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**THE AMERICAN UNIVERSITY IN CAIRO**

**SCHOOL OF SCIENCES AND ENGINEERING**

# **4D SCHEDULE GENERATION FOR STRUCTURAL FLAT SLAB BIM MODELS**

A thesis submitted to

The department of construction and architectural engineering

In partial fulfillment of the requirements for the degree of

Masters of science in construction management

By:

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Under the supervision of:

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July 2016

## **Dedications**

This work is dedicated to my family, friends and the construction industry. I am extremely grateful to all the students and professors who helped me to be the person i am today and helped me throughout my master's dissertation. Moreover, i am very grateful for wife & my loving parents who never doubted me and kept encouraging me to finish my studies; could not have done it without their support, encouragement, and constant love.

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I also can't forget to thank my grandparents' peace be upon them Dr. Ahmed Hosny and commander Adel Soliman for giving the love and care that made men pursue my dream.

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Leaving the best for last, I would like to thank my wife whom I owe everything for being with me at each step in my dissertation and trying to help in every possible way and her encouragement through this phase, just kept me going.

## Abstract

Planning & scheduling has made some amazing progress in the past 20 years, a period when numerous site engineers felt that utilizing formal planning was unnecessary to everyday operations and a period expending diversion. From that point forward, it has turned into a necessary piece for most projects, yet remains a period consuming, mistake inclined and manually initialized tool. This process is dependent on the method statements and the construction logic that are defined at the beginning of the project which will help in the development of the time schedule of works. Contractors use a set of defined productivity rates for the different construction activities that satisfy the required finish milestones specified by the contract; overcrowding and overmanning are not taken into considerations between labor in the project when selecting the productivity rates for the activities. Moreover, the site management team takes a huge amount of efforts and time to optimize the formwork area available and their reuse in different parts of the project.

This research was divided into three stages; first stage was the collection of data stage which is mainly the interviews stage where interviews were held with about 14 experts. Second stage was the model was developed based on a number of algorithms to develop the time schedule and the cost estimation of a BIM model by minimum user inputs as well as including many parameters that are not being taken into considerations by planners in the contractors or the engineers side. Parameters include: the area of formwork available for construction in m<sup>2</sup>, the reuse of formwork in different zones for cost reduction, crowdedness and overmanning reduction for increase of productivity per crew, automatic zoning of building with relation to the construction joints in a building, optimization of number of crews and their allocation and the enhancement between the area of formwork available for construction and the number of crews.

The model was validated with a case study project where the approved baseline schedule and the used method statement were compared to the model outputs. The results highlight the model's robust features in terms of: generating construction zones that account for the available amount of formwork and their reuse while minimizing the construction cost, optimizing the productivity rate per crew while considering the crowdedness of the job location per construction zone and over all optimizing the construction schedule in terms of

time, cost and generating different method statement through formwork movements. Thus, using this model, a contractor could significantly improve his productivity, effectively generate construction schedules and method statements of a project.

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# Chapter I - Introduction

## 1.1 Construction project planning & Scheduling

Construction project planning is highly dependent on the know-how and the ability of a contractor to select the most efficient construction methods for the different types of activities in a project as well as to provide a proper construction sequence that aims at optimizing the use resources, thus minimizing the construction time, the construction costs and cherishes the construction quality. Prior to preparing a construction plans, some points need to be first addressed [1], including: (1) the general approach in the project, (2) the project breakdown into categories and activities, (3) the dependencies between the different subsections and activities, (4) the logic and sequence of works, (5) a network of the work plan, and (6) project team endorsement.

The outcome of the construction planning process is the establishment of a general method statement of works for the whole project, as well as the development of method statements for each of the major activities in the project.

Scheduling is a tool to predict the project duration of any project. The scheduling calculates the timing of the activities associated in a project and which are identified in the planning phase where it represents the sequence and phasing of the construction activities and the sequence of the subsections that the project was divided into in the planning phase. Moreover, it accounts for the resources available for constructing the project [1].

Scheduling is a very important step for all parties in a project as it defines the critical activities that affect the project duration, which includes the cpm procedure which is in other words the critical path method procedure, which define the activities that if delayed will affect the finish date of the project. The benefits of scheduling process are [1]:

- Providing estimate for the duration of project
- Project monitoring tool
- Cash flow generation
- Coordination between parties involved in the projects
- Resource allocation and demand

The planning and the scheduling processes are prepared through many tools but the most common tools or procedures used in these processes are [1]:

- Narrative of the project (project scope, logic of works, milestones, general method statement) in other words it provides the framework for the project
- Work breakdown structure (wbs) – the tool for breakdown of the project into subcategories to track the project effectively with a defined level of detail.
- Activity durations estimation (which is calculated by the relation between the productivity rates of the crews and the quantities of the elements in the project)
- Resource allocation and number of resources available for construction
- Resource levelling

## 1.2 Workspace and crowdedness

Stacking of trades, overmanning and overcrowding are three different problems that affect greatly the productivity rates of labors in all types of projects. Stacking of trades is the relation between the different trades of resources with the measured workspace needed for each trade to work effectively [2]. Overcrowdings is the increase of all types of trades within a construction zone area and overmanning is the increase in a particular trade to increase its productivity rate per day. In bidding stages, these concepts are not being taken into consideration by contractors and they assume that the work will be performed by very minimum intrusion between trades. The minimization of these concepts can lead to more accurate scheduling and will allow for proper construction process and increase the safety on site[3]. In previous research, the overcrowding of the labor was calculated by taking the increase in personnel in the crews with a defined area zone and dividing it by the total number of crews which will give an indication of the percentage loss in the productivity rates due to overcrowding.

A survey was done by J.ross [4], to identify the causes of staking of trades which are: rework, scope change, acceleration & poor planning. Inappropriate site arrangement and overcrowding cause obstructions in the productivity of labors and they result from the poor site planning of contractors. According to earlier, smith., the workspaces of the trades vary on different types of project and workspaces [6]:

- Main workspaces: defines the areas of each zone in a project and the changes that happen due to the addition of scope of work
- Support workspace: which are the spaces specified for each activity in the project and are not dependent on the progress of works. It includes the pathway space needed in each zone, the area needed for storage of material used in construction of the project and the transfer of the material.
- Object workspaces: which are the permanent spaces allocated to each element in the project which include the size of doors, windows, etc..
- Safety workspaces which is the space required between the trades and personal to ensure their safety.

### 1.3 Utilization of resources (reuse of formwork)

Medium sized contractors' sometimes face the problem of limited resources in the project and need to utilize their resources to be able to fulfil the duration specified in the contract for the construction of a project. One of the approaches in utilizing the limited resources is the reuse of formwork in different zones in the same project.

Reuse of formwork is dependent on the nature and type of project. Reuse of formwork are commonly used in repetitive structures; the different layout will require production of different revisions of the formwork which will be cost consuming and require efforts. Moreover, the reuse of formwork depends on the layout, the flexibility in fabricating the formwork, lifting equipment (cranes, etc..) and the phases defined within a project [8].

The opportunity of reuse of formwork should be considered in all types of projects, however it is much easier in small modular projects where there are no complex structures and requirements, than in larger projects where it depends on the forming system chosen and ties of the form. Other factors that affect the reuse of formwork, in particular plywood formwork and its efficiency are [9]:

- Edge protection
- Early planning
- Storage
- Vibration

- Workmen attitudes,
- Workmen efficiency
- Dismantling process of formwork

A formwork plan should be established from early stages in the project taking into account the use and reuse of formwork and their movements within the project whether between buildings or zones. To be able to prepare the formwork plan for a building, there are steps that can be taken into consideration [9]:

- 1- Find the largest area of Slab in the project that will need the greatest placement or number of forms to be used which will identify the sizes of the forms that need to be used and finally prepare a list of all the forms that are going to be used in this part.
- 2- Check for the possibility of using the form sizes used in the previous step and prepare other two lists; one for the form sizes that will not be modified when put for use in another location and the forms that will be subject to minor modifications.
- 3- Forms available from other parts can be used in case of modifications
- 4- Identification of the number of forms needed to complete the remaining placements.
- 5- A form flow diagram should be established based on the forms available and the logic of the construction work.
- 6- Moreover, a flow diagram for the placement will be helpful to show the constrains due to logic more clearly.

#### 1.4 Labor resources usage

The most efficient usage of resources available need to be studied in each and every construction project. Planners always assume that the resources are available while doing the time calculations for a project [10]. The demands of the resources are dependent on the activities that work simultaneously; at the duration of each project, there is always a peak demand for the resources which may not be desirable at some parts of the project. This can be very costly for the contractors as the hiring of skilled workers are expensive and very hard to find whilst they do not need them at this part of the project [11].

A uniform resource allocation is desirable in the construction project and to implement this a modification in the scheduling of some activities need to be established by utilizing their floats. A graph relating resources with time is very useful in construction projects.

The intermittent activities, the type of activities that can be broken and rescheduled at a later stage, are the activities which can be used to achieve the uniform resourcing process; the other type of activities which is the continuous ones, are very difficult to handle to achieve uniform resources and when started cannot stop till it finishes [12].

In case of limitation in labor resources, some scheduling of activities need to be modified to accommodate this type of constrain. The activities that need the same resources can be adjusted in consecutive or serialized methods to overcome this limitation, which might affect the float of the project and this might cause delay in the completion date of the project [13].

### **1.5 Automated construction scheduling**

Several research efforts were examining how to speed up the procedure of scheduling through automatic generation of activities, estimation of durations and identifying the schedule logic automatically. However, many of these endeavors require considerable manual information including that of the physical model. Scheduling is still being made by planners manually which is very time consuming as it is hard to link between the time scheduling software and the BIM applications [29].

BIM software provide very useful information that may assist in the generation of the time schedules which will result in significant saving of time [29].

Research has confirmed the possibility of integrating and developing schedules for construction projects by using the BIM technologies.

Current scheduling tools require the manual translation of design information to activities and typically do not provide dynamic links between cost estimates and corresponding schedules. To take advantage of the increasingly electronic and object-based descriptions of designs, schedules, and estimates, integration mechanisms that translate design descriptions into schedule and cost views of projects are needed. Moreover, construction projects are becoming progressively larger and more complex in terms of physical size and cost. Building

information modeling (BIM) is being regarded as a revolutionary change for managing the entire lifecycle of a construction project [29].

## 1.6 Problem statement

When preparing construction schedules, contractors use a set of defined productivity rates for the different construction activities that satisfy the required finish milestones specified by the contract. Contractors do not take into their considerations the overcrowding between labor in the project when selecting the productivity rates for the activities; instead, an estimate for the number to be used to achieve the wanted productivity rates. Moreover, the optimization of the formwork area available and their reuse in different parts of the project takes a huge amount of time and efforts by the site management team to develop options for the decision makers to choose from.

## 1.7 Research objectives

The global objective of this research is to develop a model that automatically generates different alternatives of construction time schedules and cost plans for structural BIM models by optimizing: (1) the number of construction crews available, and (2) the available amount and types of formwork systems that will be used and reused throughout the construction process while respecting the construction logic between the structural components in the BIM project; (3) the crowdedness of the job site including the maximum number of crews per construction zone.

## 1.8 Scope of work

The scope of work of this research is limited to the planning and scheduling of concrete & structural works for projects using BIM. The model works with columns and slabs components and breakdown the activities of each component into formwork fixation, steel fixing, concrete casting and dismantling of formwork; other types of structural components are excluded from the scope of work of this research.

The thesis is also limited to BIM models which have a uniform grid of columns and rectangular shaped flat slab buildings. Lastly, the types of formwork that can be chosen by the user is either traditional formwork or early strike.

Figure 1 shows the scope of work

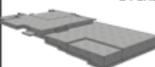
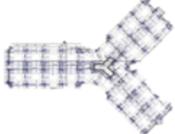
Scope of Work	Rectangular Structural Model	Elements	Activities	Types of Form	Grid of Col.
Included		 Columns	 Rein.	 Traditional Form	
		 Slabs	 Form.		
		 Cores	 Pouring	 Early Strike	
Excluded		 Foundations	Other activities ( Insulation, finishing, etc..)	Other types o formwork ( Slip Form, table form, Glass induced form)	

Figure 1: Scope of Work

## 1.9 Research methodology

To fulfil the objectives of this research, the work in the thesis is divided into three stages:

### 1.9.1 Literature Review

The review of literature in BIM developments & the uses of BIM in 4d scheduling, the previous researches on overcrowdings and workspace identification, zoning reasons and their scheduling process and previous researches regarding automated construction scheduling needed were acquired.

### 1.9.2 The collection of data stage:

The specifics and the knowledge of the works sequencing, planning and scheduling, zoning, crowdedness and cost estimation of the construction projects were collected through interviewing experts in the construction field from different parties, some from the engineer's

& contractor's side to discover the different approaches in preparing the time schedule of the project. The results of the interviews can be summarized as follows:

- There are two types of sequences that must be taken into consideration;
  - Within each zone
  - Between zones
- Types of formwork frequently used are the traditional type of formwork and the early strike ones
- Zoning is sought in the following cases:
  - When there are large areas of slab in the project and it is difficult for the concrete crew to pour them at the same time.
  - Limited labor resources
  - Limited area of formwork
- Lags between the steel fixation and formwork are dependent on the productivity rates of the formwork crew and the steel reinforcement crew.
- Staking of trades, overcrowding and overmanning are factors that affect the productivity of the labor
- Workspace for each personnel need to be identified and taken into consideration.

### 1.9.3 The model development & verification stage:

A model is developed through an induced BIM environment software that enhances the inputted user data and collected data from the interviews. The parameters that the model respects, implements and enhances are:

- Optimization of formwork areas and suggesting zones
- Trying to use the formwork reuse method
- Not exceeding amount of formwork available
- Avoiding crowdedness and overmanning inside each zone
- Respecting the logic of the construction sequence
- Cost estimation for material and labor
- Time schedule generation that can be imported into ms project

A total of 8 algorithms has been done to accommodate the above parameters and to make the model establish an interface easy for the user to read and they are verified using a Pilot project of two story building Model on Revit.

#### 1.9.4 Case study and validation

Validation of the developed algorithms and model using an actual case study to compare the outputs from each algorithm and highlight their features and efficiency.

Figure 2 below explains the research methodology

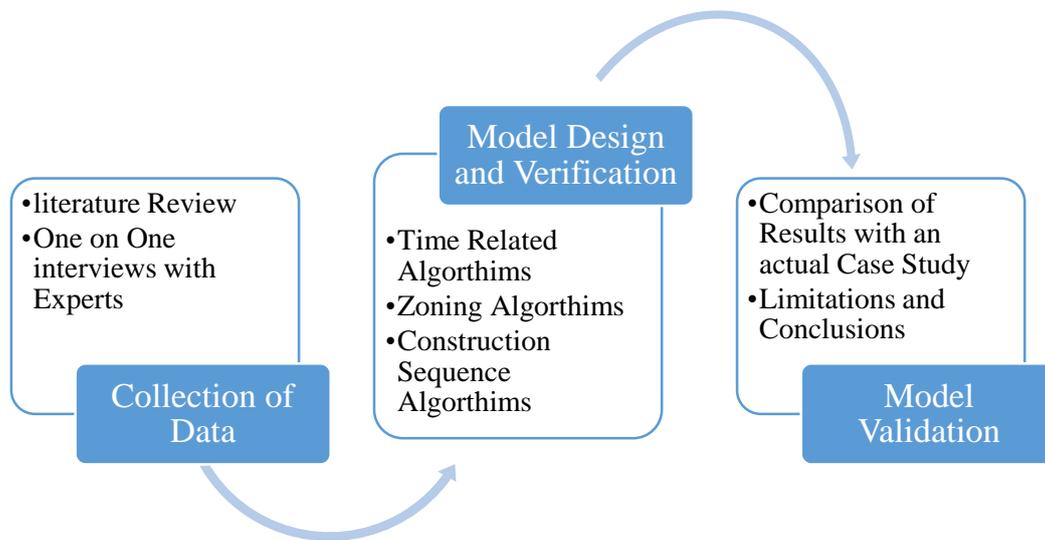


Figure 2: Research Methodology

#### 1.10 Thesis organization

This thesis is organized into 5 chapters as follows;

Chapter 1 – introduction: provides a general introduction on sequencing and planning, overcrowding of labor and its effects on productivity, effect of limited number of crews in the project and finally the effect of the limited resources in particular the formwork and the steps to reuse the formwork and its benefits. Moreover, it Provides the problem statement and the methodology used to develop the model.

Chapter 2 – literature review: provides an in-depth review of literature in BIM developments the uses of BIM in 4d scheduling, previous researches on overcrowdings and workspace

identification and zoning reasons and their scheduling process and previous researches regarding automated construction scheduling.

Chapter 3 – model development: discusses in details the collecting of data phase followed by the conclusions that were conducted from the interviews and then discusses in detail what each algorithm does and a flow chart is presented for each parameter identified in the model.

Chapter 4 – cases study and validation: the model is tested on an actual case study to validate the outcomes extracted from the model with the outcomes that were done normally in any project and these are compared in a table to highlight the features of the model.

Chapter 5 – conclusions and recommendations: concludes the research and provides recommendations for future research.

## Chapter 2 - Literature Review

### 2.1 BIM role in construction projects

This section gives an overview on building information modeling (BIM) and its role from a construction management point of view. First, BIM is defined and broken down into main principles highlighting its significance to the field. The uses of BIM in terms of productivity and tools are also discussed from a construction management perspective. Finally, advantages, disadvantages and cost are highlighted to conclude this section.

#### 2.1.1 What is BIM?

According to the national BIM standards, building information modeling is defined as "a digital representation of physical and functional characteristics of a facility and 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. Hence, the building information model is a three dimensional digital representation of a building and its parameters. It is made of a series of intelligent building components that include detailed data, attributes and parametric rules for each object in the model. The outcome is not only numeric, but a full representation of the model with all its coordinates, allowing the user to browse through the model from different views and meanwhile saving a lot of time. [14] in other words, building information modeling can be described a process of practicing virtual reality of a design and construction throughout its lifecycle. Allowing more than one participant to share and communicate knowledge digitally and have access to the model [14].

The idea that BIM software have a built-in ability to produce 3d models caused a great change in the practice of traditionally executing 2d drawings. Here, 2d drawings are individually produced with all the layers needed, such as structural and mep drawings. After the completion of those design documents, a 3d model can be generated to allow 3d shots and walkthroughs, helping the user to visualize a design. This process can be very expensive and time consuming compared to the parallel practice that BIM provides, using the 2d and 3d at once [15].

### 2.1.2 Moving from 3d to 4d and 5d

BIM models come in a three dimensional format and have an ability of exploring a 4<sup>th</sup> dimension. That is, projects can be modelled in the digital environment, revealing all possible conflicts with the schedule. The fourth dimension, therefore, allows users to instantly detect clashes and plan for them in advance. Additionally, the fifth dimension includes the financial aspect of the project. Like all project components, cost estimates for materials, labor and all construction related aspects can be linked to the model. With any change, pricing is automatically affected, such as in the case of finding a better bid. Accordingly, a life cycle costing is immediately apparent to the owner, who is now capable of projecting matters such as cost savings and operational costs over lifetime of a building [16].

### 2.1.3 4d scheduling sequence

Figure 3 shows The Generated Process of the 4D Scheduling Using BIM.

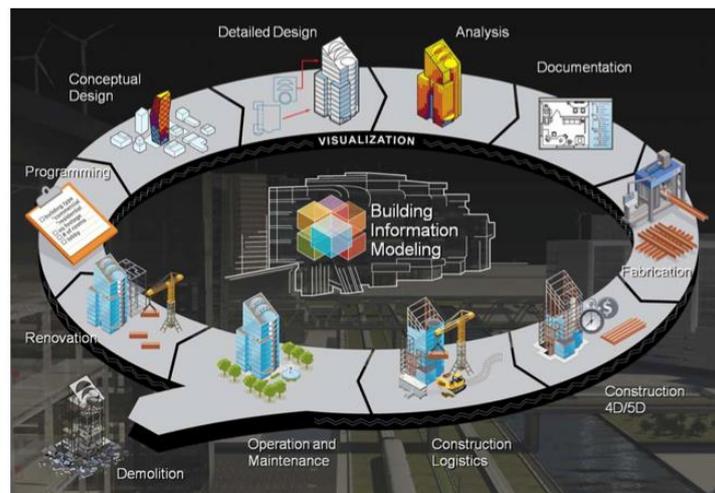


Figure 3: 4d scheduling BIM [16]

Identifying the perfect sequence to accomplish the job may sound quite straight forward, however the different aspects of a project, environmental aspects, labor and many other issues have to be taken into consideration and they make everything more complicated. Fortunately, BIM software can be put in use and ease the process using methods such as 4d scheduling. One of software frequently used is navis works. Figure 4 shows the typical sequence in using BIM.

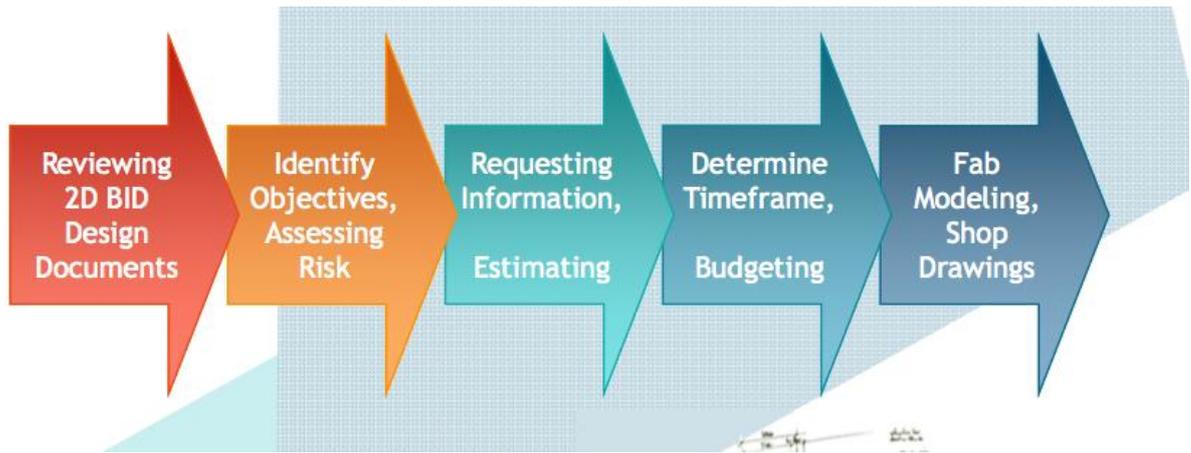


Figure 4: sequence of process for using BIM [16]

As previously mentioned, construction sequence can be quite complicated, and planners need to take more than one aspect into consideration all at the same time. Decisions are being made to get the best outcome with the most suitable budget and in the shortest duration required. A planner, therefore, needs to have good knowledge of the different assets and resources at hand, and most importantly when to use what.

#### 2.1.3.1 Navis works :

A tool that simulates construction logistics and schedules in 4d to analyze activities within a certain project and, then, communicate with other teams. This helps in reduction of delays and sequencing problems that may arise during project execution. It validates the viability of the project through sequencing development by linking geometry model and dates in order to have a dynamic connection between project models and schedules [16].

## 2.2 Model optimization parameters

This section will discuss in more depth aspects of consideration to better demonstrate the process of the parameters chosen for optimization in the model. Formwork reuse, labor and their workspace are highly significant in every project. Calculations have to be made to make sure crowdedness of labor on site is in control and a high level of productivity is maintained.

### 2.2.1 Construction planning

An overview is given on the uses of BIM throughout the processes of scheduling, workspace calculations, construction sequence, zoning on site and the variation of framework to be used.

Before elaborating on the specific processes potentially carried out in the management of a construction project, the focus needs to be shifted to an earlier step, which is decision-making. In order for the project to proceed and tasks to follow, every step needs to be primarily planned for first. That is, construction planning takes place prior to taking action.

Construction planning is essentially the division of work tasks in a certain time frame. It involves making a lot of project-related decisions such as the choice of technology, sorting out and assigning work tasks, estimating the resources required and the durations necessary for the tasks to follow. Additionally, a key role of the planner is identifying the interactions needed among different work tasks. In other words, a construction planner needs to develop a framework for the budget, schedule of work and communication required among work parties to get the job done. There are different ways to perform this mission depending on the case of the project and its circumstances. It is very common to start off with *cost control*, making it easier for a project to be divided according to cost category. In other words, a planner identifies categories of expenditure through the distinction between costs acquired directly in the performance of a work task and, on the other hand, costs that are indirectly incurred for completing the project [17].

Another way to proceed, would be starting off with *schedule control*. That is, shifting focus onto the scheduling work tasks over a specified period of time. In that case, planners are required to concentrate on the organization of work tasks in order. Here, for instance, *construction sequence* comes in handy. This will be further explained later. To conclude, construction planning is all about weighing the different aspects of a project and its

circumstances, and plan it out based on cost or schedule in coordination with available resources or (in more complex projects) integrating both to accomplish the project. Figure 5 shows the general concept of construction planning.

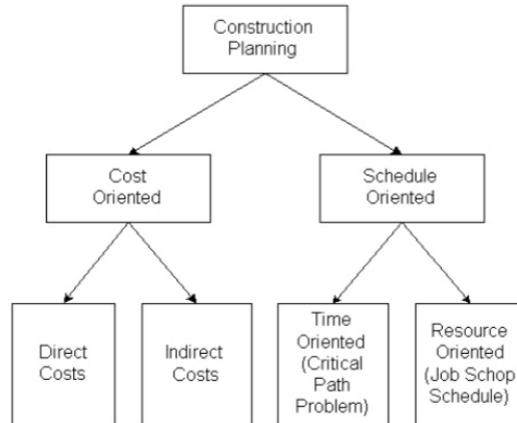


Figure 5: construction planning [17]

### 2.2.2 Construction sequence

As previously mentioned, one of the first jobs a planner performs is identifying work tasks of a project and its activities. Once that is done, relationships between activities are drawn to identify precedence and ensure they are taking place in a certain sequence. Figure 6 shows an example of construction sequence for a pilot project [18].

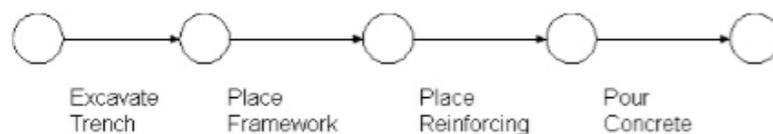


Figure 6: example of construction sequence [18]

Sometimes precedence can be more complicated, when an activity needs time to start (i.e concrete might need time to cure before formwork is removed). This is called lag, it's a restricting condition that will control organization of precedence. There are plenty of BIM software's that can be worked with to deal these situations. However, a few mistakes should be avoided:

- Activities can't be organized in a cycle, so that one depends on the other in a continuous manner, this will result in an impossible plan to be accomplished. Figure 8 shows an example of an impossible work plan [18].

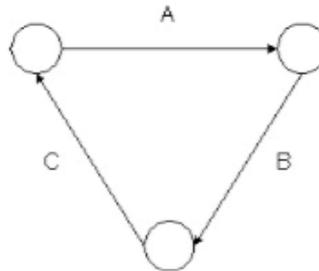


Figure 7: example of an impossible work plan[18]

- Forgetting one important precedence relationship along the way. This can happen and many times it requires high cost and time to fix this issue. Sometimes planners use simulations to check errors like these and eliminate them.
- It is important to remember that there are different types of precedence. Some that are technically necessary, others that cannot be performed without the process of a certain activity, and some that are based on implicit decisions. Such as cost related decisions or equipment availability, for instance.

### 2.2.3 Workspace demand

Clients are usually forcing contractors to deliver project in the least amount of duration, which leads the contractor to make lots of activities work concurrently with each other which will make him need to use more resources and thus the project needs more control. Most of the contractors do this step without prior planning for the workspace demand by the labor. According to research, the conflict in workspaces between labors cause a decreased productivity rate as well as clashes between space & time that will affect the duration of the project negatively. It has been documented in some projects that the effect of the workspace clashes may result to forty percent reduction in productivity of crews [19].

Any required space around any building element to allow the fulfillment of the tasks for this element is defined as the workspace i.e. It is a non-visible volume in the building needed for execution of works. [19]

There are many variables that effect the work space of the crew; first of all the shape and size of the element, duration of the activity and the productivity rate of the crew, direction of construction and starting point, the method statement for the element and the size of crew and composition, amount of material storage [20]. Figure 8 shows a work space based on size of the element.

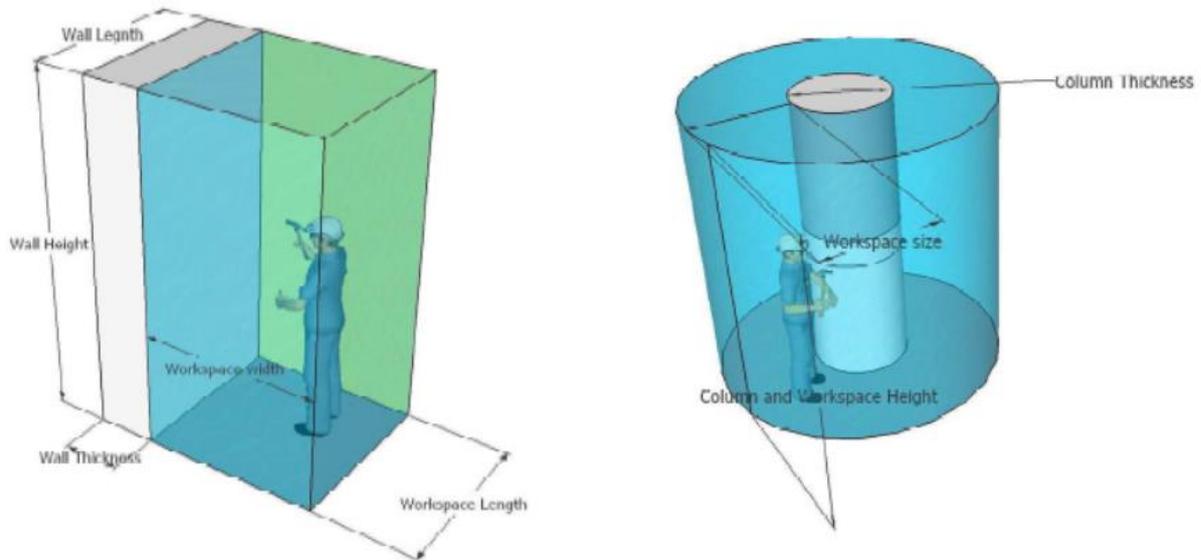


Figure 8: Work Space Based On the Size of The Element [21]

Figure9 shows a workspace based on direction of construction chosen by the contractor

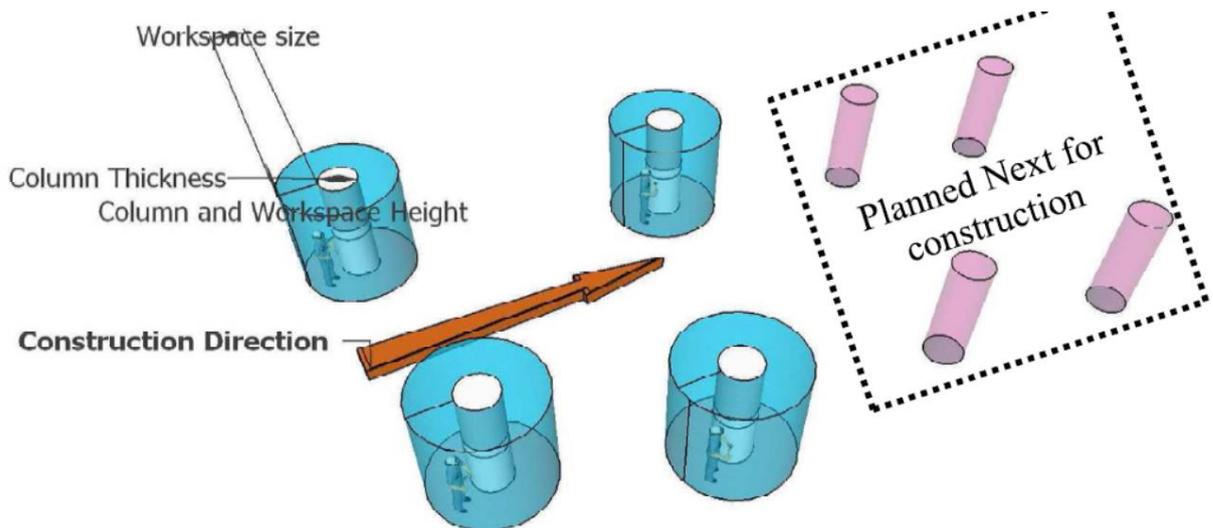


Figure 9: Workspace Based On Direction Of Construction [21]

#### 2.2.4 Formwork usage

The number of forms available on site for construction is a very important step that need to be taken into consideration in the planning stage. The factors that affect the formwork reuse are the measuring the areas that they will work on, cycle time of each form set, type of formwork, method of stripping the formwork, nature of construction (if repetitive it will be much easier to reuse the formwork, complex shapes will need custom formwork to be designed and cut each reuse) [22].

In a traditional formwork system, there are no specific rules for reusing of formwork, the number of sets of formwork are defined according to the area available to cover a floor or a region. [22]

The number of labor crews that are regularly involved in this procedure are the formwork and steel fixing crews as well as the pouring crew. The number of crews available will affect the movement and re-usage of the formwork throughout the project and they must be taken into consideration while developing a formwork plan for the movement of the sets within the project [22].

There are various types of formwork that can be reused.[23]:

- Wood formwork: which is a combination of plywood and lumber, (limited reuses)
- Steel and aluminum formwork is used as they provide longer spans and they have a high capability of reusing.
- Fiber reinforced polymer (frp) which is a glass induced formwork, its advantages is that the material is very light weight and is used regularly in complex of concrete structures. Moreover, it requires very little effort to disassemble and it has a high capability for reusing.

Moreover, the reuse of formwork need some care of the labor while stripping the formwork and storing it to use in another part. The material need to be handled carefully and avoidance of dropping the propping is very important. The formwork need to be checked for any defects or curves before reusing it in another place as this can affect the final appearance of the concrete structure [23]. According to researchers, the reuse of formwork is very cost saving

as the formwork material constitutes a good amount of the construction cost of the structure around 10%. According to JR, the formwork materials cost will drop by 40% after five reuses of formwork in different areas [23].

## 2.3 Section iii

The next section will discuss in more depth, the aspects of the automated construction scheduling using the BIM techniques and the previous researches and outcomes of such method.

### 2.3.1 Automated construction scheduling

There are two types of automated construction scheduling case based/knowledge based type and the model based type. Some examples of each type are

#### 2.3.1.1 Case-based reasoning and knowledge-based approaches

It was Mikulakova [24] et al. Who suggested the development and evaluation of automated BIM schedules through a “knowledge-based approach”. Throughout their research, the use of ifc (industry foundation classes) interface, which provides building component data, made it possible to integrate project constraints as well. Constraints help in further visualizing construction conditions and all related problems. Here with, construction processes are obtained and can generate an automated schedule that is presented in a cad environment with the aid of IFC software interfaces.

Navinchandra et al. [25], at 1980s developed a model where their input was a set and activities and their output was these set of activities with their predecessors or in other words their sequence of work which respected a set of basic physics and rules in the construction industry defined by them. Then Benjamin et al [30] developed a model that was designed to generate time schedules by helping the planners to develop the relationships between the activities and develop the WBS by representing the method of the professional’s decision making.

Muñoz-Avila [26] developed a CBR (case based reasoning) planning algorithm model which generated schedules for projects based upon past cases. In 2003, they modified their model by creating an environment that planners can modify the time schedule or choose & edit from

the database a past project which can be re-used in the preparation of time schedule process which decreased the irregularity between the different cases. The model choose the cases used in the previous plans and re-used them to generate a brand new plan. Konig [27] did similar approach as Munoz-Avila but by using the feature logic generic language along with the CBRR to develop time schedules for projects with respecting the present constrains.

There were many trials of automated scheduling long before BIM technology was discovered. It was Gorostiza et al. Who linked cad software to construction schedules by implementing knowledge-based systems. However, data extraction still remained a challenge, despite the improved level of productivity that the research had brought to the table. It was Fischer and Aalami who took this research a step further to generate activities and their sequence with the aid of construction method templates: CMMT (customizable construction model templates) by putting together an elaborate sequence of activities. As a result, activities could be performed and presented with the different levels of desired details, yet still a lot of manual input was required. [24]

Recently, more attempts were made to extract information from 3d cad models or BIM in order to generate automated schedules. Tulke and Hanff performed an attempt of using element quantities in the BIM model resulting into a schedule of tasks using productivity rates. The objective of their work is to use this technique to generate a 4d process rather than just a schedule creation. This was further developed by karaoke, who took the concept of using simple 3d models to develop quantity take offs, schedules as well as 4d visualizations with the help of a split (interpretable template system). This system turns simple building geometry into possible building construction configurations by applying construction methods. This method focuses on constructing different possible framing systems and comparing schedules instead of generating the schedules for a BIM design.[24]

Then, a more developed version was proposed by Tauscher et al. That generates semi-automated schedules based on data extracted from the model by using IFC (industry foundation classes) standards. They had to use case-based reasoning (CBR) to locate task durations with the aid of comparing similar cases. Unfortunately, the research did not elaborate on outputs of this proposed method. [24]

David k.h. Chua, t.q. Nguyen, k.w. Yeoh [28]

Chua, Nguyen and Yeoh argue in their paper that functional requirements are one of the most important factors that direct the sequencing logics of a schedule. These are the fundamentals of the functional dependencies amongst components in construction and completion. Automatic reasoning from the functional requirements to be implemented into sequencing logics is recently challenging in the planning process. The paper introduces a model called FREMAS – functional requirement model for automatic sequencing. It is an attempt to automate scheduling and sequencing from functional requirements. The model provides a representation schema as well as systematic reasoning framework to reason and convert the functional requirements into temporary constraints between the schedule elements. The model is implemented in eclipse. FREMAS determines possible sequences automatically and, then, produces all schedule alternatives satisfying all construction constraints. The model helps in improving the efficiency of the planning process.

Figure 10 below explain the schematic of FREMAS implementation.

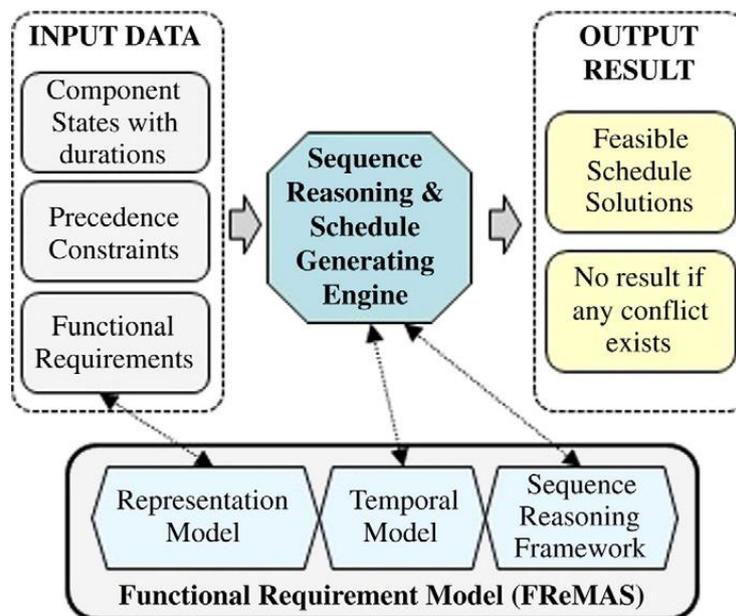


Figure 10: fremas model [28]

Fremas produces a representation and reasoning framework to derive possible sequences automatically and generating schedules that take into consideration the imposed construction requirements. Capturing complicated functional requirements that are entered by multiple users with various functionality types is one of the most important benefits of fremas. This makes it easier to produce several alternative schedules giving more engineering solutions to be discovered pre-scheduling. Currently, fremas analysis is performed on individual component level yet it could be further extended to be applied to aggregated components that represent sub-systems. This is necessary for hierarchical planning of larger scale projects to assist in reduction of problem size and control of detail degree of the produced schedules. [28]

### **2.3.1.2 Model based approaches**

Martin a. Fischer & Florian Aalami [29]

Fischer explains computer-interpretable models for representing construction models as one model including designs, schedules and estimates to convert design descriptions into schedules and costs. There are no present mechanisms that are able to dynamically link construction plans to schedule information. There are five attributes that define any construction design: constituting activities, domain, activity sequencing, resource requirements and constituting objects. The produced model assist owners, contractors and architects in evaluating cost and schedule implications that may arise from designs and simulate different alternative designs to figure out the best option that can be used[29].

Fischer's tool simply matches construction methods with higher level activities. Activities are linked to the building components and scheduling starts after the user produces a high-level activity. The building components with assigned activities are elaborated at the desired detail level producing a plan. Fischer's tool links the input with applicable templates giving the user several applicable options to choose from. This defines lower level activities and their components. The tool also provides sequencing and resource library as shown in figure 11 showing schematic of the algorithm used for planning [29]

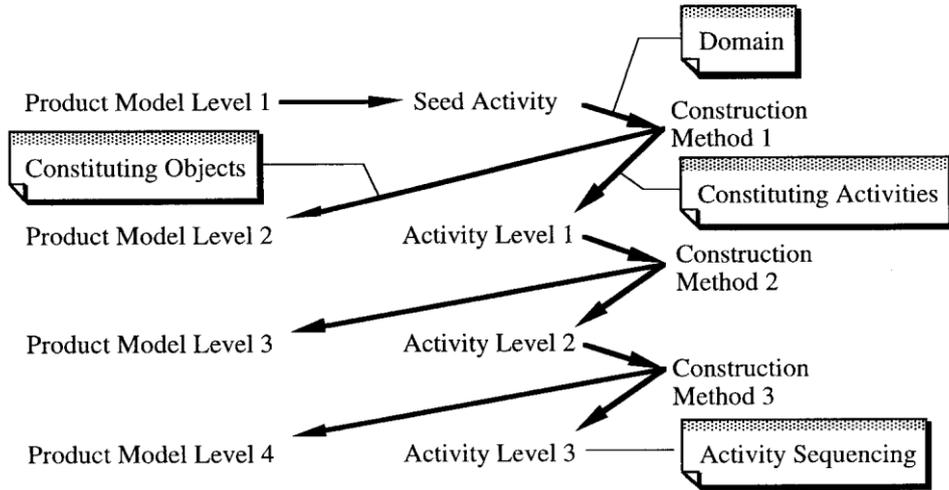


Figure 11: fichers approach[29]

This process can be refined with more details that can be input by the user to create more sophisticated models. Afterwards, the five attributes of construction method should be applied. Figure 12 below is an example of how the five attributes could be implemented in the model.

**Construction Method Definition:**

(Name (Domain: activities)  
 (Constituting activities: activities)  
 (Activity sequencing: component-constrained, activity-constrained)  
 (Constituting objects: objects)  
 (Resource requirements: labor, material, equipment))

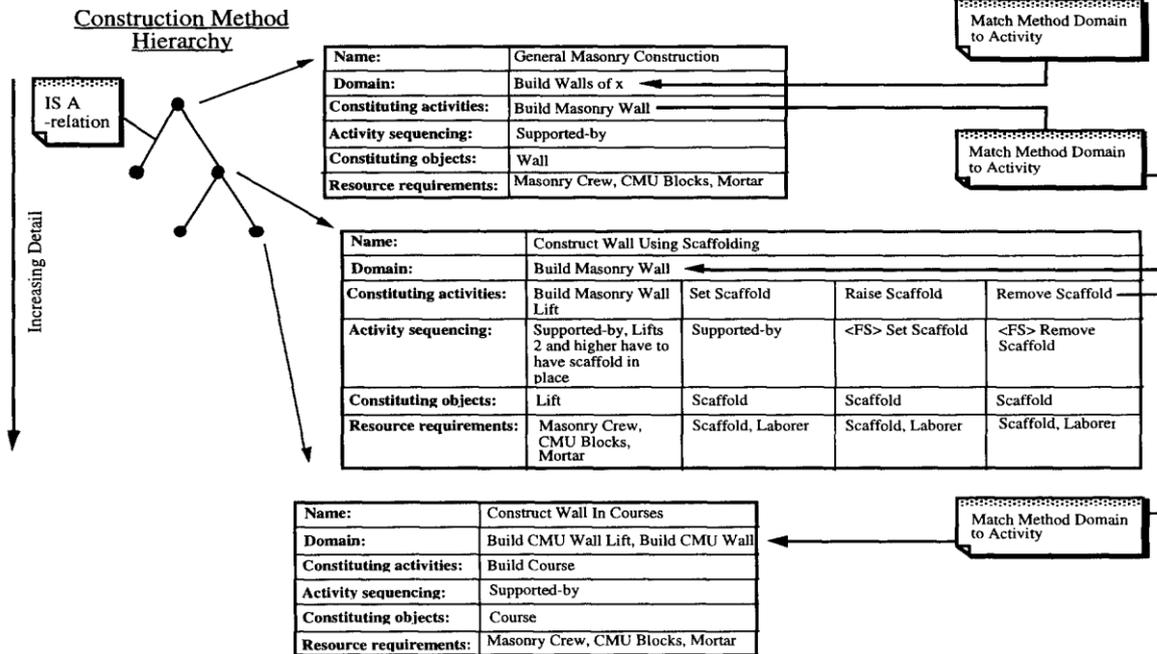


Figure 12: five attributes[29]

The concept of the five attributes of construction design acts as a template to enrich the knowledge of the whole process. Knowledge can be presented at different levels of details for every attribute to exemplify a certain scheduler's approach to a project. Best practices for each attribute can be used to build libraries to be reused for similar projects which save scheduling time for recurrent projects.

The paper presents a tool that assumes the tool user to be the decision maker of construction methods. There were observations that more project managers are getting more involved in project schedule generation and maintenance since 1992. This trend is believed to be continuing as long as there are ongoing improvements to the technology. The tool provides schedule generation during early stages when there is only schematic product model available and, then, refined with more project details as the process goes on. The scheduler can add models at desired details level. With projects' conditions changing, Fischer's tool can

accommodate such changes with schedule assumptions to adjust the schedule with efficiency. [29]

### Firat[30]

Firat [30] developed\_a model that initiates a master time schedule by introducing three modules that were based on three objectives as shown in the following table.

Table 1: modules and objectives [30]

Module	Objective
Building construction information module (bcim)	Design
Building construction process module (bcpm)	Activity
Building product module (bpm)	Resource

Then firat [30] used the alob method (location based line of balance) to extract the quantity takeoff along with alob to generate the scheduling process but it needed manual input from a professional of detailed information to be completed.

### Vriesa and harink [31]

Vriesa and harink [31] developed an algorithm that pulls out the sequence of construction from a 3d model by choosing the objects from downward to upward and detect the intersection between the elements. Moreover, in the model based alternative, there were other methods like developing construction method templates for automation of construction schedules, rule based spatial reasoning for constructing the logical relationships between the elements in BIM model [31].

### **2.3.1.3 Knowledge based & model based approach**

#### Mikulakove[24]

In their study, Mikulakova et al. Raised awareness to the importance of construction-process planning and how unfortunate it is to not take it into consideration. Construction- planning is indeed a process that requires multiple stages and the involvement of many participants. Stages of the process start from planning to build up until project realization, which makes it

very difficult to avoid errors and inaccuracies, especially when following a schedule that will include so many attributes. This is when it is clear that, errors are inevitable especially when schedules are manually developed, due to insufficient information and complexity of task planning. On another note, if it were to be precise, manual schedules are not flexible for change, which is why usually one construction process is being chosen and proceeded with regardless of what comes along the way. Additionally, manual schedules seem to highly affect productivity, as project managers need to waste a lot of resources to generate new schedules for repeated or similar processes carried out for the realization of the project. One more drawback, and a very significant one, would be the absence of sharing and linking information among project teams. This is why, Mikulakova et al. [24] suggest the implementation of a knowledge-based approach to generate automated schedules that will have increasing flexibility in terms of updates and modifications. Moreover, using a decision-support system will decrease the possibility of occurring errors and allow for an evaluation of construction-planning alternatives with all relevant factors prior to realization of planning stages.

Therefore, Mikulakova et al. Suggested using BIM in the development and evaluation of automated schedules through a “knowledge-based approach”, resulting in a 4d model. Throughout their research, the use of ifc (industry foundation classes) interface, which provides building component data, made it possible to integrate project constraints as well. Constraints help in further visualizing construction conditions and all related problems. Here with, construction processes are obtained and can generate an automated schedule that is presented in a cad environment with the aid of ifc software interfaces.

#### Konig and habenicht [27]

##### Interdependencies between activities

When simulation approaches started being implemented more increasingly in order to support construction scheduling, multiple ways of planning data had to be taken into consideration. Now planning data were to be analyzed and well-integrated into the system to get closer to reality and have suitable simulations for building projects. That is, simulations now required a rich set of data starting with a building information model, bill of quantities, framework schedules, delivery dates and available resources. However, coming up with the most

efficient specifications for a realistic and valid set of interdependencies between construction activities formed a great challenge. This step has proven to be error-prone and changes here would only mean extensive modification, no matter how small they were. This is when Koning and Habernicht suggested proposed a storing concept for construction interdependencies between activities. Konig and Habenicht [27] suggested further development in this area by automatically assigning process patterns and defining activities to result in construction operation simulation with regard to constraints. By linking several models and adding quantity take offs, it is possible to develop schedules as well as construction simulations as an output.

Wang et al [32]

#### Linking multiple models and modules

According to Wang et al, the system proposed gathers, stores and transfers data among various linked models presenting a proposed framework consisting of the following: a BIM model, duration estimation interface module (DEI), operation simulation, project schedules and 4d presentation.

Firstly, the BIM model can be established using Autodesk Revit architecture, which allows an input of geometric data such as length, width and height of each one of the building components to result in material quantity take offs. This, of course is only a sample of quantity take offs, as not all materials can be calculated from a BIM model. Yet, BIM models will allow links and access to other software permitting more accuracy [32].

Secondly, and very importantly come the duration estimation which is the core of this system and responsible for its operation by providing specific durations to work tasks. This stage is subdivided into three functions: it starts with an input of the construction conditions consisting of task productivity values such as kg/man-hour for steel work and sq.m/man-hour of formwork, number of workers with their payment policy in terms of overtime and hours of work, and the number of equipment resources (i.e cranes). The second function in this stage is the activation of operations simulation. Here, a great regard is given to the durations in three different cases for each work task; meaning, the use of a hypothetical set of optimistic durations, most likely and pessimistic durations. This helps the simulation become closer to

reality. Finally, during this stage, simulation results are used to generate a project schedule. When speaking of a simulation, it refers to 1000 simulation runs that are transferred to an excel file, which is formatted so that it can be read by MS project for further scheduling analyses [32].

Then, the system uses simulations to figure out project difficulties and point out uncertainties that may cause problems in stages of the construction process. This evaluation influences productivity of construction tasks and clashes among resources. Finally, the system is completed by generating results and site-level simulations, permitting users to produce site-level schedules. Users can benefit the most out of this system and generate more sophisticated schedules, when activities are grouped into activity milestones. Figure 13 shows a schematic for Wang’s model.

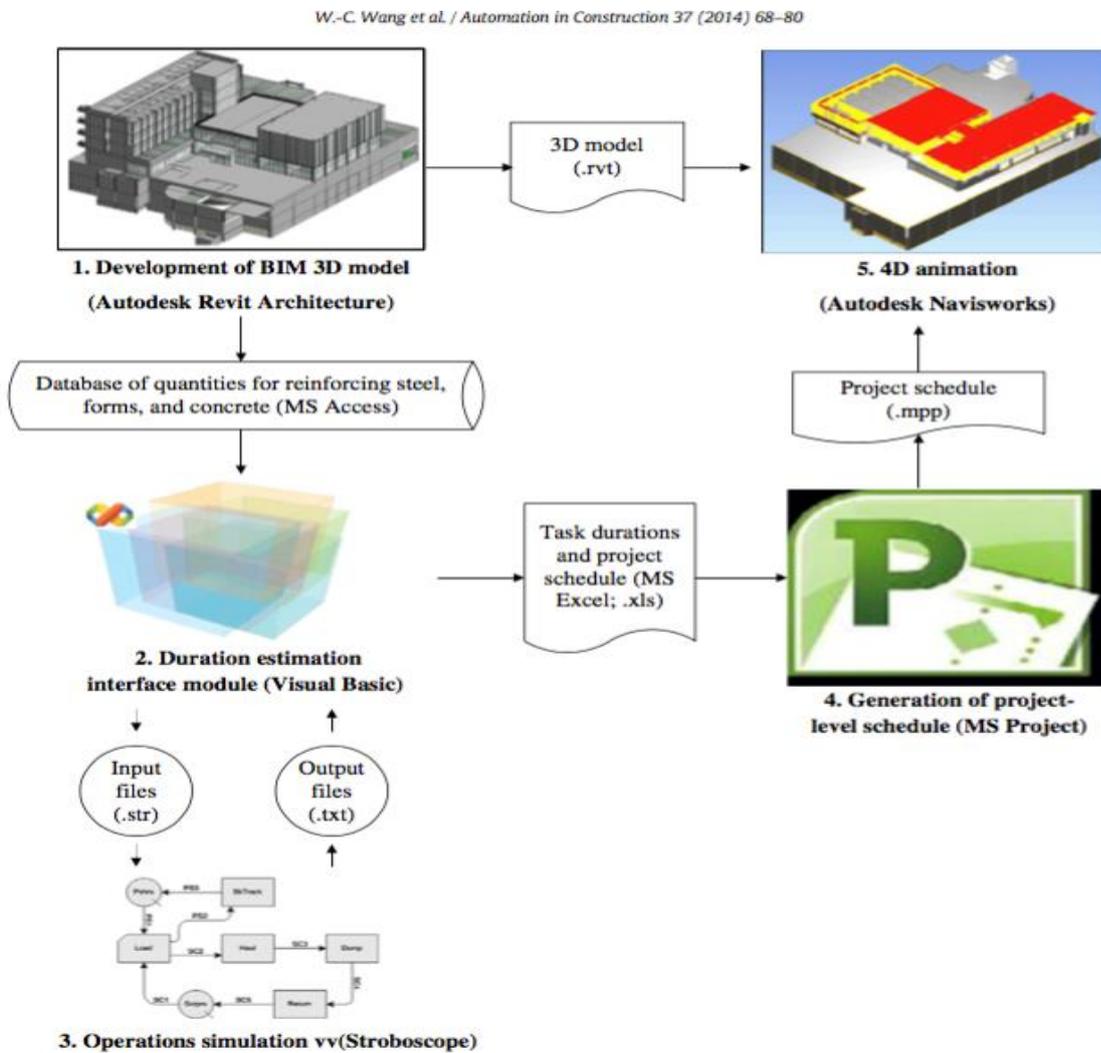


Figure 13: Wang's Model [32]

Akinci, Fischer and Kunz argue in their paper that workspace planning involve representing different types of spaces required by construction activities in 3d dimensions and across time. The fact that schedules contains hundreds of activities needing multiple types of spaces makes it almost impossible to carry out the planning manually to produce 4d work space presentation. In Akinci, Fischer and Kunz present mechanism that are able to produce project specific workspaces automatically. Workspaces are represented in this model as relevant to construction activities and methods while having attributes describing when, where and how long they are present and how much volume is occupied. This space-loaded production modelling enables a more rich 4d cad simulations, proactive planning and time-space conflict analysis prior to construction [33].

Figure 14 below represents the proposed model implemented by the researchers.

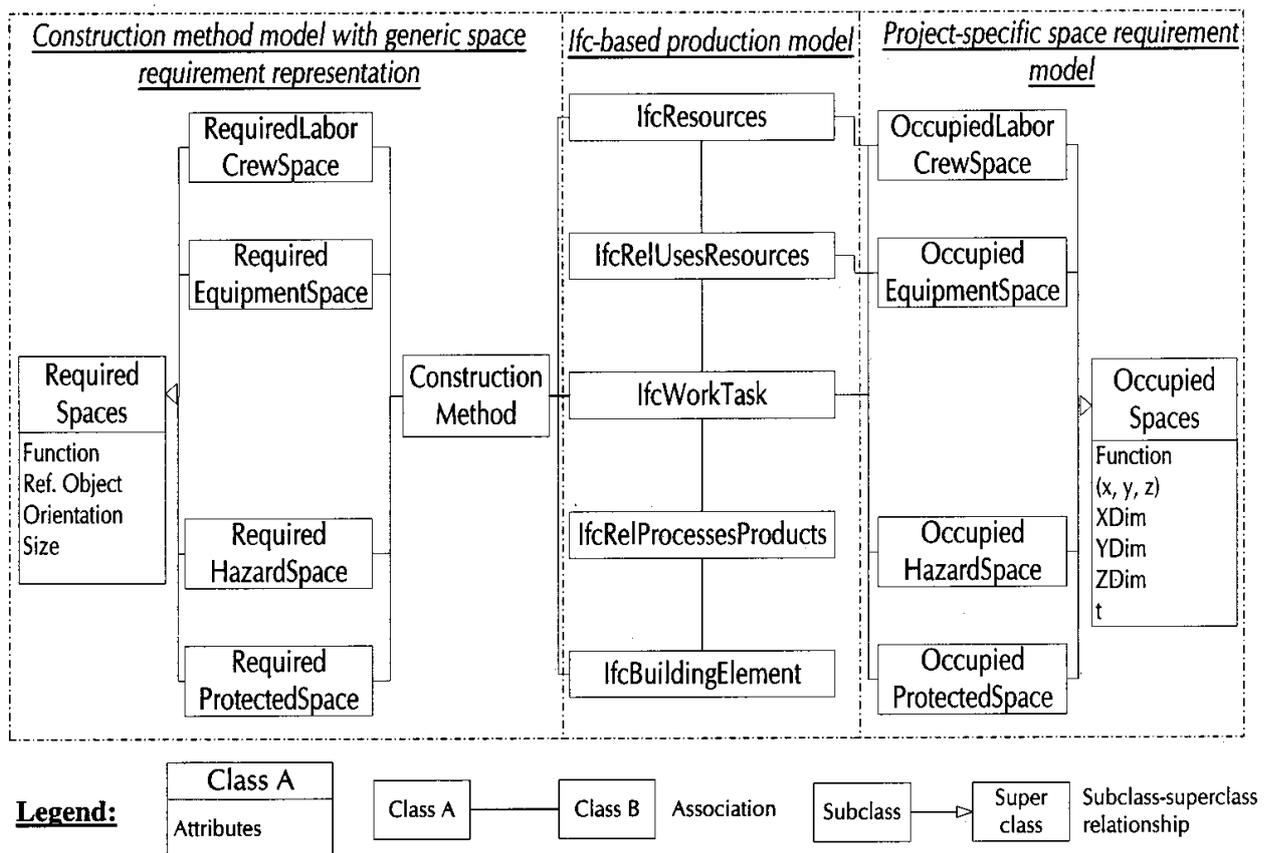


Figure 14: model proposed by akinci et al[33]

The model provides project-specific activity space prerequisites automatically by interpreting space descriptions along with using 4d production model information. Construction superintendents define required space in relation with construction methods planned to be used. Space definition represents the position of every space qualitatively as being introduced with respect to an object that is taken as a reference. The aim of the space generation mechanisms is to interpret the descriptions in order to produce a 4d model. The generation of computer-interpretable representation of construction information allows the development of reasoning mechanisms in order to automate certain tasks such as production and maintenance of workspaces which is almost impossible to be executed manually. Mechanisms implemented within the proposed model are general enough to analyze the predefined set of size and orientation requirements for the production of the four types of workspaces. Generated workspaces represent occupied spaces realistically by the corresponding activities held at the construction sites. Automated system used reduces the input data amount by the user enabling the user to visualize usage of the site space as well as detection of potential conflicts between activities [33].

#### **2.3.1.4 Genetic algorithm**

The third type that was used in the automated generation of time schedules was through genetic algorithms. The first researcher to try it was Davis [40] for optimizing scheduling process in 1980s.

Throughout the years, researchers kept using the ga method in the automation process of time schedules through:

- Schedule generation by limited resources was developed by wall [24] with more than 300 activities and 3 to 10 types of resources.
- Chan et al [24] developed a model that levels the resources to establish a more optimized time schedules.
- Toklu [[24] defined a model that automatically generates the relationships between activities by developing a set of equations to calculate the ss, fs, sf, ff of the activities

- Jaśkowski and Sobotka [24] developed a system that takes the relationship between activities, available resources and requirements for each activity and automatically produce time schedules.
- Time and cost optimization models were developed by Feng et al.[24] & Zheng et al. [24] during the process of developing the time schedule for the projects by using the weights allocation methods for each element.
- Azaron et al [24] developed a model linked between pert method to optimize the time schedule whose objectives was to minimize the cost of the project, the variance of duration & the mean of the project duration

One of the bright researches was presented in *implementing genetic algorithm (GA) was Faghihi paper [34]*

After highlighting the significance of construction scheduling, Faghihi draws attention to the use of genetic algorithm to generate construction-planning schedules as well as optimize different project aspects such financials, resources and on-site movements. The implementation of GA calculations comes from BIM data, which is built into the model. The extraction of 3d model information and project data is what generates construction schedules, which are eventually put in comparison using pareto frontier graphs, 4d simulations and a scores system to find the most preferable construction schedule. Here, Faghihi's objective is to create an algorithm that generates automated and optimized schedules using a 3d model, and additionally, test the proposed outcome from the algorithm to see whether or not construction schedules are in fact feasible. To do so, Faghihi starts off by developing a project network from the 3d model by listing all the elements the model consists of, which can be realized using the IFC file format. [34]. Figure 15 shows sample IFC definitions for beams and columns.

```

#143
= IFCCOLUMN('2ed437SVDCI8RyHuUeaHBs', #42, 'W – Wide Flange
– Column: W10X49: W10X49: 161188', $, 'W10X49', #142, #139, '161188');

#375 = IFCBEAM('2ed437SVDCI8RyHuUeaH5r', #42, 'W
– Wide Flange: W12X26: W12X26: 161319', $, 'W
– Wide Flange: W12X26: 116116', #297, #374, '161319');

```

Figure 15: sample IFC definitions for beams and columns[34]

The algorithm would now be capable of using extracted data to calculate all related spatial information. Using predefined stability rules, MOCC (matrix of constructability constraints) can be generated in matrix format, representing the project network by itself using DSM(directed adjacency matrix) characteristics. Figure 16 shows Faghigi's proposed BIM project network. The newly generated project network is further developed using timed sequencing of construction operations and installations, which is an optimization tool for solving scheduling problems.

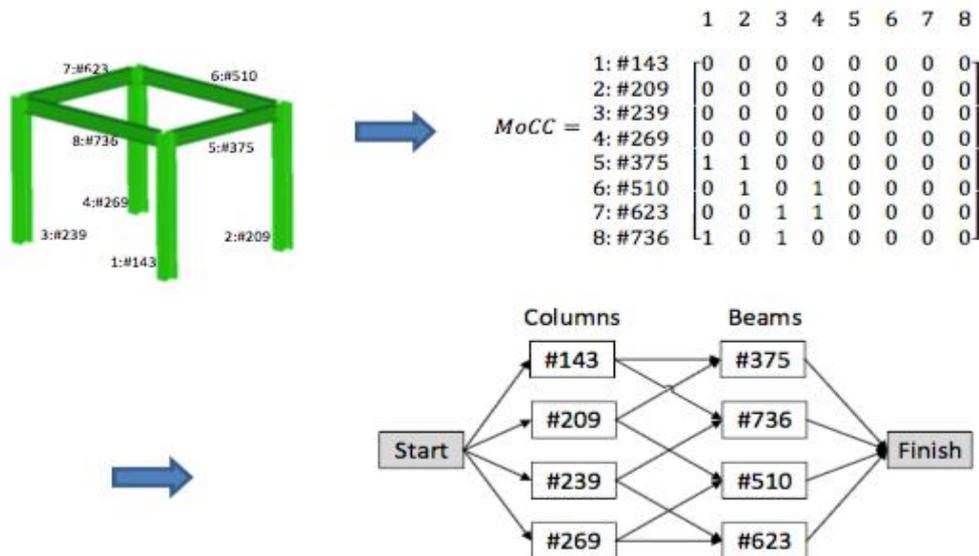


Figure 16: faghigi's proposed BIM project network[34]

## **Chapter 3 – Collection of Data (interviews)**

### **3.1 Sampling**

The purpose of this stage was to collect information regarding many fields in the construction scheduling and cost estimation of models. One on one interviews were carried on with several experts in the construction industry to benefit from their experience; the number of experts that were interviewed were 13 experts from the construction industry. The sampling were based on years of experience of different experts and their work environment i.e do they work with the contractor or the engineer to get a diverse views of time scheduling and cost estimation.

### **3.2 Sessions**

The interview sessions were semi structured interviews, where a list of questions was prepared and given to the interviewee to answer and then an open discussion was held at the end of each session. The time for each interview was about 20 minutes and they were conducted at different dates, depending on the availability of the experts.

### **3.3 Areas discussed in the interviews**

#### **3.3.1 Structural sequence of works**

Experts were asked of the construction sequence of works for the structural components in the building in particular cores, slabs and columns with their associated activities and the relation between them (formwork, steel fixation and concrete pouring). Moreover, the relation between each floor with the other and whether their work can be concurrently or not.

#### **3.3.2 Effect of available formwork area and its effect on sequence of works.**

The effect of the area of formwork available for use on the sequence of works and what are the different approaches they take to avoid stoppage of works if the formwork area is not enough for the building.

### **3.3.3 Usage of different types of formwork and its effect on sequence of works.**

Types of formwork used and their effects on the construction sequence as this is a major indicator in the time schedule preparation to decide which zones can start with each other due to the formwork type.

### **3.3.4 Crowdedness of labor and its effects**

The effects of the crowdedness of labor on productivity; and the space needed for each personnel according to each trade.

### **3.3.5 Sample composition of crews for structural works**

A table was handed to the interviewees to ask them what are the sample composition of a formwork crew, steel fixation crew and concrete pouring crew for cores, columns and slabs & their associated production rates/day.

### **3.3.6 Zoning types and reasons**

Reasons why contractors seek zoning and how they manage the concurrent working in different zones.

### **3.3.7 Lags in the construction sequence**

The lags between the start to start activities in the construction schedule and how it is calculated and on what basis.

### **3.3.8 Schedule of cost and prices of materials, crews price/day**

A table was given to the interviewees to add the cost and price of material in market and the cost of each crew used in the structural construction of the building per trade.

### **3.3.9 Area of formwork usage in the absence of construction joints**

What contractors do in case they don't have area of formwork available less than the area of the slab.

Table 1 shows the interviewees used for the collection of data stage with their year of experiences and the side they are on (contractor or engineer side).

#	Experts	Years of experience
1	Project manager	20+
2	Project manager	30+
3	Planning manager	15+
4	Site manager	10+
5	Planning manager	12+
6	Project manager	8+
7	Planning manager	8+
8	Site manager	10+
9	Planning engineer	5+
10	Site engineer	7+
11	Planning manager	12+
12	Site manager	8+
13	Planning manager	8+

Table 2: collection of data stage

### 3.3.10 Outcomes of the interviews and results:

- There are two types of sequences that must be taken into consideration;
  - Within each zone: the regular activities within the structural schedule of each zone are: formwork, steel reinforcement, pouring, dismantling for columns and slabs.
  - Between zones: sequence between zones are dependent on the number of crews available & quantity of formwork available in m<sup>2</sup>.
- Types of formwork frequently used are the traditional type of formwork and the early strike ones; where in case of traditional it is usually used per floor and early strike can be used in two floors concurrently.
- A database was developed for the composition of the crews and their associated productivity rates for use in the model.
- Schedule of cost for materials used and crews available was developed for cost estimation
- Zoning is sought when there are large areas of slab in the project and it is difficult for the concrete crew to pour them at the same time so basically their pouring joints and location need to be respected and by this they define the zone.
- The main activities that incorporate the structural Component scheduling are formwork, steel fixation, pouring of concrete & dismantling for slabs, columns and cores.
- Lags between the steel fixation and formwork are dependent on the productivity rates of the formwork crew and the steel reinforcement crew; for example, if the formwork crew productivity rates are 3 m<sup>2</sup>/day and the steel reinforcement are 1.5m<sup>2</sup>/day. Then the lag will be calculated accordingly.
- Crowdedness between trades and labor on site decrease the efficiency of labors and decrease their productivity rates; however, contractors in Egypt do not respect this issue despite its effect. Moreover, it is a major issue in construction industry these days as they do not only affect the productivity of the workers but also their safety as well.

- A database for the space needed for each personnel for each crew was concluded from the interviewees to be able to calculate the maximum crew allowed to work for each element per each zone.
- According to the Egyptian code, the formwork has to stop at the span of the zone + 0.25 the span of the adjacent zone for it to be able to withhold the loads.

## Chapter 4 - Model Development

The developed model is composed of three modules; (1) inputs module, (2) engine module, (3) output module, where each module is built on a number of sub modules as shown in the figure 17.

- 1- The inputs module: consists of (6) sub modules, (1) a native BIM project designed for the purpose of possible zoning at later stages, (2) start point for the construction to start, (3) type of formwork to be used, (4) desired time of completion or number of resources available per trade, (5) start date of the project, (6) start point.
- 2- The engine module: consists of (8) sub modules; (1) zoning algorithm module to define each zone already according to the area of formwork available implanted in the BIM model, (2) crowdedness algorithm module, (3) construction duration algorithm to calculate the duration of activities in the time schedule, (4) time and date calculation per zone algorithm to link the start date of the project with the duration defined for each activity, (5) construction sequence algorithm to link the activities within each zone and among the zones, (6) cost estimation algorithm that calculates expected cost of the project, (7) time scheduling algorithms linking the activities among the different zones to calculate the total project duration, (8) Quantity take off algorithm.
- 3- The output module: which consists of (4) sub modules, (1) options for detailed time schedule for structural construction activities with their dependencies. (2) total duration of the project, (3) number of crews used through the project in construction of the project, (4) options for cash flow for the projects.

Used tools: the BIM environment used in the development of the model was autodesk® revit® & an add-in implement in revit; dynamo® which is a compiler for the visual programming language as designscript® .

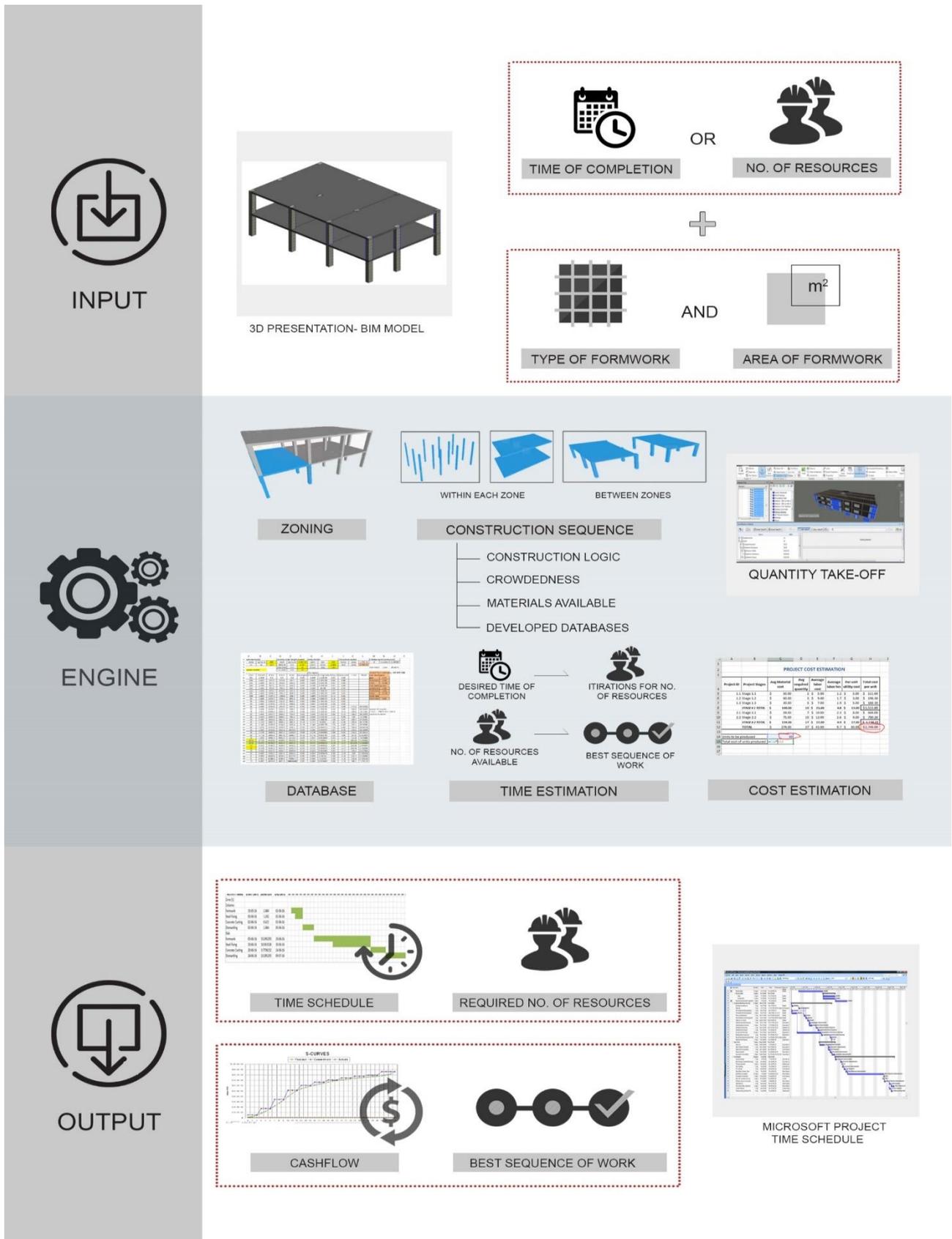


Figure 17: Framework of thesis

## 4.1 Model working principle

The model working principle (figure 18) of the thesis starts with the user inputs the BIM model, number of crews available per trade (a) or the desired time of completion (b) and type of formwork available with optional area in m2 for construction through excel interface forms. The algorithms in the model start by translating the user inputs into the used BIM environment and applies the specific calculations for the outputs to generate.

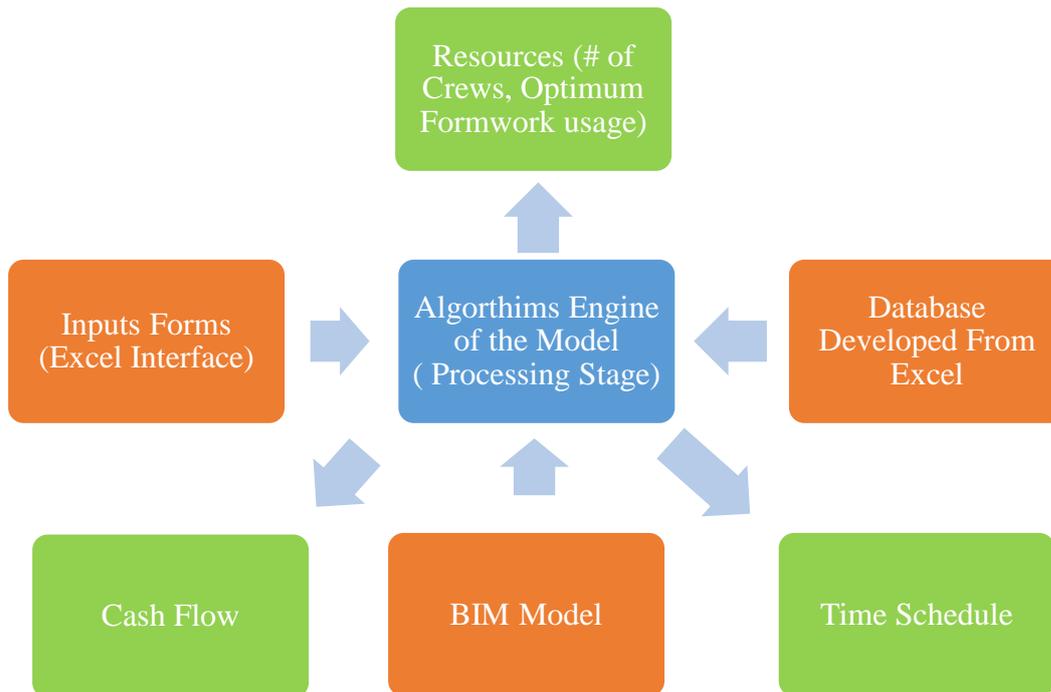


Figure 18: working principle

First, the minimum area of formwork is identified through the formwork optimization algorithm where it is dependent on the maximum span between two adjacent columns in both directions plus the 0.25 of area of the adjacent span according to the egyptian code of practice.

Then, the BIM model is translated into different areas through the zoning algorithm (1) that first generates by getting each element per level of the model and then the model projects the columns to reach the slabs and then the intersection of the slabs, columns and cores (if available) are then translated into areas according to the different spans identified between

each two adjacent columns in the model plus 0.25 from the adjacent areas in both directions and starting from the specified corner by the user.

The zoning also is dependent on the optimum formwork area where comparisons between the areas of the slabs and the area of formwork that is chosen by the model and check what are the applicable areas or combinations areas to check which areas can be combined to specify the zones ( area of slab < area of formwork) implanted in the excel interface by the user. If the area of formwork is not specified by the user, the model starts by trying the different areas of formwork defined in the model and keeps generating time schedules till it reaches the time span specified by the user.

The crowdedness algorithm (2) along with the zoning process starts by processing a developed database collected from interviews with experts and processes the database of the number of personnel in the user inputted crews to calculate the max crew that can work in each zone.

The construction sequence algorithm (5) takes place with each area of formwork chosen by the model and with each zoning approach, the algorithm starts processing the data to implement the construction sequence among activities in the same zone and among the zones with each other, the model checks the areas that are near to the 1st area specified that starts from the specified corner by the user and then checks the largest area between both adjacent zones and then prioritize them than the other areas, if they are applicable i.e less than the area of formwork available. If none of the areas can start with the area 1 then the model starts comparing with other areas in the model to check which models area are applicable to work in and can start along with the 1<sup>st</sup> area. Then it checks the # of crews available and if it is possible to work in more than one zone at the same time. Then it assigns to each zone a number of crews for the activities in the zone adjusting the productivity rates according to the developed database collected from previous research. A check is made to link the area of formwork available and the number of crews inputted in the model by the user to detect for the user whether all the number of crews available can work within the specified area of formwork for usage in construction. After the maximum crews per zone is specified, the model runs another check to identify if it possible for the maximum number of crew to work in one zone according to the space demand database and the sequence and distribution of

crews are defined automatically in the model. After these steps, it develops a list with the sequence of zones to start.

The sequence of activities inside each zone is designed in accordance to the standard practices in construction activities and logic sequence.

Construction duration algorithm (3) then takes place to calculate the duration per each activity in the model by linking a developed database of the productivity rates for each crew per trade and the quantities that are calculated automatically in the BIM model. These durations are then linked to the start date of the project through another algorithm to generate a list of activities with the start date, duration and end date of the activity.

Finally, the zones are then linked to each other by the duration parameter through the last algorithm (4) to give the end product of the time schedule developed.

At the same time an algorithm (6) for the cost estimation links a developed database with the activities incorporated in the model to establish a cash flow that takes into account the cost of the crew for each trade and the cost of the material used.

## 4.2 User inputs:

### 4.2.1 BIM structural model:

This model works on BIM structural models only; in particular columns, slabs and cores of buildings as shown in figure 19.

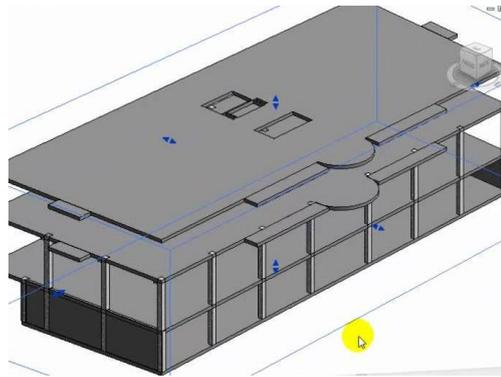


Figure 19: Samples of BIM Structural Models

### 4.2.2 Type of formwork to be used:

The type of formwork that can be inputted in the model are traditional formwork and early strike formwork. The model follows the following criteria in case of the chosen type of formwork: -

- 1- In case of traditional formwork, the formwork crew can't work at two zones at the same locations at two floors simultaneously; only one floor is operational till the floor slab is completed and it has to finish at least one of the zones to be able to go to the next level. (figure 21)
- 2- In case of early strike, two zones in two floors can work simultaneously (figure 20)



Figure 21: In case of traditional Formwork

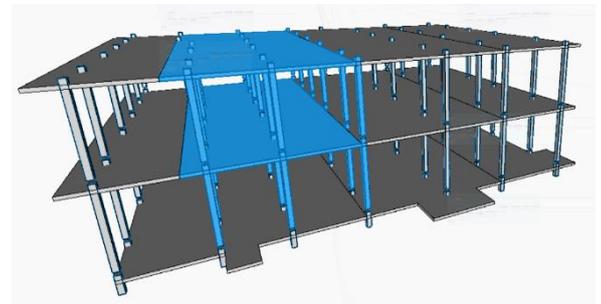


Figure 20: In case of Early Strike Formwork

#### 4.2.3 **Start date:**

The user has to input the desired start date that the time schedule will be based upon.

#### 4.2.4 **Specified corner of start:**

The user has to input the desired corner of the slab that he wishes the model to start from.

#### 4.2.5 **Time constrain or resource constrain**

##### 4.2.5.1 **Time constrain:**

The user can choose the option of time constrain, where the user specifies a specific period of time, the building has to finish on.

##### 4.2.5.2 **Resource constrain:**

The user can choose the option where he specifies the number of resources available (crews) in case there is a limitation in resource availability and the model will come up with the total duration then the model will start with the number of resources specified and work accordingly.

Figure 23 shows the developed excel interface for the user inputs.

BIM Time Schedule ×

Project Start Date  Start Point

**Constraints**

Time Constraint      Completion Date

**Formwork**

Type of Formwork

Minimum Quantity  m2

Maximum Quantity  m2

Resource Constraint

**Formwork**

Type of Formwork

Minimum Quantity  m2

Maximum Quantity  m2

Maximum No. of Crews

**Steel Fixing**

Maximum No. of Crews

**Figure 23: user input interface**

### 4.3 Engine of the model

#### 4.3.1 Minimum formwork calculations

Figure 24 shows area of formwork optimization flowchart.

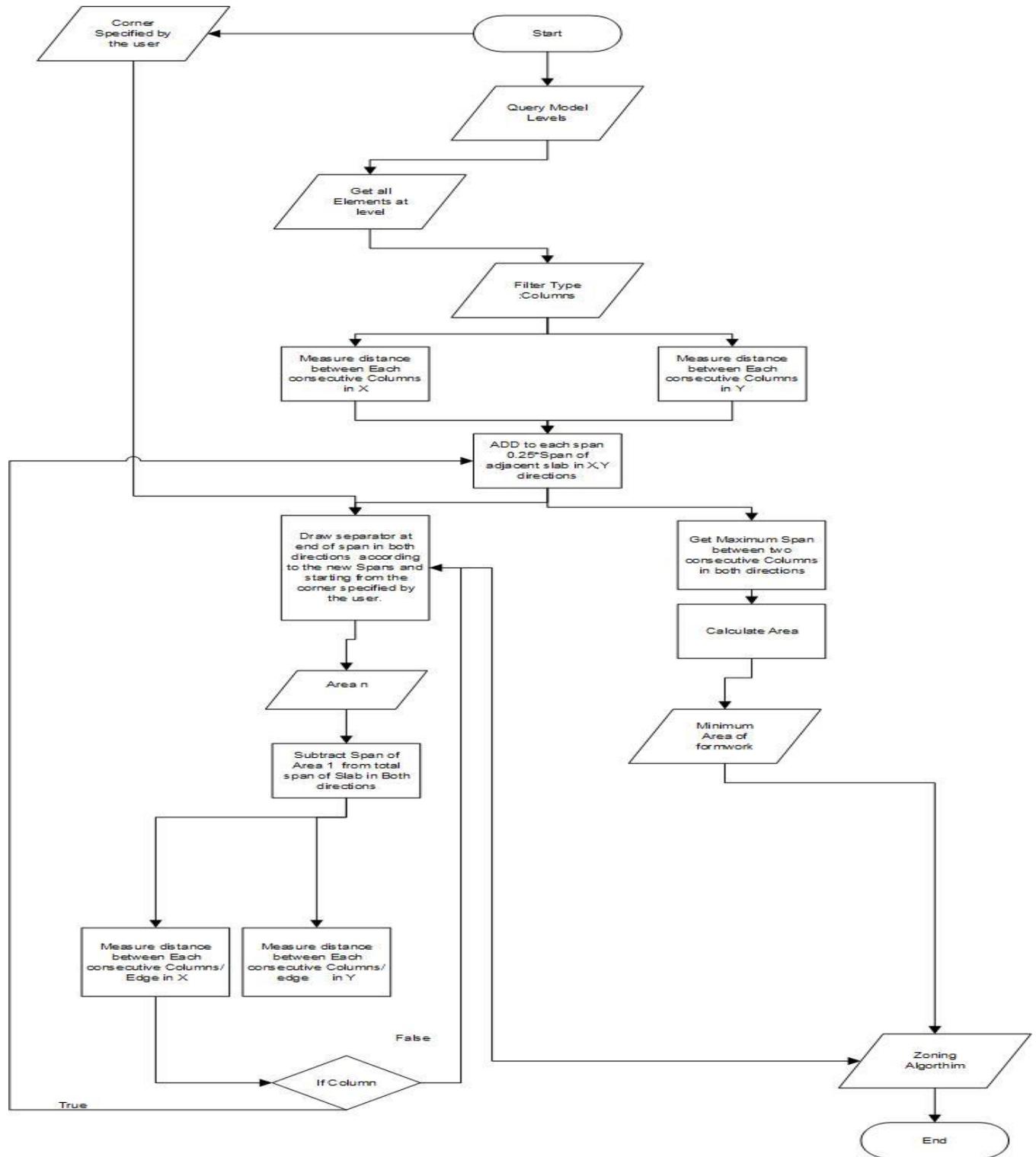


Figure 24: Area of Formwork Optimization Flowchart

The model starts by measuring the spans between each two adjacent columns and adding 0.25 of the span adjacent to it starting from the corner specified by the user. (figure 25)

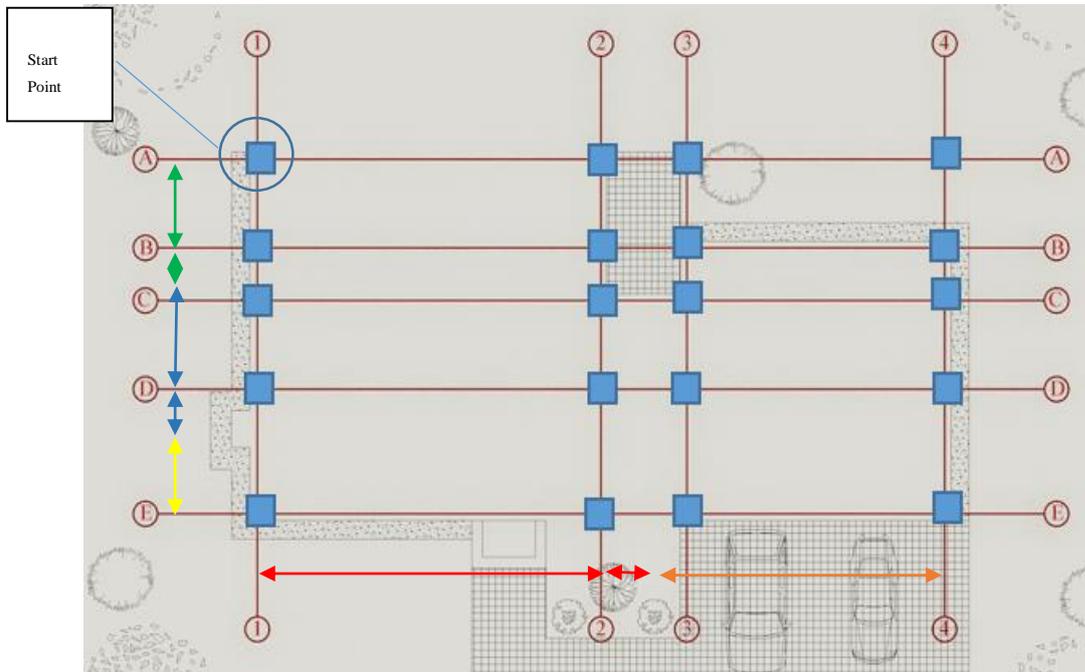


Figure 25: identification of spans

The model then generates the algorithm and starts by calculating the areas for new spans and divide the area of slab into smaller areas as shown in figure 26.

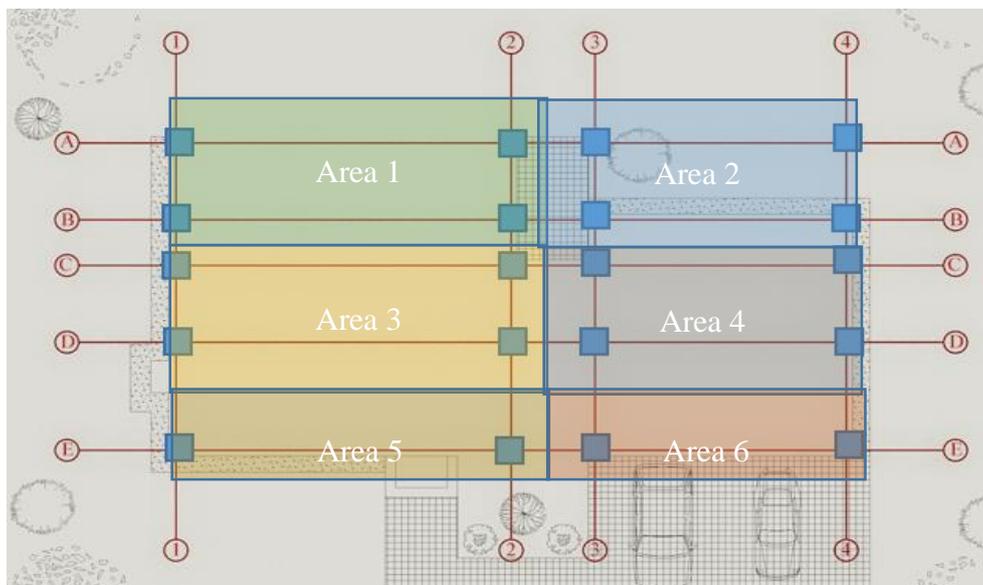


Figure 26: identifications of areas for slabs

The minimum formwork needed to start the iterations was calculated from the largest area that was defined in the previous step (largest span between columns in both directions).

Figure 27 shows max span chosen

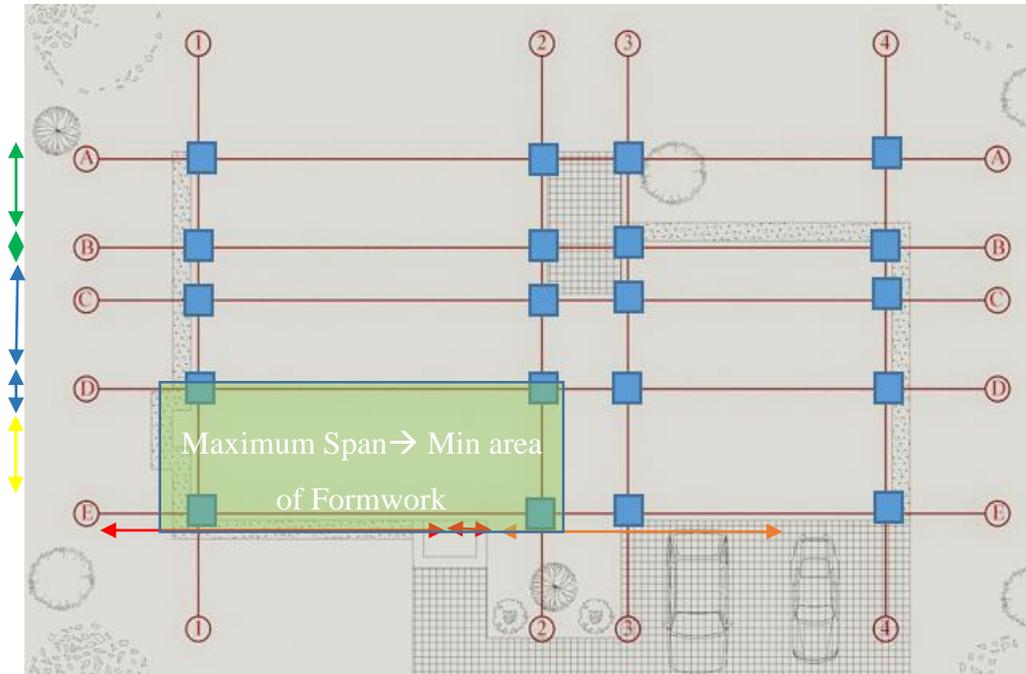


Figure 27: max span chosen

Figure 28 shows 0.25 of adjacent span

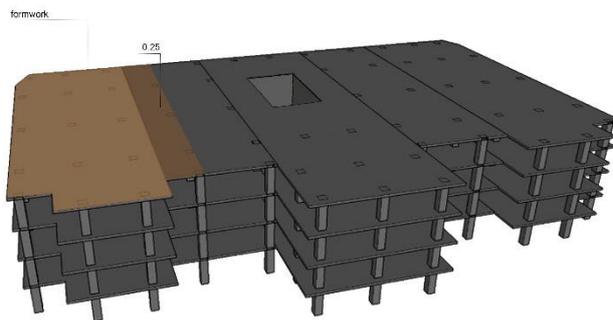


Figure 28: 0.25 of adjacent span.

After obtaining the minimum formwork area needed, the model starts by applying the different algorithms till reaching the final output. The model then automatically increases the formwork area needed by an area of an extra span and keeps initiating different time schedules and different cost estimates till it reaches the users desired time of completion.

In case of the choice of resource constrained model, the model generates different choices for the user to choose between respecting the max number of crews defined by the user.

#### 4.3.1.1 Zoning

Figure 29 shows the zoning algorithm flowchart

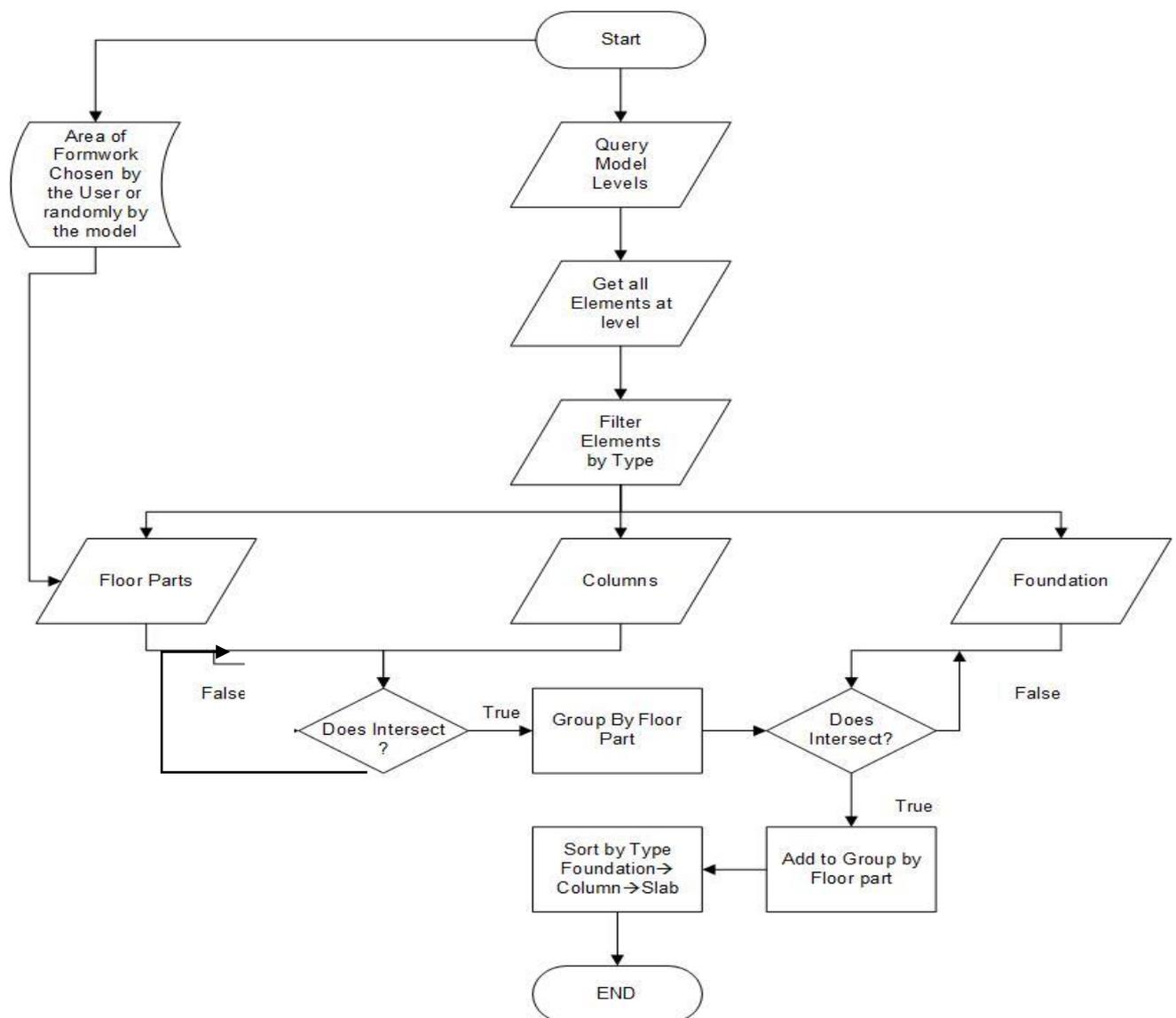
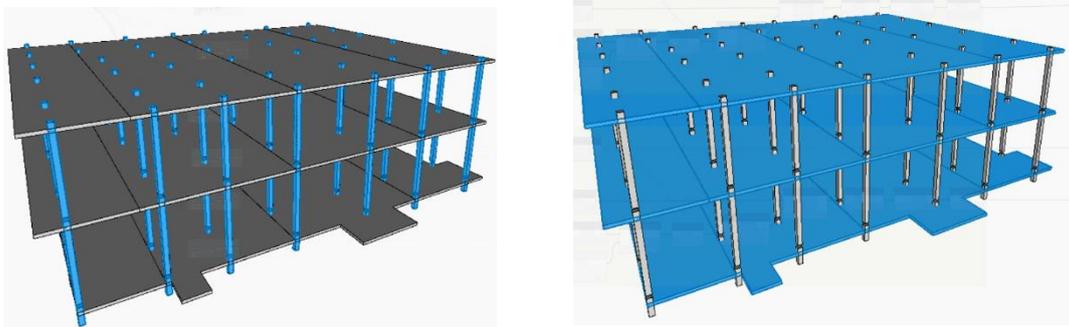


Figure 29: zoning flowchart

For the zoning part, the model identifies according to the area of formwork given by the user or chosen by the model and automatically categorized zones at its own.

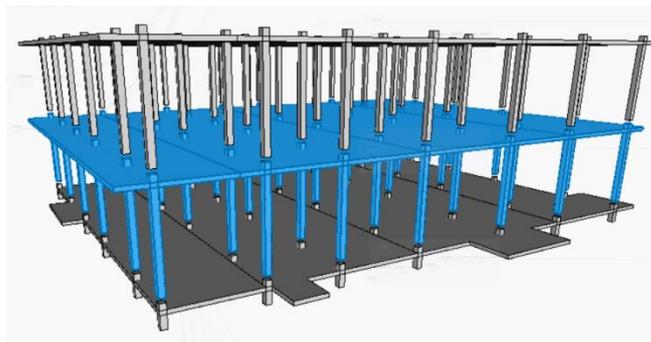
The problem in the zoning was that there was a difficulty in joining the elements in each zone with each other (columns & slab in each zone); so several algorithms were developed to solve this problem to create a list for each zone in the BIM software.

The first step the algorithm does is to detect the different level in the BIM model then to select all the elements per level i.e. Choose all the slabs and columns at the level; afterwards to filter elements by type to create two different lists for slabs and columns. (figure 30)



**Figure 30: Choosing all the elements in the Model Separately**

Then categorize each level separately (figure 31)



**Figure 31: Each Level Separately**

The 1st trial in the algorithm is to link both columns and slabs in each slab was to make the model automatically get the vertices of each slab and then let it draw a diagonal from the center of slab to the corner of each slab. Afterwards, the model would get the center of each

column and draw a line between it and the center of the slab; then a comparison between the diagonal in each slab and the line between the center of the column with the center of the slab to be compared; if the distance between the center of the column to the center of the slab is less than the diagonal of the slab that means that the column lies in the same zone as the slab and if not then it will be categorized in another zone. ( figure 32)

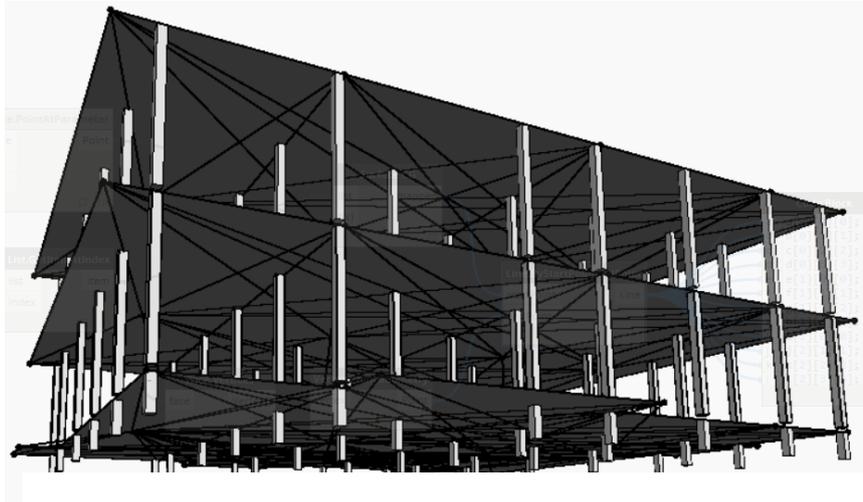


Figure 32: 1st trial to connect lines

However, this method did not work as it was very hard to track which columns and slabs lie in the same zone as the lists extracted were with family names and coordinates not the name of the element that can be tracked.

The 2nd trial was to ignore the lines and make the model automatically divide the number of columns by an even number and then insert a slab after each list of columns, but this method did not work too as the lists generated randomly selects any column and any slab in the model not respecting level nor position. (figure 33)

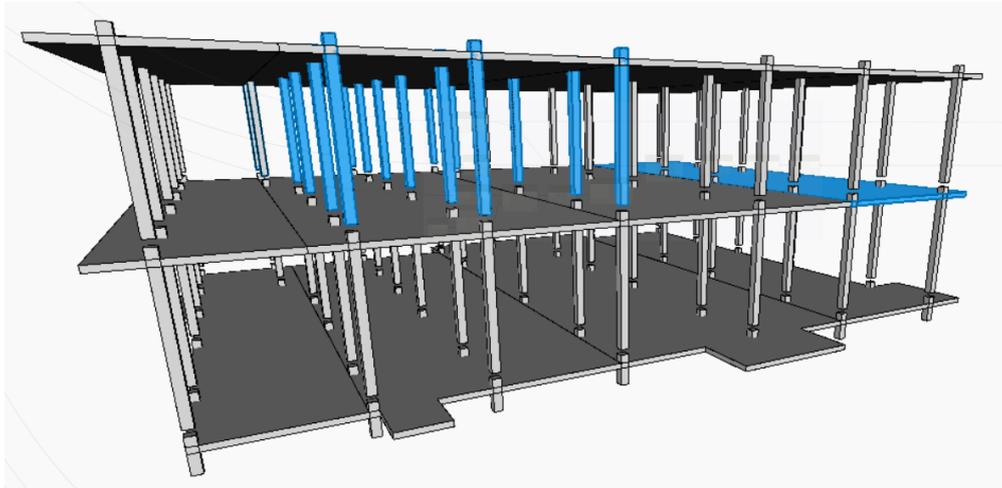


Figure 33: 2nd trail

The 3rd trail and the successful one was to project the columns to go through the slabs and then develop an if scenario to see which columns intersect which slab and to categorize them in different lists which will develop different zones in the model reflecting a successful zoning procedure.

In case the columns intersect two zones at the same time then the model will just account for the columns in one of the zones and remove it from the other; this was done by a simple equation where to remove second identical elements in different zones. (figure 34 & 35)

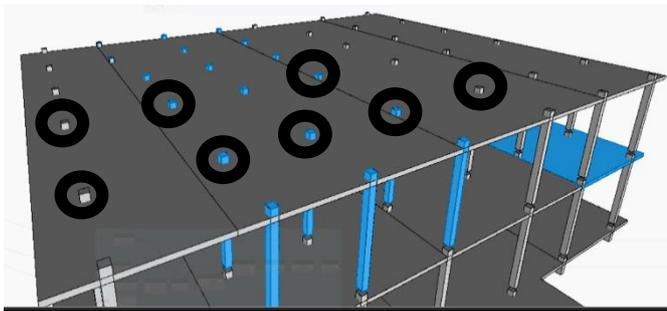


Figure 35: Intersection Between Columns and Slabs

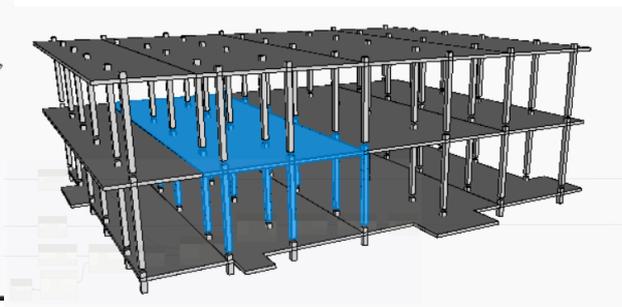


Figure 34: Successful Zoning

### 4.3.2 Crowdedness:

Figure 36 shows crowdedness algorithm

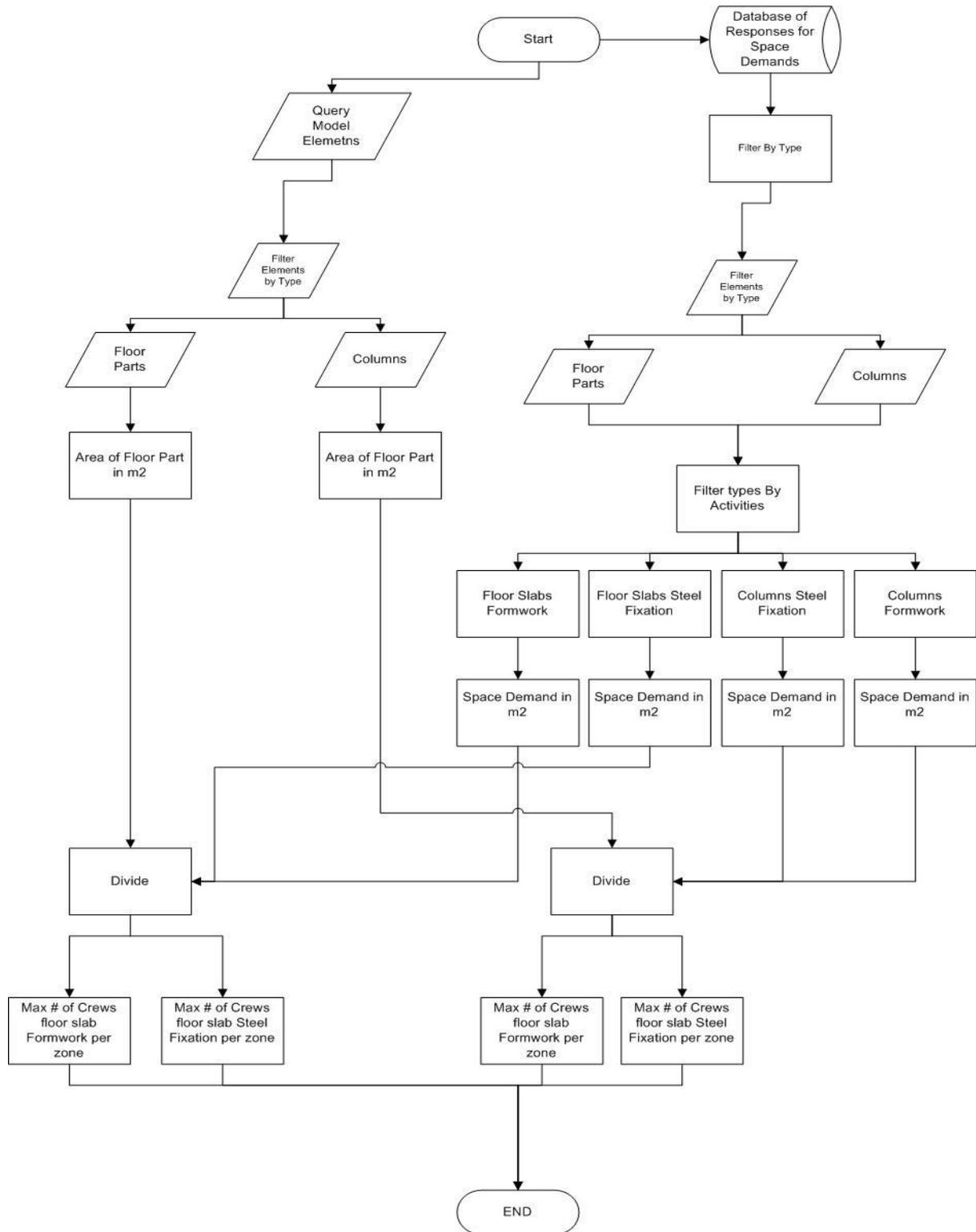


Figure 36: crowdedness algorithm

In this step, the collection of data stage was of great help as the average space needed per personnel per trade was collected from the experts and incorporated in a database for use in the algorithm.

The two crews that were of interest in this model were the formwork and the steel fixation crew. The space demand was broken to two categories per element; first of all, for the column formwork crew, it was estimated from the experts that the average space needed for the carpenter to work on the columns is about 2 m<sup>2</sup> for each side of columns.

For the slab formwork crew, the estimated space need for the carpenter is about 2 to 2.5 m<sup>2</sup> and this space is the same with regards to the slab steel fixation crew.

The algorithm takes these numbers and calculates the maximum number of crews for each trade to work per zone by the following equations.

$$\begin{aligned} & \textit{Space Demand Needed for Each Crew} \\ & = \textit{Space Demand for person} * \# \textit{ of Person in Crew} \end{aligned}$$

$$\textit{Max \# of Crews per zone} = \frac{\textit{Area of element in m}^2 \textit{ per zone}}{\textit{Space Demand needed per Crew}}$$

The algorithm takes the area of slab in m<sup>2</sup> and then calculates the max number of crews that can work according to the space demand of each personal; for example, if the area of slab is about 60 m<sup>2</sup> and the available crews for the formwork of the slab are 20 crews, which consists of 1 carpenter and 1 helper.; each worker needs a space of 2 m<sup>2</sup> then by dividing the available area with the space needed per worker, then the max number of crews are 15 crews to work in this area only.

Two databases were developed for each type of formwork (early strike formwork & traditional formwork), from interviews and previous experiences that are linked to the algorithm model by excel.



There two types of construction sequences that are applicable in the model as shown in figure 38.

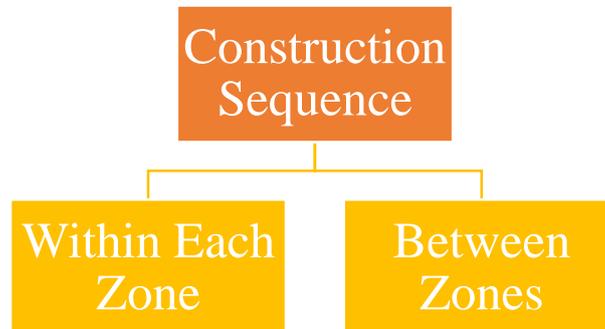


Figure 38: Construction Sequences

#### 4.3.3.1 Within each zone:

The structural sequence within each zone was defined according to the literature and to the direct interviews with experts.

It was agreed between all experts that the main activities for each zone will be as follow:

- a- Rc formwork for cores
- b- Rc steel fixation for cores
- c- Rc pouring for cores
- d- Dismantling of formwork
- e- Formwork for columns
- f- Steel fixation for columns
- g- Concrete pouring for columns
- h- Dismantling for columns
- i- Formwork for slabs
- j- Steel fixation for slabs
- k- Concrete pouring for slabs
- l- Dismantling for slabs

Each activity mentioned in the above list are dependent on one another in each zone; to link the activities with each other, the model had to simulate the durations of each activity and add them to each other to get the total duration per each zone; for example, if the duration of the formwork for columns in 4 days & the duration of the steel fixation for columns is 5 days then the model will automatically add the durations to each other to result in a total duration of nine days for both activities and then continues to do so for rest of activities.

Some of the activities has a relationship of start to start; which means the activity does not have to end for the following activity to start; this relationship was taken into account while linking the activities with each other; for example, the steel fixation and the formwork installation in the slabs does not have to be a finish to start activity, they can work concurrently so basically according to literature and experts the lag between the formwork and the steel fixation of the slabs are dependent on the productivity rates. The lag is calculated by linking the area of the zone with the productivity rate of the formwork to calculate the duration for the formwork and then doing the same thing to calculate the steel fixation duration and by then determining the lag between both activities, for example, if the formwork crew productivity rate is 4m<sup>2</sup>/ day, steel fixation rate is 3.5m<sup>2</sup>/day and the area of zone is 30m<sup>2</sup>. The duration of the formwork will be 7.5 days and the duration for the steel fixation will be 8.5 days. The lag calculated for this example will be a lag of 1 day between both activities.

The lags for the hardening of concrete was taken into consideration in the dismantling activity of the slab which was assumed to be 14 days for curing.

Basically the sequence of works for each zone is shown in figure 39 & 40:

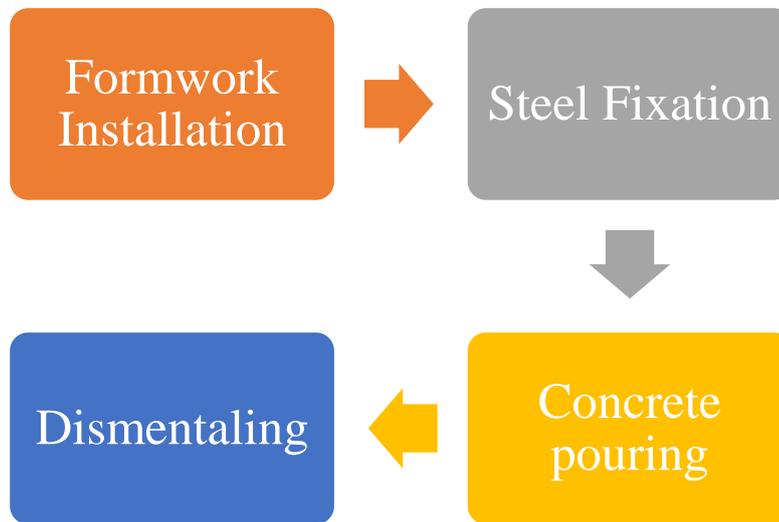


Figure 39: Columns Sequence of works

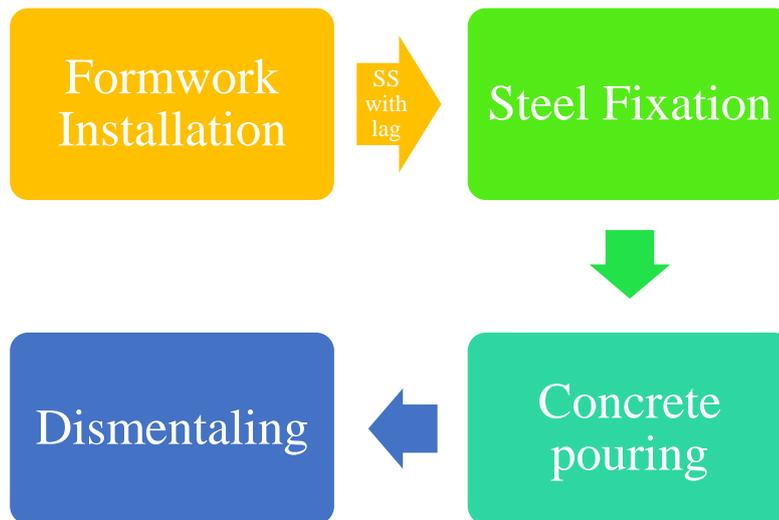


Figure 40: slab sequence of works

The relationship between the columns and slabs in each zone is assumed to be a finish to start relation; which means all the columns of the zone need to be finished (dismantling activity) for the slabs to start (formwork activity).

#### 4.3.3.2 Between the zones inside the model:

The other type of construction sequence is the sequence between the zones with one another. This construction sequence depends on two factors:

- The area of formwork available for use in construction that is generated from the model
- The number of crews available
- The site constrains

##### 4.3.3.2.1 The area of formwork available for usage:

The formwork available for usage is a huge factor for the construction sequence between zones the formwork area will define for the model how many zones can work at the same time.

The area of formwork is identified by the model and then by a simple method of boolean comparison between slab areas and area of formwork available, the excel extracts which zones can start concurrently and then defines the sequence of the other slabs to start after till it develops a list that arranges the sequence of slabs.

First step is that the model extracts a list that contains the floors and under each floor the already defined areas according to the area optimization algorithm ( figure 41)



Figure 41: Excel Node

Second step that is also extracted from the model is the areas of slabs in each zone for the comparison as shown in table 4

Areas	Areas (m2)
<b>Ground floor</b>	
Area 1	50
Area 2	70
Area 3	90
Area 4	30
<b>First floor</b>	
Area 5	100
Area 6	150
Area 7	90
Area 8	30
<b>Second floor</b>	
Area 9	90
Area 10	50
Area 11	150
Area 12	50

**Table 3: areas of each zone**

Then a comparison starts between the area of the formwork and the area of each slab to check which slab area is less than the area of the formwork available as shown in table 5.

Zones	Areas (m2)	Area of formwork <=area of slab
<b>Ground floor</b>		
Area 1	50	Y
Area 2	70	Y
Area 3	90	Y
Area 4	30	Y
<b>First floor</b>		
Area 5	100	Y
Area 6	150	Y
Area 7	90	Y
Area 8	30	Y
<b>Second floor</b>		
Area 9	90	Y
Area 10	50	Y
Area 11	150	Y
Area 12	50	Y

**Table 4: comparison between area of formwork & area of slab**

4.3.3.2.2 In case of traditional formwork:

The excel sheet also checks combination between slabs in similar floors and see if the addition of the areas of the zones is less than the area of formwork used then they can start concurrently as shown in table 6. For example, if the area of slab in zone 1 + 2 are 100 m2 and the formwork area available for usage is 120 m2.

#	Zones	Areas (m2)	Area of formwork ≤ area of slab	Area of a +b	Area of c+d	Area of a +c	Area of b +d	Area of b +c
<b>Ground floor</b>								
<b>A</b>	Area 1	50	Y	Y	Y	Y	Y	N
<b>B</b>	Area 2	70	Y					
<b>C</b>	Area 3	90	Y					
<b>D</b>	Area 4	30	Y					
<b>First floor</b>								
<b>A</b>	Area 5	100	Y	N	Y	N	N	N
<b>B</b>	Area 6	150	Y					
<b>C</b>	Area 7	90	Y					
<b>D</b>	Area 8	30	Y					
<b>Second floor</b>								
<b>A</b>	Area 9	90	Y	Y	N	Y	Y	N

<b>B</b>	Area 10	50	Y					
<b>C</b>	Area 11	150	Y					
<b>D</b>	Area 12	50	Y					

**Table 5: combination comparisons**

The model checks the combinations between the different areas of slab and compares them with the area of formwork identified by the model

The next step is the model gets the areas of the applicable combinations and then arranges the zones in a list on excel which is called in excel model “prioritization” this prioritization is based upon:

**4.3.3.2.1 Area of combinations of slabs in different zones:**

The model starts to prioritize the combinations according to their area, the bigger areas in the combinations, takes the priority of starting taking into its considerations its level; which means the first zone to start will be the largest area zone whether it is a combination or a single slab on the 1st level of the building as shown in table 7

<b>Zones sequence</b>	
<b>Ground floor</b>	Zones
<b>Area 1 + 3</b>	Zone 1
<b>Zone 2 + 4</b>	Zone 2
<b>First floor</b>	Zones
<b>Zone 7 + 8</b>	Zone 3
<b>Zone 6</b>	Zone 4

<b>Zone 5</b>	Zone 5
<b>Second floor</b>	Zones
<b>Zone 9 + 10</b>	Zone 6
<b>Zone 11</b>	Zone 7
<b>Zone 12</b>	Zone 8

**Table 6: prioritization of zones**

4.3.3.2.3 In case of early strike formwork:

The excel sheet also checks combination between slabs in similar & different floors and see if the addition of the areas of the zones is less than the area of formwork used then they can start concurrently.

As the early strike of formwork is used in most cases to start two levels at the same time, so the zoning in the case of early strike is different, more options for the zoning as shown in table 8.

#	Zones	Areas (m2)	Area of formwork <=area of slab	Area of a +b	Area of c+d	Area of a +c	Area of b +d	Area of b +c	Area of a1 +a2	Area of a2+a3	Area of b1 +b2	Area of b2 +b3	Area of c1 +c2	Area of c2+c3	Area of d1 +d2	Area of d2 +d3
<b>Ground floor</b>									Y	N	N	Y	N	N	Y	N
A	Area 1	50	Y	Y	Y	Y	Y	N								
B	Area 2	70	Y													
C	Area 3	90	Y													
D	Area 4	30	Y													
<b>First floor</b>									N	N	N	N	N	Y	Y	
A	Area 5	100	Y	N	Y	N	N	N								
B	Area 6	150	Y													
C	Area 7	90	Y													
D	Area 8	30	Y													

Second floor														
<b>A</b>	Area 9	90	Y	Y	N	Y	Y	N						
<b>B</b>	Area 10	50	Y											
<b>C</b>	Area 11	150	Y											
<b>D</b>	Area 12	50	Y											

**Table 7: comparisons of combinations in case of early strike**

The next step is the same as in case of the previous section where the model gets the areas of the applicable combinations and then arranges the zones which is based upon several factors:

**4.3.3.2.3.1 Area of combinations of slabs in different zones at the same level and different levels:**

In this case the prioritization depends on the level of the zone and the area, where it gives priority for the largest areas in the different floors as in case of early= strike by a maximum of 1 floor difference as this may affect the building negatively if it continues vertical sequence (soil settlement) , a vertical sequence is applicable; for example, if the area in the gf of the model for zone 1a + zone 2 a is larger than the area of zone 1a + zone 1b, then it chooses the zone 1a + zone 1b for the sake of vertical sequencing.= and then if the same applies in the 2<sup>nd</sup> floor then it never choose the vertical sequencing again, it chooses rest of the zones in the ground floor as shown in table 9.

Zones sequence	
Area 1 + 2	Zone 1
Area 3 + 4	Zone 2
Zone 7 + zone 8	Zone 3
Zone 6	Zone 4
Zone 5	Zone 5
Zone 9 + 10	Zone 6
Zone 11	Zone 7
Zone 12	Zone 8

Table 8: prioritization of zones in case of early strike

### 4.3.3.3 The number of crews available

The sequence of the work does not only depend on the area of the formwork but it also depends on the number of crews available and their productivity rates as well.

The number of crews is a major indicator for the number of zones that can work concurrently as if there are not enough crews to work in concurrent zones at the same time, then the zones cannot work at the same time and the model has to enhance the area of formwork available with the number of crews available with the space demand of each personal defined above.

To enhance both constrains with each other, a crew check had to made before inputting the data back in the software the algorithm, so the maximum crews per zone calculated from the crowdedness equation above has to be compared with the available crews available inputted by the user.

For example, if the slab area is 50 m<sup>2</sup> and the number of crews available are 30 crews, the area of the formwork available is 100 m<sup>2</sup>, maximum number of crews calculated is 12.5 crews. And productivity rate of crew 4m<sup>2</sup>

This means that the productivity rate per zone for each crew is 49 m<sup>2</sup>/day. And the rest of the crews can work in concurrent zones at the same time if the area of the formwork fits.

If the crews are available to work on two zones concurrently then the data will be inputted into the algorithm for the rest of processing, if not then excel will regenerate the equations to build a new construction sequence to break down the concurrent specified zones that works with each other and break them down to satisfy the crew constrain with regards to space and number that only depends on one zone per crew. After the steps above, the prioritization lists are translated into the algorithm, for the sake of completing the programming stage as shown in figure 42.

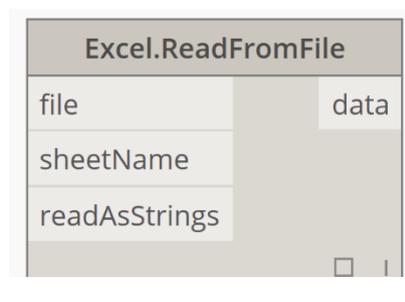


Figure 42: Excel Node

### 4.3.4 Generation of the time schedule

Figure 43 shows construction duration algorithm Flowchart

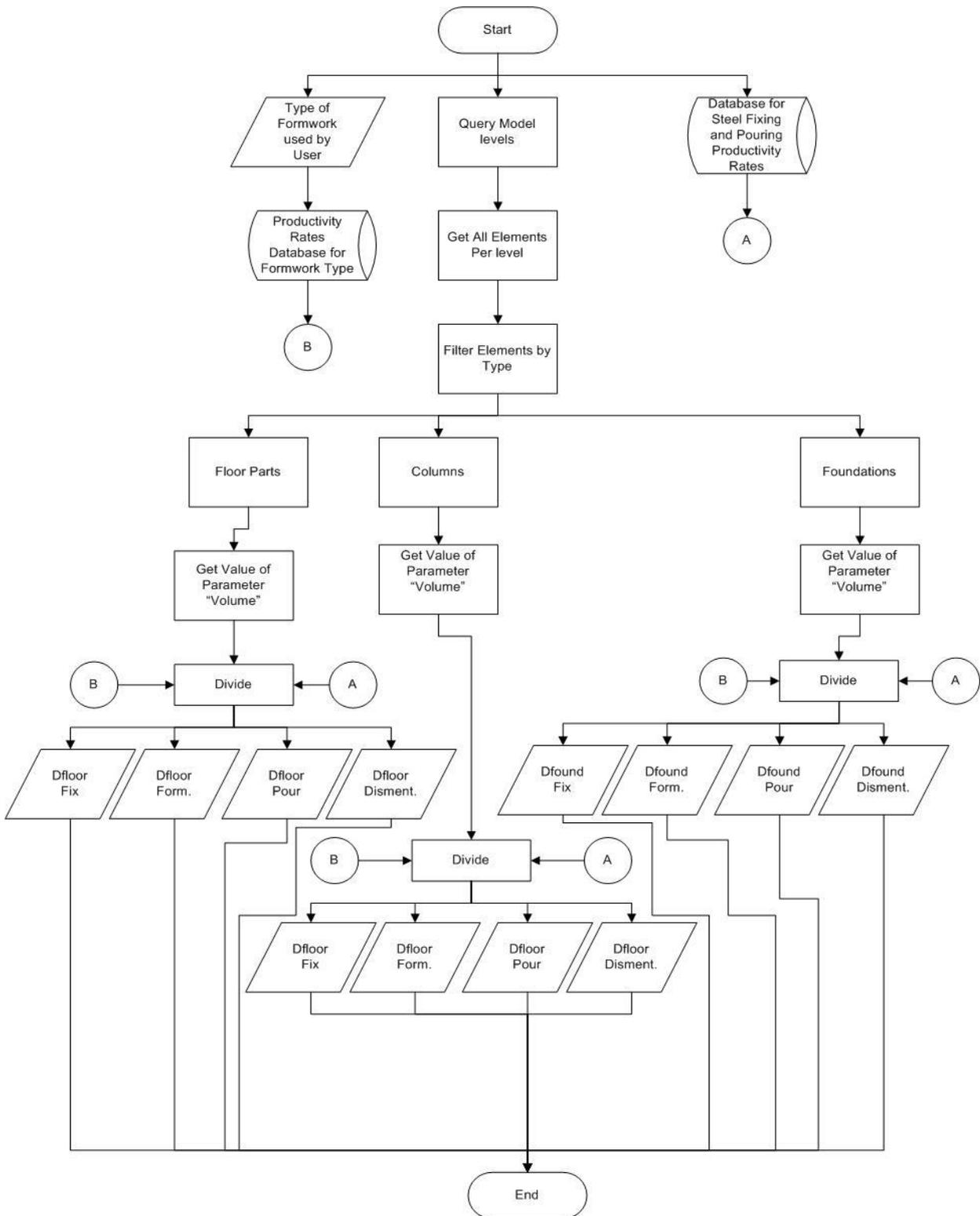


Figure 43: construction duration algorithm

The 1st process in this step is the wbs creation; a wbs automatically for the building is created for all the activities, zones, building for each model to be extracted on excel as shown in figure 44.

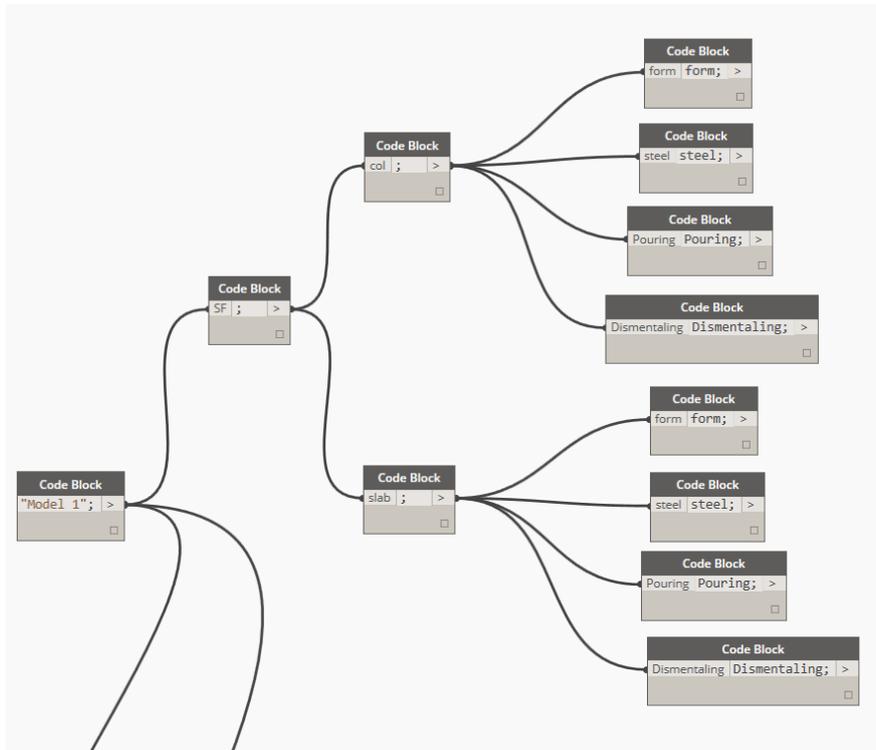


Figure 44: sample of WBS created

The sequence of works are based on start dates and durations. The start date for the first output from excel is added to its translated zone then the model automatically calculates the duration according to the standard and well know equation of the duration calculation for any activity which are:

*Productivity Rate per Zone*

$$= \text{Max \# of Crews per zone} * \text{Productivity Rate per crew}$$

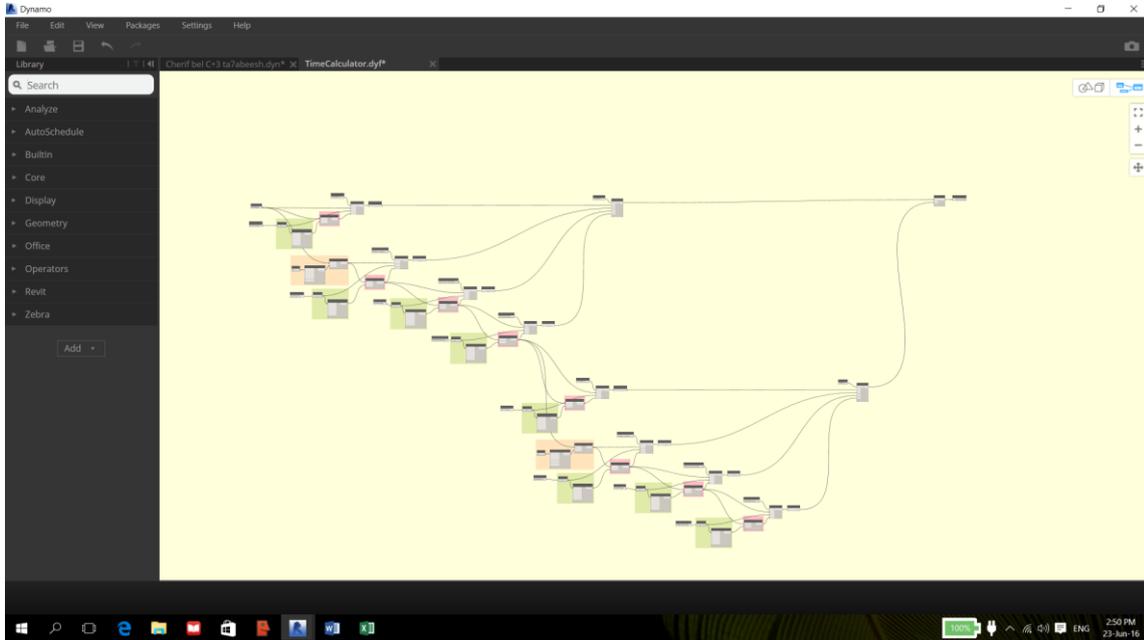
$$\text{Duration of Activity} = \frac{\text{Quantity of Element}}{\text{Productivity Rate of Crew}}$$

The productivity rates are given from two developed databases for each type of formwork which was collected from different project experiences.



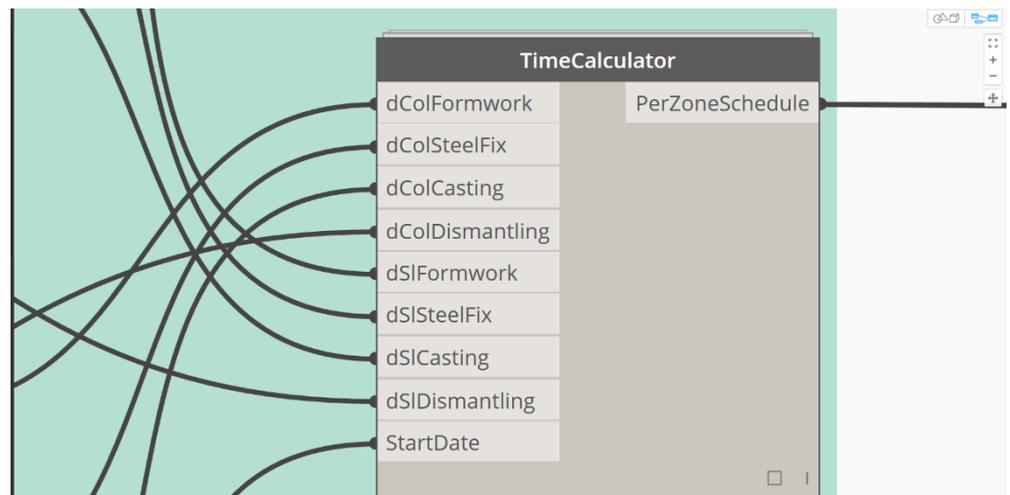


Another algorithm was done to accommodate this step where for each activity there are a couple of nodes that links the duration to the start date of the activity to the lag between activities within each zone by additions of durations, special nodes to add duration on date, etc.... as shown in figure 47.



**Figure 47: within each zone sequence of work preparations**

In order to minimize the model, a customized node was developed for the process of calculation of durations and the linking between the activities with each other in each zone as shown in figure 48.



**Figure 48: customized node for durations within each zone**

The duration for each zone is known according to the above steps, so by respecting the durations and the construction sequence that was specified in the above steps the model starts developing its process for arranging the zones according to the list developed from the comparison; moreover, it also compares the durations of the zones with each other, and it doesn't wait till both zones finish if they work concurrently, the least duration is added to the next zone at once. For example, if the zone 1 + 2 are chosen to work concurrently at the ground floor and the duration for zone 1 is 8 days and zone 2 is 6 days then the model will automatically add the durations of zone 2 to the next zone at the list and then when zone 1 is finished, it will do the same thing to the other zone, and it goes on till all the zones finish.

### 4.3.5 Cost estimation for the project

Figure 49 shows cost estimation flowchart

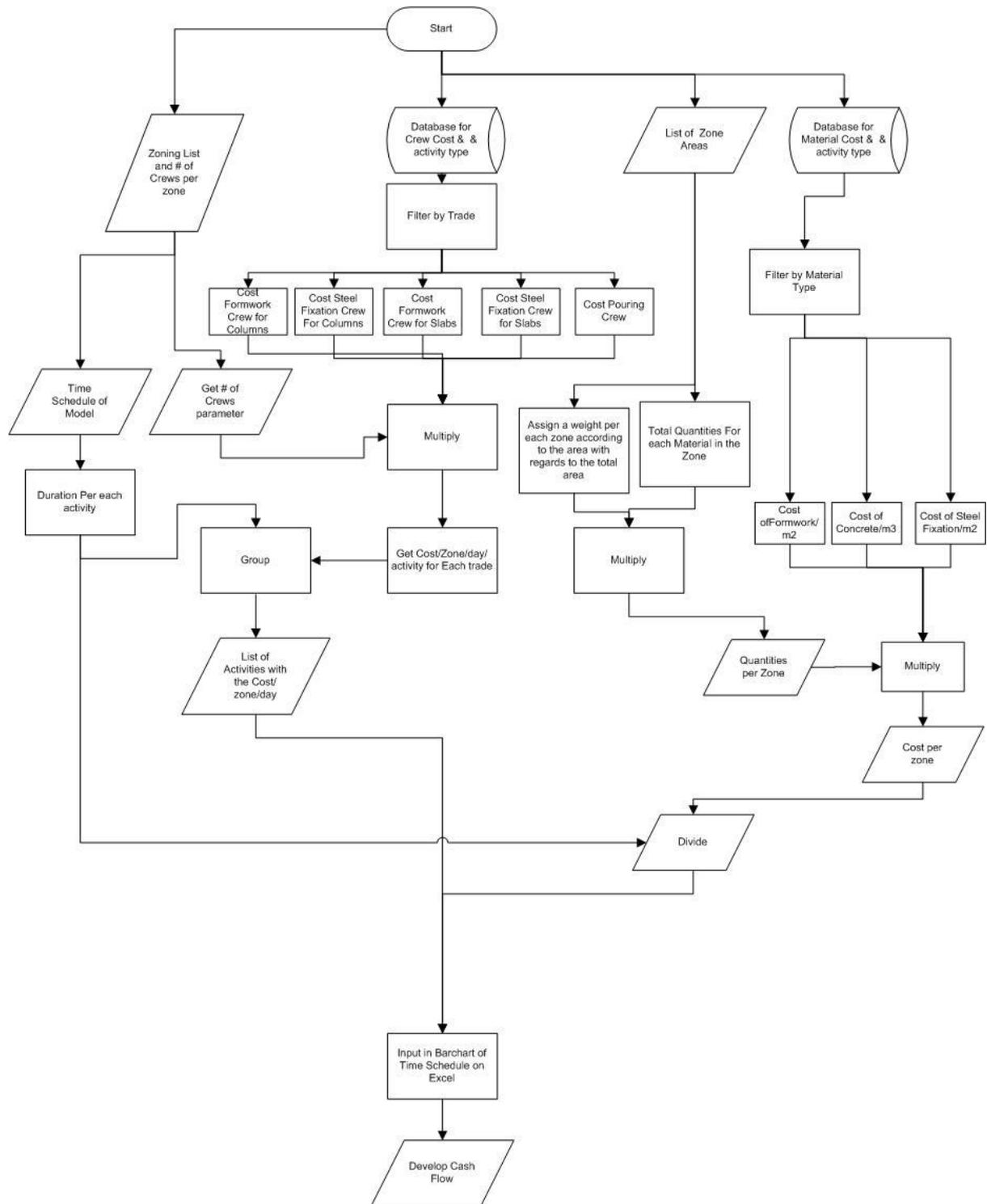


Figure 49: cost estimation flow chart

The cost estimation for the model is a simple multiplication equation that is inputted to calculate the cost/activity & crew/day and multiply it with the number of crews working at each zone, then this cost is then translated into excel to develop a cash flow for the project. Not only the cost of the crews is taken into the calculations but also the cost of the material used are both combined in the cost of concrete/m<sup>3</sup>. The costs of crews/day and the material used on site are estimated as an average from previous projects database from egypt and some interviews with experts.

The cost/ concrete in m<sup>3</sup>, the cost/formwork material and the cost per crew were all combined to reflect the cost for the zones in the buildings building as follows.

The volume of the zone was calculated in m<sup>3</sup> and multiplied by the market price of the ready mix concrete, and it was added by:

- 1- The area of formwork used in this zone and in case of reuse of this formwork set, it will be calculated once and multiplied by the market price of the m<sup>2</sup> of formwork
- 2- The amount of steel used in this zone (kg/m<sup>3</sup> \* m<sup>3</sup>) and multiplied by the market price of the steel reinforcement per ton and according to the  $\phi$  of the steel reinforcement used
- 3- The number of formwork crews used in this zone multiplied by the duration of the zone which is then multiplied by the crew cost/day.

Databases have been developed from the direct interviews experiences and the market price of the material to be used in the cost estimation process.

## Chapter 5 - case study and validation

### 5.1 Project general information

An ongoing construction project at the time of writing this research was used as a case study to validate the developed model. The presented case study is a four-story residential building project in Cairo, Egypt. Autodesk® Revit® 2016 was used as the BIM modeling tool for this project. Works on this project were divided into four packages, the scope of work for each package included:

1. Enabling works package includes the site excavation, grading, foundation works and backfilling works.
2. Structural works package includes the construction of the structural system of the building, starting from floor one and up to the roof floor.
3. Architecture/mep works package includes all the internal/external finishes of the building as well as the MEP for the building.
4. Interior design and furniture package includes all the interior design works as well as the loose and fixed furniture.

Figure 50 shows the 3D BIM model developed for the case study.

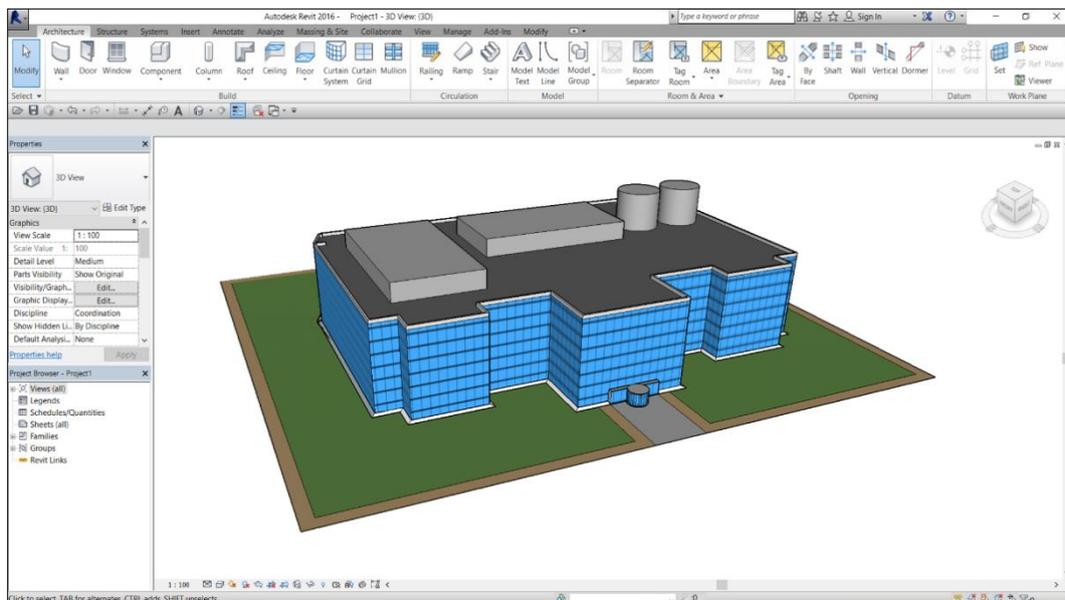


Figure 50: case study axonometric view in Autodesk® Revit®

In this case study, on the structural works package was only used to validate the developed model and highlight its accuracy and essential features. The structural system of the building is flat-slab system. (figure 51)

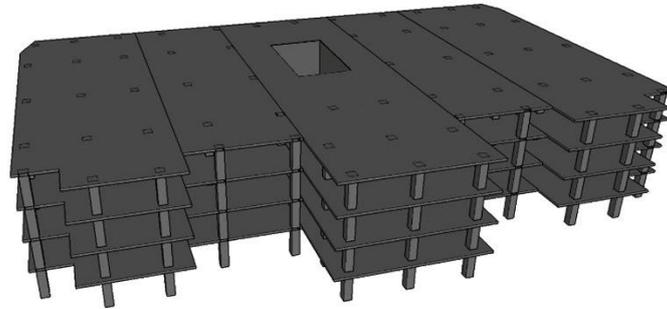


Figure 51: the structural model of the case study

Information from the structural package contractor was obtained which included: general project information, the on-site contractor's resources and the approved baseline schedule for the project. To provide basis of comparison, the outcomes of the model were compared to the approved resource-loaded baseline schedule and to the approved method statement for the construction of the structural works package of this case study.

## 5.2 Model application

The verification of the model was applied on a number of steps (figure 52). First, the structural BIM project was loaded on autodesk® revit®. Second, the project requirements and the site conditions were input in the model input form on ms excel. Third, the model was executed on dynamoBIM® with revit® running in the background. Fourth, the generated outcomes were imported to ms project 2010. Finally, a comparison between the model outcomes and the approved baseline was discussed, in terms of time, resource loading and cost.



Figure 52: model application steps

### 5.2.1 Load structural model

The first step is loading the structural model in revit®. The project was designed as separate linked revit files including; (1) site works, (2) foundations model, (3) structural model, (4) architectural model, (5) façade model, (6) mechanical model, (7) electrical model and (8) furniture model. All these models were unloaded but the structural model for the project which shows the structural system of the building.

### 5.2.2 Input parameters

The second step is to input the project parameters and requirements as obtained from the package’s contractor. The set of project parameters can be summarized in the table 10.

Table 9: project data

<b>Project start date</b>	30/6/2016
<b>Type of formwork available</b>	Traditional system (posts, joints, ledges and sheeting)
<b>Available quantity</b>	300 m <sup>2</sup>
<b>Formwork crew</b>	1 carpenter + 1 helper
<b>Production rate per formwork crew</b>	3.5 m <sup>2</sup> /day
<b>No. Of formwork crews</b>	50
<b>Steel fixing crew</b>	1 steel fixer + 1 helper
<b>No. Of steel fixing crews</b>	50
<b>Production rate per steel fixing crew</b>	3 m <sup>2</sup> /day
<b>Availability of concrete</b>	Ready-mix concrete
<b>Concrete casting crew</b>	3 labor + 6 helper + 1 concrete pump
<b>Concreting production rate</b>	500 m <sup>3</sup> /day
<b>Desired time of completion</b>	390 days

### 5.2.3 Execute the model

The obtained parameters were input through the model interface and then the model was executed as presented in figure 53.

BIM Time Schedule

Project Start Date 30-6-2016 Start Point

**Constraints**

Time Constraint Completion Date 25-7-2017

**Formwork**

Type of Formwork Traditional

Minimum Quantity None m2

Maximum Quantity None m2

Resource Constraint

**Formwork**

Type of Formwork

Minimum Quantity m2

Maximum Quantity m2

Maximum No. of Crews

**Steel Fixing**

Maximum No. of Crews

RUN Cancel

Figure 53: model inputs interface

Start point of the model was identified by the user in figure 54.

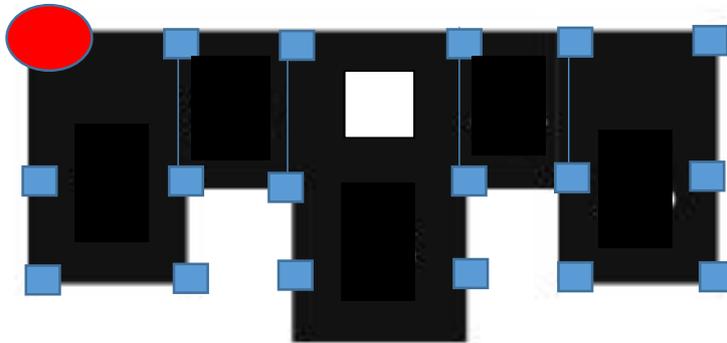


Figure 54: Start point identified by User

#### 5.2.4 Generated outcomes

The run time for the model was almost 8 minutes. Several outcomes were generated; the outcomes were several time schedules with different areas of formwork with the highlighted time schedules that are less than the duration desired by the user in the form of a “.csv” (comma separated values) file. This file was then imported to ms® project® 2013 to be compared with the approved project baseline. The other outcome was cash flows for the different approaches of the model and lastly a graphical outcome of the different approaches of the calculated zones of the model, where each construction zone is determined based on the type of formwork system selected (traditional system) and the area of formwork indicated by the model. Each zone represented a part of the concrete slab per floor including all the supporting columns to each slab.

##### 5.2.4.1 Minimum area of formwork needed.

The model first got the distances between each two consecutive columns and then added 0.25 of the span adjacent to this span. Figure 55 shows calculation of new spans.

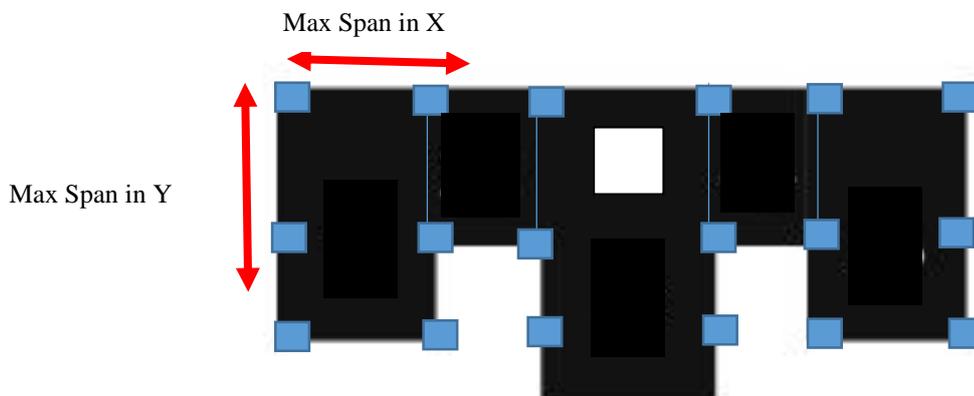


Figure 55: Calculation of new spans

Then it calculated the area of this identified slab which was equal to  $(26+4) * (9+1.5) = 325$  m<sup>2</sup> and this was the minimum area needed for the formwork.

Then the model generated the different areas in the zone by the same calculation of adding 0.25 of the span to the span of the formwork. Figure 56 shows areas identified by models.

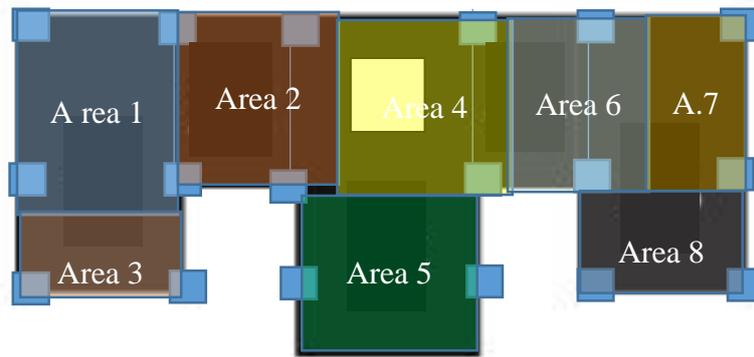


Figure 56: Areas Identified by Model

#### 5.2.4.2 Zoning & construction sequencing

The construction sequence between zones has been identified according to the available formwork area in m<sup>2</sup> and number of crews available as described in the flowchart above.

<b>Available formwork from model</b>
<b>325 m<sup>2</sup></b>

Table 10:available formwork

<b># of crews (formwork &amp; steel)</b>
<b>50</b>

Table 11: number of crews

	Area of slab	Area < area of formwork	Combinations with adjacent	Area	Area < area of formwork
Area 1	230	Y	1+2	420	N
Area 2	190	Y	1+3	380	N
Area 3	150	Y	1+3	380	N
Area 4	230	Y	4+5	460	N
Area 5	230	Y	4+6	430	N
Area 6	200	Y	6+7	350	N
Area 7	150	Y	7+8	330	N
Area 8	180	Y	7+8	330	N

Table 12: comparisons for sequence between zones

	Area of slab	Other combinations	Area < area of formwork	Applicable areas
Area 1	230	1+4, 1+5,1+6,1+7,1+8	N	N/a
Area 2	190	2+3,2+4,2+5,2+6,2+7,2+8	N	N/a
Area 3	150	3+4,3+5,3+6,3+7,3+8	Y	3+8
Area 4	230	4+7,4+8	N	N/a
Area 5	230	,5+7,5+8,5+6	N	N/a
Area 6	200	6+8	N	N/a
Area 7	150		N	N/a
Area 8	180		N	N/a

Table 13: combinations with all areas

Table 11, 12 and 13 gets the area of each zone and compares it with available formwork to check which area of zone is applicable to the area of formwork. Then, it gets the combinations where in this case it is traditional formwork, so basically it tries the combinations of zones in horizontal sequencing and check which combinations can the formwork sets cover to work concurrently.

Areas	Zones
Area 1	1
Area 2	2
Area 3	3
Area 4	4
Area 5	5
Area 6	6
Area 7	7
Area 8	3

**Table 14: final prioritization of the model**

The above table shows the final result of the model outputs with regards to sequencing of zones after all the calculations conducted and then it is ready to be re inputted again into the BIM software to continue the rest of the algorithms and to continue the process of generations of the time schedule and cash flow.

### 5.2.4.3 Crowdedness

The algorithm for crowdedness defined the max number of resources per each zone in the model for the two structural elements within the model by drawing a grid for each crew on the model which is based on the workspace required for each personal in a crew that was collected and identified according to the direct interviews with experts and the research conducted.

A grid was identified for the workspace available for each crew around each element and the productivity rate for each zone was calculated. An example of the outcome is presented in table 11, where the area of formwork divided the model into 5 zones.

Table 15: max crew/zone

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Max # of crews	30	30	30	50	30	16	15

### 5.2.4.4 Time schedule generation

After the above steps are implemented, the model combines all the outputs, zoning, max number of crews & sequence of zones and then start by calculating the durations of each activity by getting the max number of crews per trade/zone and multiplying it with the productivity rate/trade and by having the area of each zone, it calculates the duration/activity/zone and by then the durations of each activity per trade within each zone is calculated and connected with the time and date algorithm described in the model stage. Then it takes the output of the prioritization of the zones and start building the dependencies between each zone with the next to generate the final time schedule. An example of one of the time schedules is presented in figure 57.

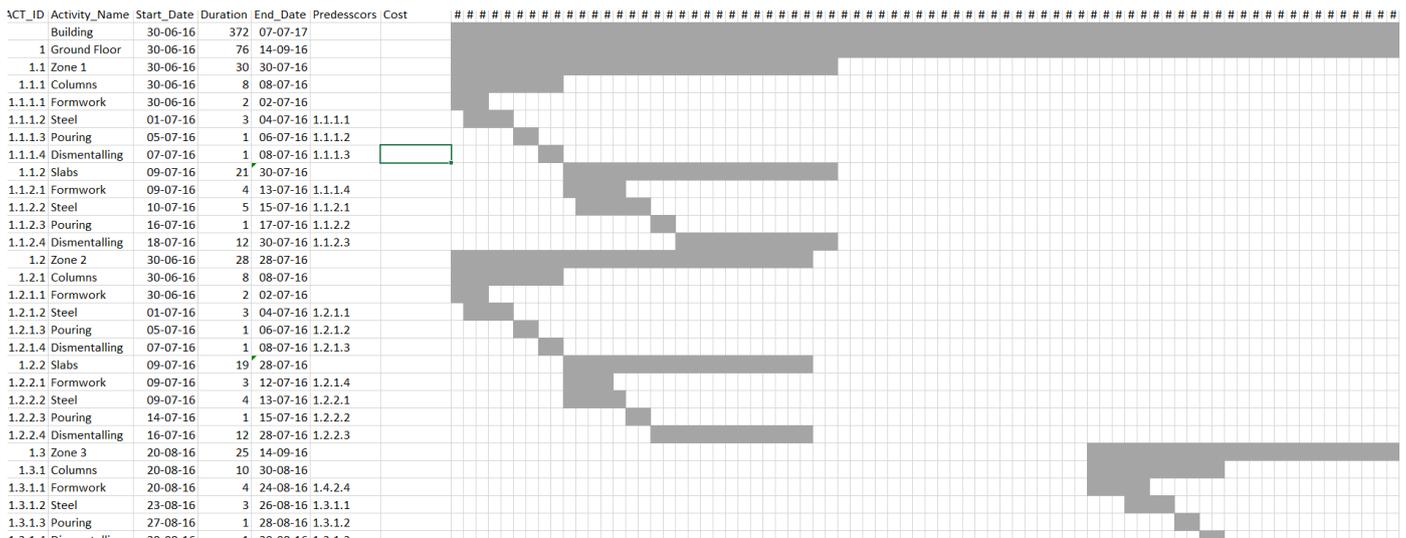


Figure 57: Extracted Time Schedule in .CSV file

The above figure shows the time schedule that was extracted from the BIM where the columns are divided to the activity id, start date of the activity, duration of the activity, finish date of the activity and finally the predecessors of each activity. Furthermore, it shows a simple excel bar chart to give a graphical presentation for the user for the duration of the project.

Figure 58 shows an extract of the time schedule saved in .csv file that is imported automatically into microsoft project software with the dependencies between each activity with the other.

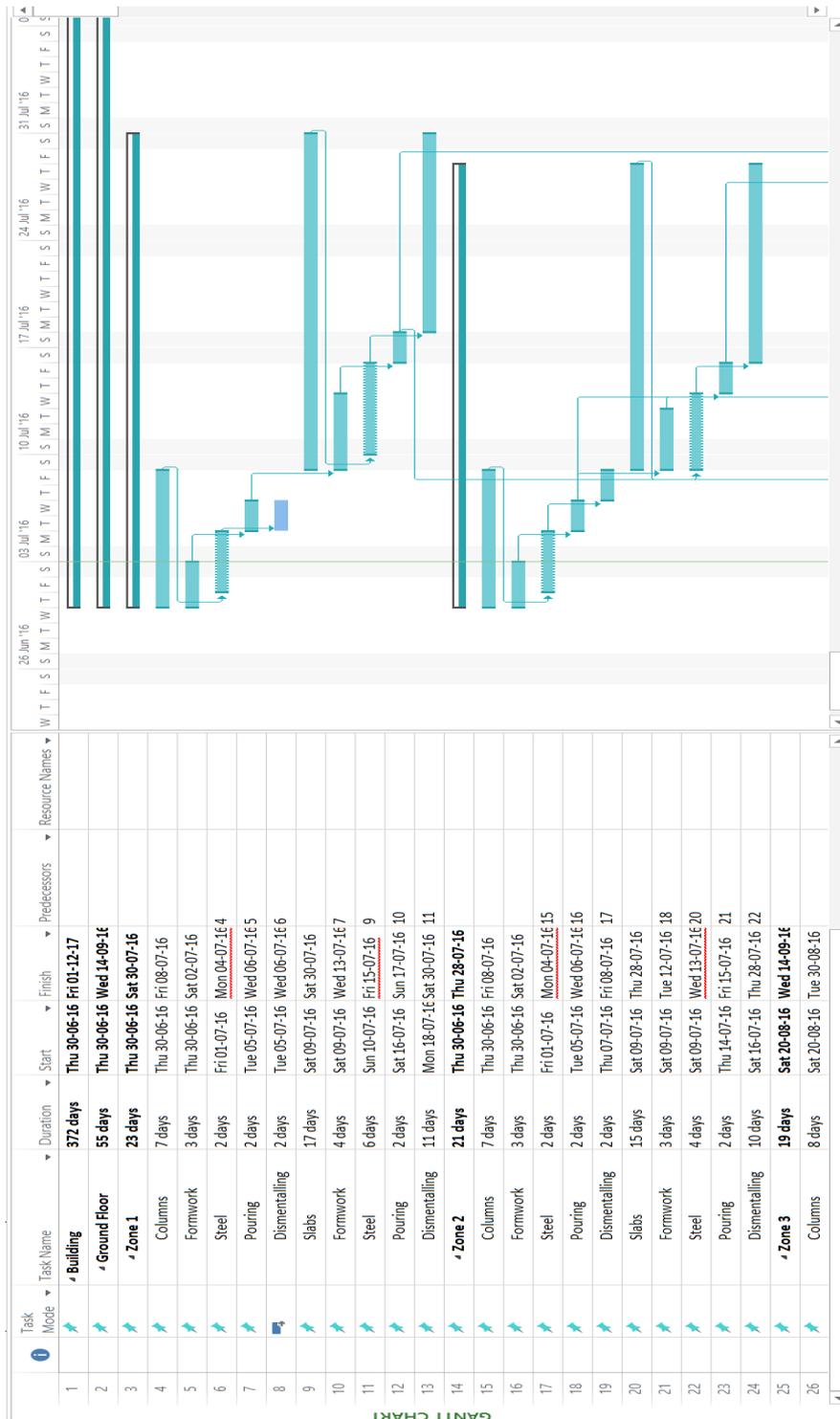


Figure 58: Microsoft Project Screenshot

#### 5.2.4.5 Cash flow generation

After the time schedule is generated, the model starts implementing the cost estimation algorithms where it connects the databases collected and connects them to each activity in the model where the calculation occurs as follows:

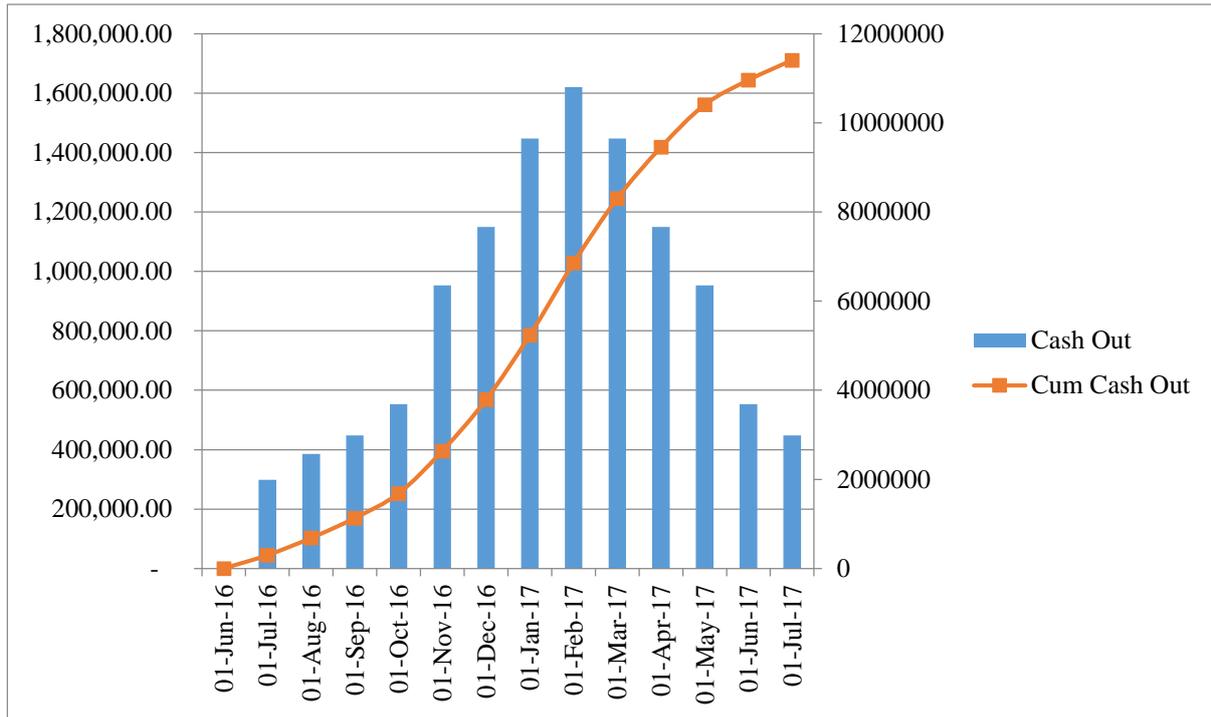
- 1- The area of formwork used per zone multiplied by the market price of the m2 of formwork
- 2- The amount of steel used in this zone ( $\text{kg/m}^3 * \text{m}^3$ ) and multiplied by the market price of the steel reinforcement per ton and according to the  $\phi$  of the steel reinforcement used
- 3- The number of formwork crews & steel crews used in this zone multiplied by the duration of the zone which is then multiplied by the crew cost/day.

Table 16 shows the extracted data from the model for the cost for each month to develop the cash flow of the model as shown in figure 59.

Date	Cash out	Cum cash out
30-jun-16	-	0
30-jul-16	298,142.58	298,142.58
30-aug-16	385,079.16	683,221.74
30-sep-16	448,127.71	1,131,349.45
30-oct-16	552,823.57	1,684,173.02
30-nov-16	953,517.86	2,637,690.89
30-dec-16	1,149,782.11	3,787,473.00
30-jan-17	1,447,706.97	5,235,179.97
28-feb-17	1,620,861.80	6,856,041.77
30-mar-17	1,447,706.97	8,303,748.74
30-apr-17	1,149,782.11	9,453,530.85
30-may-17	953,517.86	10,407,048.71
30-jun-17	552,823.57	10,959,872.29
07-jul-17	448,127.71	11,808,000.00

Table 16: cash flow table

Figure 59: cash out chart



### 5.2.5 Comparison with contractor output

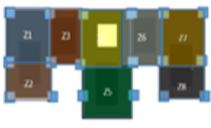
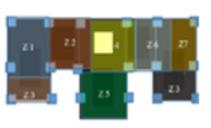
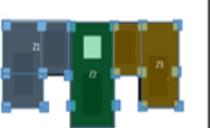
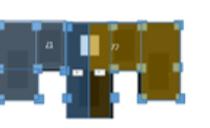
Item	Approved Baseline	Alternative 1	Alternative 2	Alternative 3
Area of Formwork m2	300	325	540	700
Zoning & Sequence	 <p>Z1→Z2→Z3→Z4→Z5→Z6→Z7→Z8</p>	 <p>Z1→Z2→Z3→Z4→Z5→Z6→Z7</p>	 <p>Z1→Z2→3</p>	 <p>Z1→Z2</p>
Time Schedule	390	385	370	340
Cash Flow	11,750,000	11,690,000	12,377,837	12,900,332
Max Crew Req.	50	50	68	88
Prep. Time	1 week	15 mins	15 mins	15 mins

table 17: comparison with approved baseline

### 5.2.5.1 Analysis of results (comparison with nearest desired duration model)

- There is a 5 day saving in the model time schedule which is because the productivity rates of the slab crews was greater in the model which resulted from the increase in productivity in the slab formworks in the model due to taking into consideration the crowdedness algorithm and also the area of formwork used was more than the area of the formwork by 25m<sup>2</sup>.
- There is about 60,000 decrease in the cost which resulted from the saving in time of the project (5 days) which decreased the amount of the crews/day.
- The different sequencing that the model and the contractor's baseline did not affect the outcomes, the model based its zoning as it has a proximity weight to choose the zones that are nearer to each other than the further apart.
- Number of activities in the time schedule generated is more than the number of activities generated in the contractor's approved baseline as the dismantling activity in the model isn't incorporated into the duration of the pouring as the contractor's baseline does which shows that the time schedule generated in the model can be more controlled.
- The preparation of the contractor's baseline schedule took about 1 week to be done as the site management team had to study the movement of the formwork sets in the building and the planning team had to calculate the time schedule and build their dependencies after the site management team finishes; on the other hand, the model took about 25 mins to extract a detailed time schedule for the model while optimizing the use of formwork in the building automatically with alternatives.
- The area of formwork in the model was more than the area of formwork in the approved baseline by about 25m<sup>2</sup>.

## Chapter 6 - conclusions & future recommendations

### 6.1 Conclusions

The study has presented a complete coherent model that generated different detailed time schedules and cost estimates for structural activities in any project. The research started by identifying the handicaps that were available in the previous studies & previous experiences. Several interviews were conducted with construction experts to collect data on the effect of formwork type & area on zoning & the sequence of work, crowdedness & its effect on labor productivity, sample composition of crews and their production rates & cost, lags to be respected among activities and spaces needed for each personal in the different crews.

An automated model to generate detailed alternatives for time schedule and cash flow forecasting was developed that consists of 3 main modules:

- An input module where the user inputs to the model, a native BIM project, type of formwork used, desire time of completion or resources available, minimum & maximum area of formwork(optional), start date & finally start point.
- An engine module that consists of eight algorithms; zoning algorithm, area of formwork algorithm, crowdedness algorithm, construction sequence algorithm, calculation of duration algorithms, time & date calculation algorithms, cost estimation algorithm & scheduling algorithm
- An output module where the model provides its users with zoning alternatives, options for time schedules accompanied with different cost plans to choose from and finally the crew requirements per month for the project.

The model was tested and verified by applying it to a pilot project of a 3 story building to ensure that all the algorithms & that the model achieves good results. Furthermore, the model was validated by applying it to an actual case study for a four story building of an area of 1240 m<sup>2</sup> and the results showed that the model can be an effective productivity tool to schedulers where it provides them with options for with the detailed time schedule & cash flow in much less time and efforts for the decision makers to choose from.

## 6.2 Future recommendations

The future work will focus on:

- Enhancement of the model to include all types of activities not only the structural activities as this will be a great asset for acceleration in the development of the time schedule process.
- Include more types of formwork in the model like table form, glass induced form, etc....
- Developing the model to export a file that is compatible by primavera p6 software as it is the commonly used software for scheduling.
- The model to be enhanced to work on more complex shapes of buildings not only rectangular.

## Appendix A - Semi Structured Interview Questions

Interview questions	
1	When do contractors decide to divide the building into different zones in the absence of construction joints
2	The criteria for the movements of formwork within one building
3	The space demand needed for each profession per the formwork, concrete pouring & the steel fixation crews.
4	The traditional composition of the formwork, steel fixation and the concrete pouring crews with their productivity rates for the traditional formwork.
5	The traditional composition of the formwork, steel fixation and the concrete pouring crews with their productivity rates for the early strike formwork.
6	The difference in the method statement between the traditional formwork and the early strike formwork usage
7	The construction sequence of the flat slab structural system.
8	The solutions for the overcrowding of labor by the contractors and how it affects the productivity rates of the crews.
9	The time it takes for a planner to develop a time schedule for the structural project activities
10	The typical sequence of the cores/shafts in the building and its effects on the zoning developed by the contractor.
11	How the lag between the steel fixation crew and the formwork installation crew is calculated
12	The cost for each type of crew for formwork (traditional and early strike)/day, concrete/m <sup>3</sup> , traditional formwork/m <sup>2</sup> , early strike formwork/m <sup>2</sup> , steel/ton

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