5	4	-

B. Simulation Results and Discussion

The use of the AnyLogic-Java based technology enable users to run the model in a fully functional interactive way. The user is asked to select the process he/she wants to simulate, enter the required parameters, and then run the model. It must be noted that since there are some stochastic values that vary between defined ranges, it was thereby decided to run each experiment with fixed parameter values for several times, in order to assess the effect of random factors on these particular stochastic variables. Therefore, the number of iterations chosen was equal to 500 in our model, and represented the number of runs for the model within the same input. The larger the number, the more precise the estimate, since each time a new scenario was run it provided at the end the mean value of the results. Fig. 20 shows a sample of one of the output with 500 interactions.

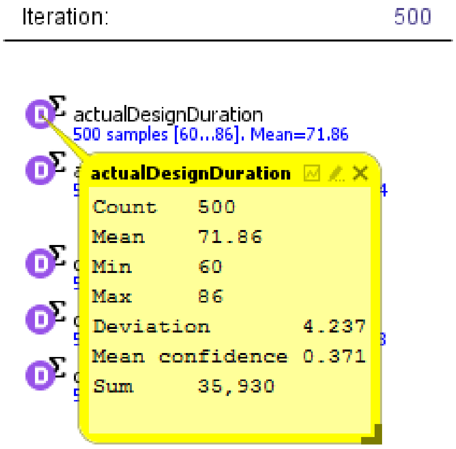


Figure 18: Sample of Output form of 500 run

Fig. 21 and Fig. 22 below represent the input and output of the model when selecting the traditional process. While Fig. 23 and Fig. 24 represent the input and output when selecting the BIM/lean process.

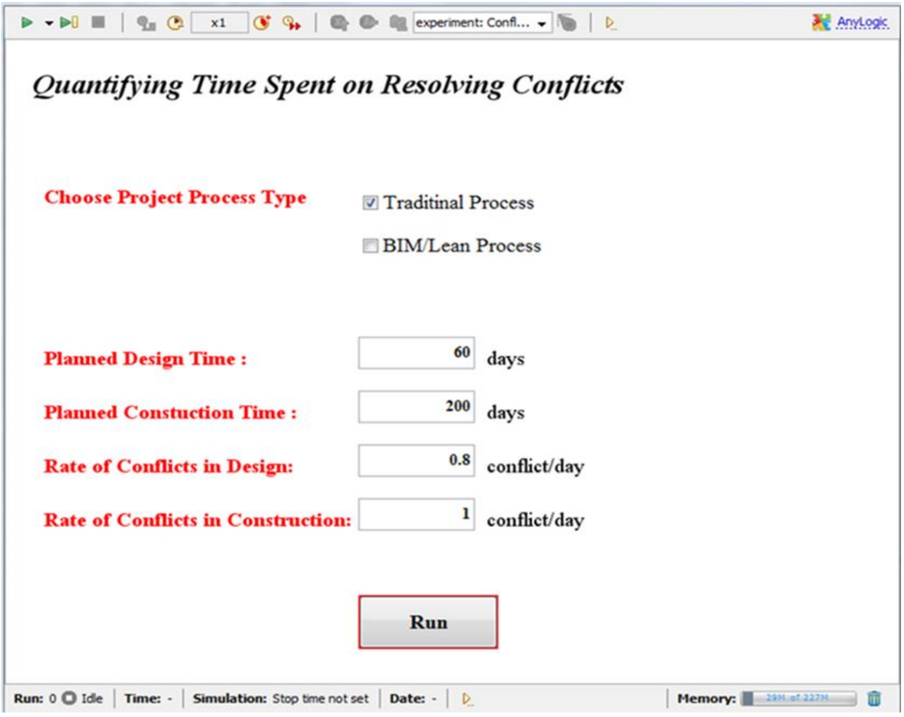


Figure 19: Input to the Model for Traditional Process

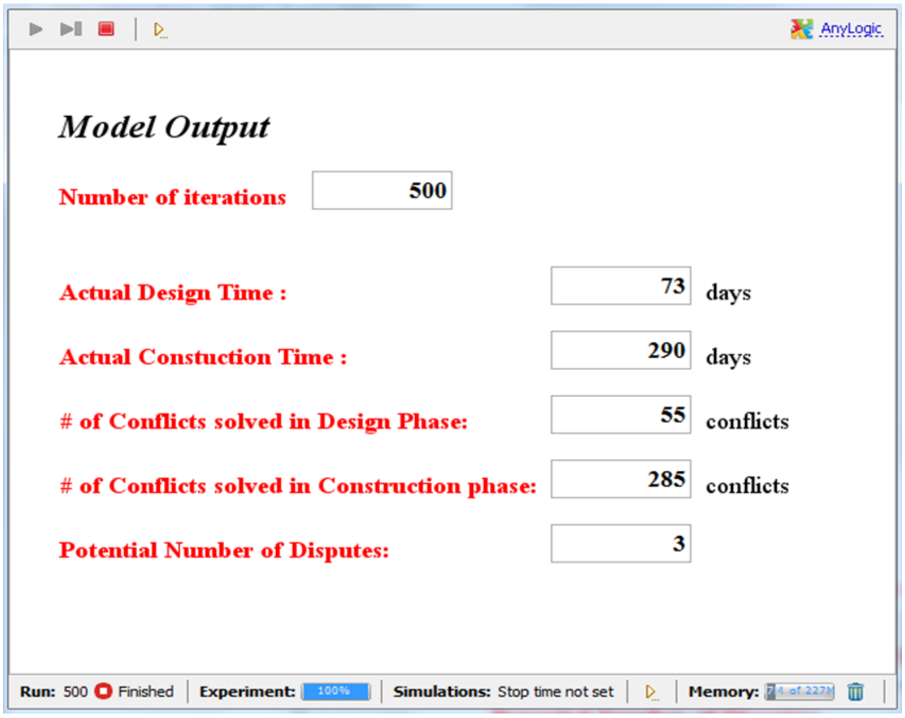


Figure 20: Output of the Model for Traditional Process

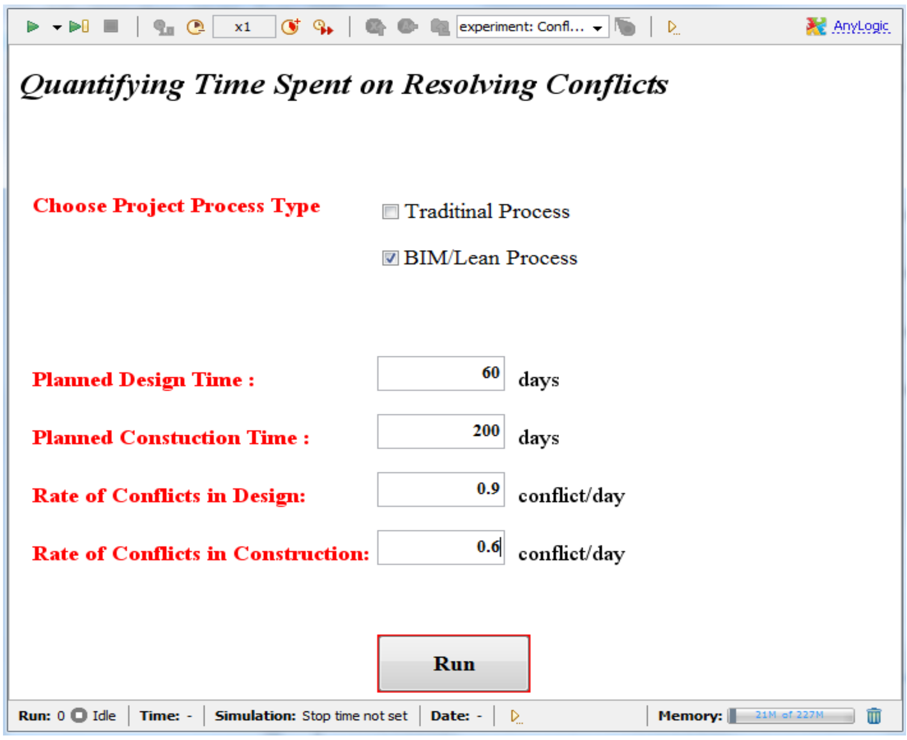


Figure 21: Input to the Model for BIM/Lean Process

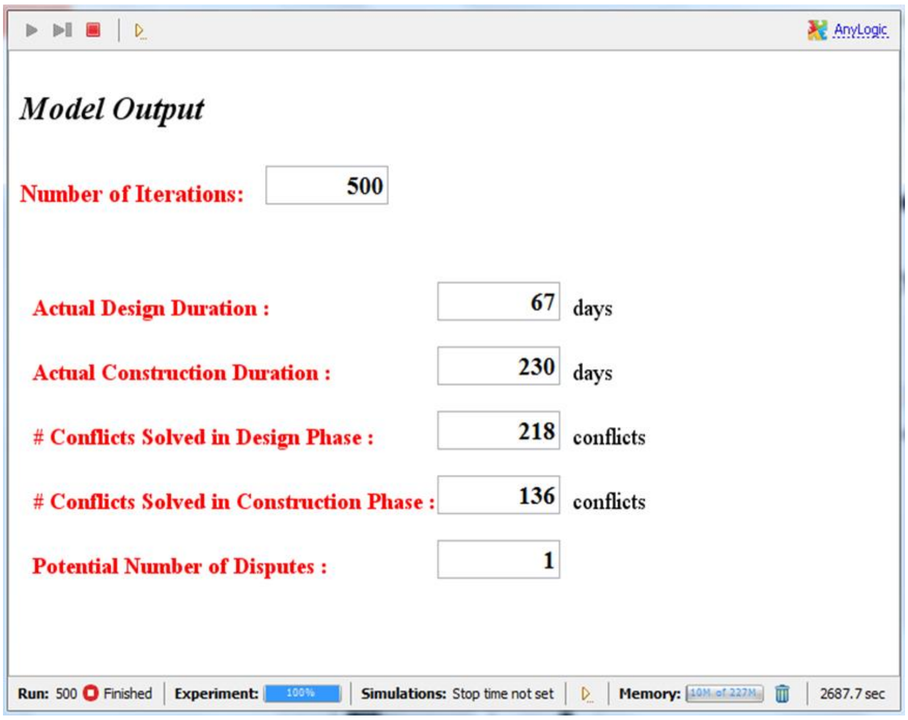


Figure 22: Output to the Model for BIM/Lean Process

The input and output for the two processes are summarized below in Table 7 and Fig. 25. It was assumed that, in both processes, the planned durations were the same.

Table 1: Simulation Results

		Traditional Process (TBP)	**BIM/Lean Process (BBP)**
Input	Planned Design Duration	60 days	
	Planned Construction Duration	200 days	
	Rate of Conflicts in Design	0.8	0.9
	Rate of Conflicts in Construction	1	0.6
Output	Actual Design Duration	73	67
	Actual Construction Duration	290	230
	# of conflicts in Design	55	218
	# of conflicts in Construction	285	136
	Potential number of disputes	3	1

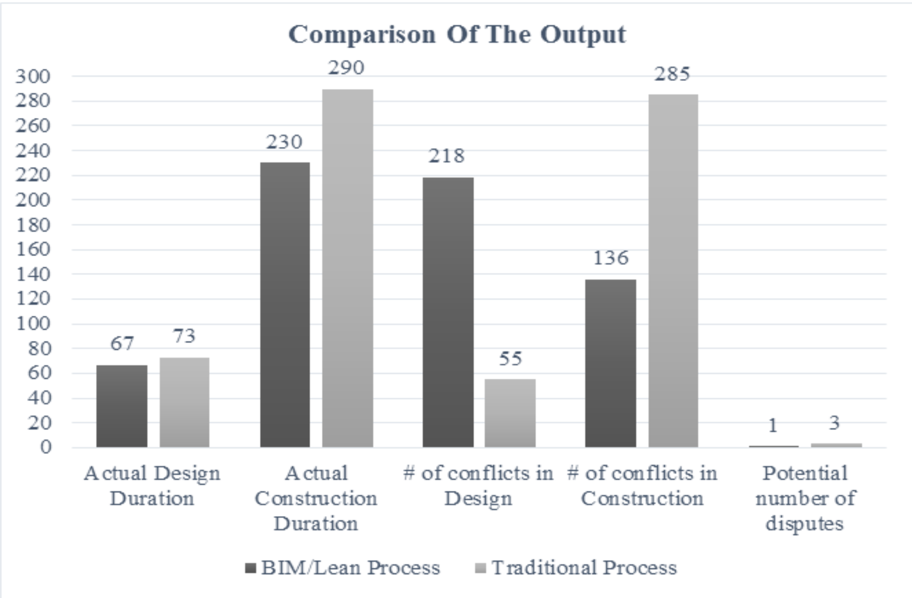


Figure 23: Graph representing the output of the two processes

First, in the design phase, it is important to note that although the number of conflicts resolved is higher in the BBP, yet still the actual duration is shorter compared to TBP. This reflects the effectiveness of time spending on resolving conflicts, which is around 10% from the actual design duration in BBP, while it is higher in TBP (18 %). Regarding the construction phase, the number of conflicts resolved was considerably lower in BBP, this is due to many conflicts being resolved in the design phase, and were thereby avoided in the construction phase.

On the other hand, the time spent in resolving conflicts in the BBP was 13% from the actual construction duration, which is less than the time spent in case of TBP computed at around 30%. In essence, this reflects the fact of the effectiveness of time in BBP where many non-value added tasks that may have been spent on resolving conflicts were avoided.

Comparatively in the traditional process, when resolving the same number of conflicts tackled under BBP before the construction phase, it led to a considerable longer design phase duration. Moreover, since most of the conflicts were resolved in design phases, as done under the BBP, these were avoided in the construction phase where an error costs more. Accordingly, this saved time, and reduced the possible losses and reworking. The difference in the actual duration between the two processes, especially in the construction phase, is due to the higher number of disputes in TBP, which meant taking more time for resolution, leading to more delays. In general, more number of conflicts was expected to escalate in the TBP due to the lower probability for resolving a conflict in TBP earlier on than in BBP.

CHAPTER V

CONCLUSION AND FUTURE RECOMMENDATIONS

A. **Conclusion and Model Applications**

This study presented an agent-based model of conflict management whereby project participants with different characteristics and attitudes work with each other, learn about each other's behavior, and act accordingly to avoid or resolve conflicts. The main advantages of this model over previous ones is that it allows the observation of the conflict management dynamics in traditional and BIM-based projects, the interaction between the different agents, and the emergent conflict avoidance or resolution patterns arising from multiple scenarios. The model performance was then assessed through a case study from China that adopted both traditional and lean approaches. Results highlighted the importance of adopting BIM in reducing time spent on resolving conflicts.

Therefore, it is envisioned that project managers, using the proposed ABM model, can forecast and quantify the time spent on resolving conflicts and the ensuing delays that might occur in a given project. Additionally, project participants can have a mutual understanding of the conflict dynamic systems and can test the effectiveness of BIM/lean practices by simulating and comparing it with the traditional approach, in order to set time contingencies. This number typically represents a percentage of the total project value that is put aside by the owner of the project to deal with unforeseen conditions that might arise during the project. Since a decision regarding which approach to implement during the design and construction of the project is typically undertaken during the planning phase of the project, the project participants need a method to estimate the initial expected time.

On the other hand, as widely attested, “Avoid is better than cure”, therefore avoiding conflicts is much more efficient and less risky than resolving them. In other words, actively controlling or managing conflicts, and using BIM for that purpose, is better than fruitless and late responses. However, it is worth mentioning that BIM is definitely not a magic model that could resolve all sources of conflicts and cope with all the challenges; nevertheless, it can surely mitigate their impact, helps in reducing the pertaining root causes, and be time efficient. Having said that, there are some kinds of conflicts and challenges that BIM has nothing to do with, such as some contractual problems, ambiguous texts, unclear information and specifications, payment delays, late delivery of materials, legal issues, which are all considered to be main sources of disputes in the construction industry. In the same token, BIM at some point could be also source of conflict, especially due to legal and technical issues arising for example from its improper implementation. Moreover, there is a wide spectrum of possible uses of BIM on construction projects. At one extreme, architects and engineers can use BIM simply to produce better quality of design documents without providing the digital model to any other party. Contractors, likewise, can separately create models for estimating, fabricating, or simulating construction without sharing the models. Yet used in such limited ways, BIM does not come close to realizing its full potential. At the other end of the spectrum, BIM can provide a collaborative framework among all project parties, allowing the free-flow of data during the design process and construction phase. Collaborative and constructive use of BIM allows it to be taken full of advantage and yield solid benefits. Therefore, applying BIM alone as a tool and failing to employ it as a lean process does not bring about the desired benefits.

B. Limitations and Future Work

The model presented in this thesis provides a methodology to assist project participants in monitoring the conflict management process during the project lifecycle and determine the time contingency needed to deal with conflicts. While the proposed agent-based model has achieved promising results under different scenarios, it exhibits some limitations and further examination is needed to advance this line of research.

Future work is needed to examine data from real construction projects and obtain information about actual occurrences and average resolving time of conflicts. For instance, although a case study is presented, yet not all the required data necessary to validate the model is available. Therefore, in order to have more accurate and reliable results, a large dataset of construction projects adopting both TBP and BBP approaches should be acquired. Additionally, further work is needed to develop a comprehensive project conflict profile by observing the acquired project dataset. This would allow for the development of a database that could define the statistical process governing the conflict rate on different types of projects. Another limitation of the current model is that the probability of resolution of a given conflict is drawn from a uniform distribution. If the probability generated is greater than 0.5, then the claim is resolved, otherwise it escalates. Therefore, it is suggested that this phenomenon should be studied on real construction projects in order to define an appropriate statistical function needed to determine the different probability values of resolving a conflict. These probabilities can also be obtained from a survey carried out across the construction industry. Furthermore, time or duration needed to resolve different types of conflicts under both TBP and BBP approaches should be better delineated either by acquiring information from real construction projects or case studies or by carrying out quantitative surveys. This model is being developed further to account for the learning curve impact in conflict management according to different types of construction projects. Therefore, it is important to study the learning effect gained after resolution of repeated types of conflicts, and observe how this can affect the rate of resolution. Finally, BIM can assist in avoiding many conflicts on site and speed up solutions; however, it could be at some point a source of conflict especially when not implemented and applied properly. This issue will be addressed in the future by studying the new types of conflicts that BIM might cause, which in turn would affect the rate of conflicts, including the time spent on resolving conflicts.

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