Simulation of Construction Processes of Multi-Story Buildings in Gaza Strip

محاكاة العمليات الإنشائية لمشاريع الأبنية متعددة الطوابق في قطاع غزة

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2013م - 1434هـ
ذَلِكَ فَضْلُ اللَّهِ يُؤْتِيهِ مَنْ يَشَاءُ وَاللَّهُ ذُو الْفَضْلِ الْعَظِيمِ 
الفَضْلِ العَظِيمِ" الجَمِيعَةُ الْآثِرَةُ (4)
Dedication

I dedicate this humble work to

My beloved parents for their endless support,

My wife for her unlimited encouragement,

My lovely kids (Karim and Yousof),

My family, colleges and friends for their sustainable support.

Hoping I have made all of them proud of me.

Mahmoud Abu kmail
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First and foremost I would like to thank Allah for what I am and for everything I have.

Next, I wish to express my deepest appreciation to Prof. Rifat N. Rustom under whose supervision and advice this thesis was developed. Without his considerable efforts, this thesis could not have been carried out through completion. Thanks to him for being my mentor and for the friendship, he offered me.

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Abstract

Multi-story building projects are classified as repetitive activities projects “RAP” that have a vital position in construction industry in Gaza Strip at present time. Many previous approaches for planning and scheduling the RAP are limited to deterministic nature and cannot ensure continuous resource utilization.

This thesis presents an integration between simulation and optimization as a key solution for planning and scheduling the RAP in terms of time and cost with the optimum number of resources. A general simulation model that is suitable for the multi-story building projects (MSB-projects) as example for the RAP was developed using Arena software. The model was designed using statistical approach for determining the activities’ durations by finding the suitable distribution functions for resources’ production rates.

The first step in model formulation was building the conceptual model, which is considered as the theoretical model for the MSB-projects and the application of the simulation model. Then the typical simulation model was developed for MSB-projects that includes the basic activities and their logical relationships. The designed model was verified and validated. The verification process was executed to ensure that the simulation model operates as intended. The validation process was executed by applying the simulation model to a real case study and compare the results versus the actual one and the results were found good. The developed model empowers the users to optimize any of the applied case parameters (cost or time) using OptQuest for Arena. The optimization process achieved decreasing in the total cost of about 7.5% from the actual cost through finding the optimum number of resources.

For more facilitation, Visual Basic interfaces were developed to facilitate the interaction of the user with Arena software where no previously knowledge with Arena is needed. These interfaces provide the user with many alternatives options for data entry at the model.
ملخص الدراسة

تُصنف مشاريع الأبنية متعددة الطوابق كمشاريع ذات أنشطة متكررة، حيث تمتلك هذه المشاريع مكانة مهمة في صناعة الإنشاءات في قطاع غزة. وحيث أن العديد من الأبحاث السابقة التي تطورت لدراسة التخطيط والجدولة الزمنية لهذا النوع من المشاريع وكانت تقتصر على الطبيعة المحددة في إيجاد الوقت وذلك لا تضمن استمرارية استخدام الموارد في المشروع.

هذا البحث يقدم تكامل بين تقنية المحاكاة والتحسين كحل رئيسي لتخفيض وجدولة المشاريع ذات الطبيعة التكرارية وفقاً للفترة والتكرار مع الحصول على العدد الأمثل للمصادر المطلوبة. فقد تم تطوير نموذج محاكاة كمصدرة مع الحصول على العدد الأمثل للمصادر المستخدمة. ف sdfg اع e م ت إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م م إل م م M

تم التحقق من صحة أداء النموذج من خلال التأكد من أن نموذج المحاكاة يعمل على النحو المنشود. فقد تم تنفيذ عملية التحقق من صحة النموذج من خلال تطبيق نموذج المحاكاة لدراسة حالة واقعية ومقارنة النتائج الأصلية ونماذج المحاكاة. تم تصميم النموذج لكي يمكن للمستخدمين من تحسين عملية التخطيط لأية حالة وفقاً للوقت والتكلفة باستخدام برنامج المحاكاة (Arena). فحققنا مساحة للتحسين (OptQuest for Arena) لخسارة التكلفة الإجمالية للمشروع حوالي 7.5% من التكلفة الإجمالية من خلال التحسينات الملموسة. لتسهيل استخدام النموذج، تم تصميم واجهات خاصة بإدخال البيانات لنموذج المحاكاة وتنبيه المستخدم من إدخال عدد كبير من الخيارات بطريقة سهلة وبدون معرفة مسبقة ببرامج المحاكاة (Arena).
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<th>Description</th>
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<tbody>
<tr>
<td>BF</td>
<td>Basement Floor</td>
</tr>
<tr>
<td>CPM</td>
<td>Critical Path Method</td>
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<tr>
<td>CPT</td>
<td>Construction Planning Technique</td>
</tr>
<tr>
<td>DP</td>
<td>Dynamic Programming</td>
</tr>
<tr>
<td>GA</td>
<td>Genetic Algorithm</td>
</tr>
<tr>
<td>GACOST</td>
<td>Genetic Algorithms with Construction Operation Simulation Tool</td>
</tr>
<tr>
<td>GF</td>
<td>Ground Floor</td>
</tr>
<tr>
<td>LOB</td>
<td>Line of Balance</td>
</tr>
<tr>
<td>LSM</td>
<td>Linear Scheduling Method</td>
</tr>
<tr>
<td>MF</td>
<td>Mezzanine Floor</td>
</tr>
<tr>
<td>MSB</td>
<td>Multi-Story Buildings</td>
</tr>
<tr>
<td>PERT</td>
<td>Program Evaluation and Review Technique</td>
</tr>
<tr>
<td>RAP</td>
<td>Repetitive Activities Projects</td>
</tr>
<tr>
<td>RF</td>
<td>Roof Floor</td>
</tr>
<tr>
<td>RSIT</td>
<td>Relative Start and Idle Time</td>
</tr>
<tr>
<td>RSM</td>
<td>Repetitive Scheduling Method</td>
</tr>
<tr>
<td>SQS-AL</td>
<td>Sequence Step Algorithm</td>
</tr>
<tr>
<td>TF</td>
<td>Typical Floor</td>
</tr>
<tr>
<td>VBA</td>
<td>Visual Basic for Applications</td>
</tr>
<tr>
<td>VBI</td>
<td>Visual Basic Interface</td>
</tr>
<tr>
<td>WBS</td>
<td>Work Breakdown Structure</td>
</tr>
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</table>
CHAPTER 1: INTRODUCTION

1.1 Background

Time, cost, quality and participation have been identified as the main criteria for measuring the overall success of construction projects. Of these, cost and time tend to be the most important and visible, always considered as very critical because of their direct economic implications (Ismail1, et al., 2010). Repetitive projects are common in construction where similar units require repetitive work from unit to unit. Repetitive projects are such as multi-story, housing, highways, tunneling projects, etc., (Lu & Olofsson, 2009).

The main challenges of planning and scheduling repetitive activities projects (RAP) are as follow: getting the optimum project duration subject to resource continuity constraints and minimum resource cost; considering the complex relationships in how resources are managed to keep resources working without idle time; and the stochastic approach for activities duration (Srisuwanrat, 2009). Therefore, there is a need for better tools for repetitive projects planning and scheduling which makes it easier for the user to create better plans with higher accuracy.

Simulation technique is a powerful tool to analyze and design complex systems. It enables to explore alternative methods or testing new ideas in advance at a fraction of the cost compared to test the ideas in reality. A simulation model may contain complex relationships between activities, which specifically consider resource usage, and uncertainties (Shannon, 1998). Simulation is a common tool supporting decision-making in manufacturing industries. In the construction industry, the use of simulation has been limited to research projects even though it has been shown that the technique can shorten design cycles, reduce costs, and enhance knowledge in the construction industry (Birgisson, 2009; Ruwanpura & Ariaratnam, 2007). Developing a simulation model typically requires the user to be familiar with specific terminology and the modeling schematics of particular software and the ability to write proprietary computer code. This may not be suitable for many practitioners who are otherwise familiar with the details needed for accurate
simulation (Zaneldin, 2008). In order to increase the value of developed simulation models, simple user interfaces were designed to facilitate the interaction of users with the simulation software.

Simulation approach is used in this research as a planning and scheduling tool to develop a general simulation model for simplifying the estimation of durations and cost of resources with optimum number of required resources for multi-story buildings (MSB) projects as example for RAP.

1.2 Research Significance

Construction sector has a significant impact on Palestinian economy and the tool through which a society achieves its goals of economic growth and development. The sector has played a crucial role in extending job opportunities for Palestinian labor force. Expansion of the construction activity in both the West Bank & Gaza Strip and State of Israel has generated a lot of jobs for skilled, semiskilled and unskilled construction workers. The contribution of housing sector is considered as an important element in the formation of the GDP in the Palestinian economy. Its share of GDP increased from 8.9% in 1994 to 13.7% in 1999, then it decreased to reach 3.9% in 2002, after that it increased to reach 6.2% in 2007 (PCBS, 2009).

It becomes a well-known phenomenon that many construction firms are facing the problem of inefficiencies in repetitive project planning and scheduling such as, delays, cost overrun and not optimum number of resources. The frequent problems of repetitive construction projects are inadequate planning and scheduling methods of the construction operations. The traditional planning and scheduling methods do not fully support the planner’s needs to see the complex relationships in how resources are used in the construction site and to consider uncertainties from using the deterministic approach. Therefore there is a need to search for better tools for project planning and scheduling to make it easier for the user forecast the a suitable durations and resources cost with optimum number of required resources to create better plans with higher accuracy. This research used simulation as a planning and scheduling tool to overcome the problems of traditional planning and scheduling methods.
1.3 Research Aim and Objectives

1.3.1 Research Aim

This research attempts to treat the debility of the methods normally used for planning and scheduling of the construction projects, especially RAP such as MSB projects, by using simulation. Simulation as an advanced technique was proposed to develop general model that supports the engineers for estimating project’s duration, cost of resources with optimum number of required resources with adequate level of confidence.

1.3.2 Research Objectives

The main objective of this research is to build a general simulation model for the MSB projects to simplify the estimation of durations and cost of resources. Moreover, find the optimum number of resources with minimum cost.

Specific objectives are as follows:

A. Formulating a conceptual model that satisfies the MSB project planning and scheduling requirements to remedies the deficiencies of the conventional methods in planning and scheduling.

B. Developing a general verified and validated simulation model, which simulates on-site construction activities in terms of time and cost of resources for MSB projects in Gaza Strip

C. Find the optimal number of resources in accordance with minimum cost using OptQuest for Arena as optimization tool.

D. Create a visual basic user-friendly interface, where no needs for previous simulation knowledge, to operate the model and facilitate the interaction between Arena software and the user.

1.4 Methodology Outline

The main objective of this research is to build a general simulation model for the MSB projects to simplify the estimation of durations and resources cost with optimum number of required resources. The approach used to achieve the major objective can be summarized in the following stages:
Stage I: System definition and project preparation

This stage includes two steps, problem formulation and identification, and setting of objectives.

Stage II: Literature review

This stage involves reading and appraising what other researchers have written about this topic.

Stage III: Model building

This is the main stage, which includes three steps; data collection and statistical analysis, conceptual model formulation and typical model development.

Stage IV: Model validation and verification

Through this stage, the model is ensured that it is correctly constructed and examines the fit of the model with the empirical data (real case study).

Stage V: Optimization process

This stage is attempts to find the optimum number of resources crew with minimum cost by using the OptQuest for Arena as optimization tool.

Stage VI: User interface building

In this stage, a visual basic user interface was built to simplify the interaction of the user who has no pervious knowledge in Arena software.

1.5 Research Organization

The thesis was divided into 9 chapters; each chapter covered certain area and went through as following:

Chapter (1) Introduction introduces the reader to the general features of the subject, represents the objectives, determines the limitations and demonstrates the importance of the research.
Chapter (2) Literature review summarizes the previous efforts made to the principles of using simulation techniques in studying construction projects, and studying the developments in the traditional methods for planning and scheduling RAP.

Chapter (3) Research methodology represents the methodology followed in the thesis, which included seven stages describing the method of research.

Chapter (4) Conceptual model formulation represents the formulation of the conceptual model by three steps; data collection and statistical analysis, building the conceptual model that satisfies the nature of MSB projects, and developing a general flowchart for the simulation model in Arena software.

Chapter (5) Model building represents the development of a typical simulation model using Arena software, and describes the model’s components and their functions.

Chapter (6) Model validation and verification demonstrates the verification and validation processes applied to the simulation modules and model. Each segment of the modules was checked solely and the integrated modules were checked jointly.

Chapter (7) Optimization process demonstrates the optimization process by OptQuest for Arena, to get the optimum number of resources crew with minimum cost.

Chapter (8) Visual basic interface (VBI) presents the development of a simple interface for data entry to the model by using Visual Basic for Applications (VBA).

Chapter (9) Conclusion and recommendation presents the conclusions from the research and recommendations.
CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

One of the most important goals that aspired in managing construction projects is completing the project with the least amount of time and at the lowest possible cost with optimum number of resources. To achieve this objective, establishing an attainable and practical planning and scheduling model in terms of time, cost, and resource utilization for the project is essential.

Repetitive activities are found commonly in the construction of multi-story buildings, pipelines, highways, and housing development projects. For such projects, similar activities are repetitively performed from unit to unit (Lu & Olofsson, 2009). The traditional planning methods for RAP do not fully support the planners and schedulers needs to see the complex relationships in how resources are used in the construction site, the ability to keep resources working continuously without idle time, and depend on the deterministic approach (determined durations) (Srisuwanrat, 2009).

Simulation is a modeling technique involving designing and experimenting with an established mathematical-logical model. When relationships between variables are not linear and/or random variables are included in the problem, simulation is a preferable tool to model the relationships and solve the problem. Simulation enables schedulers to study the behaviors of a process without the necessity of formulating a mathematical function of an unpredictable behavior input (Banks, 2000). The non-deterministic nature of construction projects is one of the most complicated factors that are often simplified or neglected by modelers. Many deterministic approaches such as linear and dynamic programming fail to provide a result with confidence because of the simplification (Yang & Ioannou, 2001). On the other hand, simulation is considered an excellent tool for the stochastic problems because the effect of uncertainties in construction projects can be modeled and assessed by using simulation (Ioannou & Martinez, 1996).
This chapter will review the available literature that is related to RAP from several perspectives. First, it demonstrates the nature of RAP. Afterward it will discuss the previous traditional techniques used for planning and scheduling RAP and their challenges and deficiencies. Then, it presents the simulation technique as a tool to remedy the deficiencies of the conventional planning and scheduling methods. Finally, discuss the main advantages of using Arena software as a simulation tool in construction industry.

2.2 Repetitive Activities Projects (RAP)

2.2.1 Nature of RAP

Srisuwanrat et al. (2008) define the repetitive projects as “projects that consist of a series of repetitive activities requiring resources working and moving from one unit to another. These units are usually identical or similar depending on the design”. Examples of these projects are multi-story building, highways, and tunneling projects. In these projects, some or all of the same set of activities are repeatedly performed from unit to unit by the same crews (Srisuwanrat, et al., 2008). For example, the same resource crew establishes the structure works from floor to floor in a multi-story building project.

Repetitive activities projects can be classified into basic categories, first where progress units are discrete entities (nonlinear projects or vertical repetitive projects), units may be floors for multi-story buildings, houses for housing development projects, or apartments for remodeling projects. The second category is linear projects (horizontal projects) that are repetitive due to their geometrical layout rather than uniform repetition of a unit work (e.g. highway, pipeline and railroads projects), (Yang & Ioannou, 2001; Hegazy & Wassef, 2001). A discrete repetitive project (nonlinear projects) involves repetition of a unit network throughout the project. This unit network consists of the activities and their interrelationships that represent the work to be performed in each unit. Despite this repetition, the work quantities for an activity may not be the same in all units (Yang & Ioannou, 2001). Moreover, some activities may not even be present in all units, they may not start and finish at the same location and the productivity of resources may not be the same in all units.
2.2.2 Scheduling Techniques for RAP

A schedule consists of a series of work tasks that are linked to each other in a logical manner. Schedule development requires a project network to be constructed showing the technological and managerial constraints amongst work tasks (Sawhney, 1997).

Many scheduling techniques have been developed for planning and scheduling. Srisuwanrat (2009) classified the scheduling techniques into two types: the first was the techniques that are suitable for general projects such as Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT). The other, was the techniques that are designed specifically to schedule the RAP such as Line of Balance (LOB), Linear Scheduling Method (LSM), Repetitive Scheduling Method (RSM), and Dynamic Programming (DP).

2.2.3 Challenges for Scheduling RAP

There are many challenges of scheduling RAP, that show the need for a sophisticated scheduling technique and tool that must be able to model these challenges and schedule the project under precedence and resource constraints, which is summarized as follows:

The durations of sub activities, in typical activities, are not always the same because they are influenced by many factors such as work amount in each unit and resource productivity for each activity. The project duration is dependent on the relation between activities, and the shortest project duration does not necessarily correspond to the shortest activity durations, especially where resource work continuity is stipulated (Srisuwanrat, 2009).

Activities may have multiple predecessors and successors. There may be multiple relationships between each pair of predecessor and successor (Yang & Ioannou, 2001). A full set of relationships (Finish-to-Start, Finish-to-Finish, Start-to-Start, and Start-to-Finish) should be available.

Non-repetitive activities are harder to schedule in order to their resource constraints and unique dependencies between the non-repetitive activity and other activities (Srisuwanrat, 2009). The non-repetitive portion of project work should be incorporated into
the framework of repetitive scheduling (Yang & Ioannou, 2001). For scheduling the RAP such as high-rise buildings, that consider each floor as a repetitive unit, it is necessary integrating between non-repetitive and repetitive works as portion of work for high-rise buildings (Zaneldin, 2008; Ismail1, et al., 2010).

Probabilistic scheduling problems are some of the most complicated problems in scheduling RAP. The difficulty starts from estimating the probabilistic durations of activities and resource continuity, to simulating the dynamic nature of construction activities (Srisuwanrat, 2009). Another issue introduced by stochastic activity durations is the need to establish an indicator determining activity criticality (Harris & Ioannou, 1998). One of the main advantages of the PERT technique that it considers a probabilistic scheduling by using three point estimates of activity durations to determine an estimated project duration (Cosgrove, 2008).

Distinguish between hard logic that mean technical precedence constraints between activities in the same repetitive unit, and soft logic, that means the dependency between repetitive units, which it may be, resource availability constraints. Soft logic is the ability of a crew to define its own orders of repetitive units for performing the repetitive work. The dependency between activities should be modeled by soft logic constraints when possible (Srisuwanrat, 2009). Ragolia (1998) discussed that in RAP not only must repetitive units be logically sequenced, but also the activities within each unit must be identified and logically related. It should be noted that if sub-activities are technically dependent they are imposed by hard logic relationships requiring both technical and resource constraints to be satisfied. For example, structural work of the first floor must be completed and resources must be available before work in the second floor can start.

The concept of soft logic provides more than one possibilities when analyzing activity sequencing. With soft logic, activities could be scheduled in parallel, in sequence (one after the other), or part in parallel and part in sequence for repetitive construction projects. In this way, the project duration can be changed not only by crashing critical activities but also by changing the logical sequences of the activities (Fan, et al., 2012).
An activity may utilize multiple crews simultaneously. A crew may perform multiple activities, it is called “shared resource” and the activities are called “resource-sharing activities.” (Srisuwanrat, et al., 2008).

### 2.2.4 Deficiencies of Methods in Scheduling RAP

The main shortcomings of CPM technique in scheduling RAP that it does not take resource consideration into account in its calculations and cannot ensure the continuous resource utilization of a crew from unit to unit. This usually leads to an unfeasible schedule due to the unawareness of resource constraints such as resource availability constraints (Selinger, 1980 cited in Srisuwanrat, 2009). CPM is incapable of capturing the realistic and stochastic nature of repetitive projects (Harris & Ioannou, 1998).

The difference between CPM and PERT is that PERT is capable of scheduling non-deterministic activity durations while CPM cannot. However, PERT has not been widely used in the construction industry compared to CPM. From a repetitive project perspective, PERT and CPM have the same limitations due to their underlying time-based scheduling calculation and their graphical presentation in precedence networks (Sawhney, 1997; Yang, 2002).

The major benefit of LOB to construction scheduling is that it conveys important production rate and duration information in a graphical format. The application and graphical presentation of LOB facilitate schedulers in constructing a schedule that satisfies precedence constraints, resource availability constraints, and resource continuity constraints (Srisuwanrat, 2009). However, the LOB has several drawbacks such as inability to incorporate varying amount of works in repetitive sub-activities. One of the unrealistic assumptions of LOB is the assumption of activities’ constant production rates (Yang, 2002). Another shortcoming of LOB is that its graphical presentation becomes confusing when many concurrent activities take place in a particular period. It is designed to model simple repetitive works and is not readily fit to the complexity of construction projects. LOB has not been used widely because it is not as readily computerized as network methods (Srisuwanrat, 2009).
Similar to LOB, many graphical approaches provide a simple means to schedule repetitive projects. Most of them have similar advantages and disadvantages, as does LSM. It is very similar to LOB technique (Mahdi, 2004). Harris and Ioannou (1998) proposed RSM, which is a graphical method that combines graphical and analytical approaches to schedule repetitive projects. It can be applied to a repetitive project consisting of typical, non-typical, repetitive, and non-repetitive activities. Distinctions between controlling activity and critical activity are made based on the introduced concept of controlling sequence and the original concept of critical activity in CPM. However RSM, have inability to assign multiple resources in an activity and do not achieve the concept of resource continuity through the project (Srisuwanrat, 2009).

Various researchers employed dynamic programming (DP), as mathematical techniques by using computerized algorithms and establishing formulas in order to solve or optimize repetitive project scheduling problems, as follows:

El-Rayes and Moselhi (2001) developed an automated model for optimizing resource utilization for RAP based on DP formulation. It was designed to identify an optimum crew formation and interruption option for each activity in the project that leads to minimum project duration. However, their DP formulation is limited only to projects with serial activities, and does not consider sharing resources between activities. Their model can solve only deterministic problems.

Senouci and Al-Derham (2008) presented a Genetic Algorithm (GA)-based multi-objective optimization model for the scheduling of linear construction projects. The model allows construction planners to generate and evaluate optimal/near-optimal construction scheduling plans that minimize both project time and cost. The model presents three major modules; scheduling module that develops practical schedules for linear construction projects, a cost module that computes the project’s costs, a multiobjective module that searches for and identifies optimal/near-optimal tradeoffs between project time and cost.

The simulation technique is expected to be credible to be learned, in addition of the automated plans that it could produce.
2.3 Construction Processes Simulation

After reviewing the challenges and shortcomings that are facing the planning and scheduling of RAP, it is necessary to propose technique to overcome these shortcomings. Simulation provides a promising alternative solution for planning and scheduling RAP through overcoming the shortcomings of traditional techniques. This occurred by creating computer simulation model of a real system (multi-story building) based on real life statistical data, actual operations and experience. In this study, the main purpose behind conducting a simulation for the project is to implement the project activities theoretically on the computer before the actual project commencement on site.

The desired outcome of using simulation technique for planning and scheduling the RAP will be realized through considering the stochastic nature, which forces planners to treat activity duration as a random variable defined by a random distribution function. Then, ensure the continuous resource utilization of a crew from unit to unit. Moreover, determine the duration of each activity as well as the optimum number of required resources with considering soft logic.

2.3.1 Background

Simulation refers to a broad collection of methods and applications to simulate the behavior of the real system, usually on a computer with appropriate software. In fact, simulation can be an extremely general term since the idea applies across many fields, industries and applications. These days, simulation is more popular and powerful than ever since computers and software are better than ever (Kelton, et al., 2002). Simulation is one of the most powerful tools available to decision-makers responsible for the design and operation of complex processes and systems. It makes possible the study, analysis and evaluation of situations that would not be otherwise possible. In an increasingly competitive world, simulation became an indispensable problem solving methodology for engineers, designers and managers (Shannon, 1998).
Modeling methodologies may vary depending on the nature of the system to be modeled. In the construction domain, simulation techniques can be used to model a wide spectrum of operations while accounting for their associated randomness and uncertainty (Hajjar & AbouRizk, 2002).

2.3.2 Acceptance of Simulation in Construction Industry

The use of simulation techniques for analyzing and planning construction projects is slowly gaining acceptance in the construction industry (Mohamed & AbouRizk, 2005). The principal reasons for the limited field application of simulation in the construction industry include the complexity of simulation tools (programmers), the lack of familiarity of simulation to practitioners, and the amount of time and cost to develop the simulation model (Kim & Gibson, 2003). Furthermore, Shi (2001) reported that simulation suffers some serious drawbacks. First of all, it is difficult to use so that simulation is still treated as the last resort among various planning tools. Moreover, process-based simulation results should be integrated to a higher project level. It requires technical training to get the desired knowledge for conducting simulation. The learning process can be months or even years long. One of the major difficulties in using computer simulation involves in modeling because modeling elements (codes) are foreign to construction practitioners (Kosturiak & Gregor, 1998). To meet this requirement, many researchers proposed user-friendly simulation environments. The combination of simulation and artificial intelligence in object functions is suggested for more user-friendly environments.

AL-Tabbaa and Rustom (2011) developed a general framework to be used in developing multiuse simulation modules for estimating project durations at the planning phase for infrastructure projects. For more facilitation, they used VBA to create a simple user interface for data entry for estimate the activities duration of infrastructure projects.

Cheng and Feng (2003) integrated simulation with GA to develop, a user-friendly computer simulation system Genetic Algorithms with Construction Operation Simulation Tool (GACOST), as attempt to find the best resource combination for the construction operation.
2.3.3 Advantages and Disadvantages of Simulation

Simulation has a number of advantages over modeling and analyzing systems. First, the basic concept of simulation is easy to comprehend and hence often easier to justify to management or customers than some of the analytical and mathematical models. In addition, a simulation model may be more credible, because its behavior has been compared to that of the real system or because it requires fewer simplifying assumptions and hence captures more of the true characteristics of the system under study (Chung, 2004). Simulation enables to test every aspect of a planned change without committing resources to their acquisition. This is critical, because when the construction has begun, changes and corrections can be very expensive (Banks, 2000).

Shannon (1998) mentioned “Simulation provides cheap insurance and a cost effective decision making tool for managers. It allows us to minimize risks by letting us discover the right decisions before we make the wrong ones”.

In simulation, it is possible to manipulate time. By compressing and/or expanding time, simulation allows one to speed up or slow down phenomena so that one can thoroughly investigate them. It is very important to understand why certain phenomena occur in a real system (Chung, 2004).

Shi (2001), handled simulation usefulness from the perspective of describing complicated processes, where the relations are difficult to define causally, or an analytic model would be too difficult to solve. In addition, he added, “Simulation method can be recommended for firms engaged in construction of repetitive projects, especially large projects where sufficient funds for planning are available”.

With simulation, one can determine the answer to the “why” questions by reconstruction and examine the scene thoroughly to determine why the phenomenon occur. In addition, it clarifies how a modeled system actually works and understanding of which variables are most important to performance (Chung, 2004).
In addition, Cheng and Feng (2003) enriched that simulation technique has been proven useful in analyzing the stochastic perspective of the construction operation. However, to find the resource combination that produces the best system performance, all possible resource combinations should be examined which is time-consuming and becomes computationally impossible when the possible resource combinations increase explosively.

For planning and scheduling RAP, there are some researchers have attempted to show the advantages of use simulation, as following:

AL-Tabbaa and Rustom (2011) found simulation is an effective approach for developing multiuse simulation modules for estimating project durations at the planning phase for infrastructure projects.

Lu and Olofsson (2009) developed a continuous flow simulation model in order to overcome the deterministic nature for activity duration. In addition, they used different distribution functions for calculating the activities durations in each activity.

Al-Helou (2006) used the simulation to solve scheduling problems of RAP. He developed a simulation model for infrastructure projects as example for RAP that includes the basic activities and their logical relationships. The model was designed to incorporate a great amount of production and cost data of the used resources, and to handle the input data particularly according to statistical approaches. As a result, for their research he concluded that the simulation technique is able to empower the planner to be fully aware with the used resources and all of their related features during the project, just like the execution environment.

Nevertheless, the disadvantages of simulation are that creating a model requires special knowledge in simulation concepts and can be time-consuming. Furthermore, most simulation output are essentially random variables (they are usually based on random inputs). Consequently, it may be hard to determine whether a simulation output is a result of system interrelationships or a result of randomness (Banks, 2000). Simulation cannot compensate for inadequate data or poor management decisions (Shannon, 1998).
For using simulation as advance technique for scheduling RAP, simulation by itself cannot control or eliminate idle times. Therefore, an external algorithm must be developed and implemented in the simulation model in order to effectively solve the problem of scheduling RAP such as optimization tool (Yang, 2002).

Srisuwanrat (2009) presented the Sequence Step Algorithm (SQS-AL), a simulation-based scheduling algorithm for repetitive construction projects with deterministic and/or probabilistic activity durations. SQS-AL is capable of scheduling RAP under variability and uncertainty while maintaining continuous resource utilization.

Another research was developed to eliminate the idle time was by Srisuwanrat et al., (2008). They introduced an alternative method for optimizing probabilistic repetitive projects in simulation, called Relative Start and Idle Time (RSIT). The method does not impose limitations on repetitive project scheduling problems nor does it implement auxiliary algorithms in the simulation model or code. Leaving the simulation model as intact as possible, the method focuses on determining effective input variables for optimization.

Most of simulation models that deal with scheduling RAP fail to control activity start dates, and thus cannot, maintain resource continuity, allow work interruption, and analyze the tradeoff between the first two to optimized project duration and cost (Srisuwanrat, 2009). Fan, et al. (2012), presented a GA based optimization model for repetitive projects when considering soft logic that aims to assist the project team to find the minimum overall cost subjected to different output rates and logical sequences. Therefore, the project duration can be changed by changing the logical sequences of the activities.

Long and Ohsato (2009) developed a new method for scheduling RAP with several objectives such as project duration, project cost, or both of them. The method deals with constraints of precedence relationships between activities, and constraints of resource work continuity. It allows the activities interruptions and considers different relationships between direct costs and durations for activities (such as linear, non-linear, continuous, or discrete relationship) to provide a satisfactory schedule. Moreover, the method finds a set
of suitable durations for activities by GA, and then determines the suitable start times of these activities by a scheduling algorithm.

2.3.4 The Simulation Modeling Process

The purpose of simulation modeling is to help the ultimate decision-maker to solve a problem. Therefore, to be a good simulation modeler, you must merge good problem solving techniques with good software engineering practice. The following shows a set of steps to guide a model builder in a thorough and sound simulation study (Banks, 2000; Kelton, et al., 2002; Chung, 2004), see Error! Reference source not found.).

**Problem Formulation:** every simulation study should begin with a statement of the problem. If the statement is provided by the policy makers or those that have the problem client, the simulation analyst must take extreme care to ensure that the problem is clearly understood. If a problem statement is prepared by the simulation analyst, it is important that the client understands and agrees with the formulation.

**Setting of objectives and overall project plan:** the objectives indicate the questions that are to be answered by the simulation study. The project plan should include a statement of the various scenarios that will be investigated. The plans for the study should be indicated in terms of time that will be required, personnel that will be used, and hardware and software requirements.

**Conceptual model:** the real-world system under investigation is abstracted by a conceptual model, a series of mathematical and logical relationships concerning the components and the structure of the system. It is recommended that modeling begins simple and that the model grows until a model of appropriate complexity has been developed.

**Data collection:** identifying and collecting the input data needed by the model. In a simulation project, the ultimate use of input data is to drive the simulation. This process involves the collection of input data, analysis of the input data, and use of the analysis of the input data in the simulation model (Chung, 2004).
**Model translation:** the conceptual model constructed is coded into a computer recognizable form, an operational model (Banks, 2000). The objective of the model translation phase is to translate the system into a computer model that can be used to generate experimental data. This is a two-step process. The first part of this process requires that the modeler decides what type of computer program to utilize to model the system. The second part of the model translation phase is to actually perform the programming of the simulation model (Chung, 2004).

**Verification:** verification concerns the operational model. Is it performing properly? It is highly advisable that verification takes place as a continuing process. It is well advised for the simulation analyst to wait until the entire model is complete to begin the verification process (Banks, 2000).

**Validation:** validation is the determination that the model is an accurate representation of the real system. Can the model be substituted for the real system for the purposes of experimentation? (Banks, 2000).

**Experimental design:** once the simulation model of the actual system has been properly validated, the developer can turn his attention to determining how to design additional models for subsequent experimental analysis (Chung, 2004).

**Documentation and reporting:** the final step in the simulation process is to write a report and create a presentation on the simulation project recommendations and conclusions (Chung, 2004). If the simulation model is going to be used again by the same or different analysts, it may be necessary to understand how the program model operates. This will enable confidence in the simulation model so that model users can make decisions based on the analysis. Also, if the model is to be modified, this can be greatly facilitated by adequate documentation. The result of all the analysis should be reported clearly and concisely (Banks, 2000).
2.4 Arena Simulation Tools

There are several simulation tools used in simulating real systems in construction industry for different objectives. Some of these tools are Monte Carlo Simulation, Micro Cyclone, AutoMod, Simscript, SimPak and Arena (Wales & AbouRizk, 1996).

The Arena simulation software package is one of the most advanced and sophisticated simulation tools employed in business and industrial engineering. It includes a “drop and drag” feature that makes it suitable for a visual network model construction that parallels the nodes and arcs of a typical network representation (Cosgrove, 2008).

In this research, four major components of Arena were used. The first is the primary component of Arena is a graphically based software package. The graphic basis of Arena allows models to be quickly developed and easily animated. The second component of Arena is the Input Analyzer that was used to fit input data. The third component is the OptQuest, which was used as optimization tool. The last component is the visual basic editor that was used for building the visual basic interface.

There are several researches used Arena software as simulation tool, the following will describe their works.

Al-Hams (2010) developed Arena simulation model to for change orders occurrences and their impact on cost, time, and productivity for building projects in the Gaza Strip.

Cosgrove (2008) employed Arena features to simplify model construction for activity time networks based on PERT. This reduction in the burden of model construction should enhance the use of Arena in network simulation, permitting users to tap additional modeling features not typically found in more specialized network simulation packages.

Al-Helou (2006) presented Arena simulation model for infrastructure projects as example for RAP that include the basic activities and their logical relationships. The model was designed to incorporate a great amount of production and cost data of the used resources, and to handle the input data particularly according to statistical approaches.
Yahia (2004) used Arena software for modeling and simulation of an ongoing project in Gaza Strip with the intention to conclude the appropriate project construction production rates and time probabilistic during the planning and implementation phase of the project.

Hammad (2001) developed a simulation model using Arena simulation software to study the production process and to identify ways by which the productivity of a manufactured housing factory could be improved leading to a cost effective and efficient system. Also, he concluded that Arena software enables the modeler to simulate very sophisticated levels of activity relationships and also has the advantage of animating the simulation process.

2.4.1 Arena Modules

Modules are the basic building blocks for Arena models. These are the flowchart and data objects that define the process to be simulated that are chosen from panels in the Project Bar in Arena (Kelton, et al., 2002; Altiok & Melamed, 2007). The modules used in this research are described in Table (2.1) and Table (2.2).

**Flowchart Modules:** describe the dynamic process in the model. Their shapes are placed in the model window and connected to form a flowchart, describing the logic of a process.

Table (2.1) Flowchart arena modules (Kelton, et al., 2002; Altiok & Melamed, 2007)

<table>
<thead>
<tr>
<th>Module</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Create</td>
<td><img src="image1.png" alt="Create Icon" /></td>
<td>The starting point for entities in a simulation model. Entities then leave the module to begin processing through the system.</td>
</tr>
<tr>
<td>Process</td>
<td><img src="image2.png" alt="Process Icon" /></td>
<td>Processing method in the simulation. Options for seizing and releasing resource constraints are available. Additionally, there is the option to use a “sub-model” and specify hierarchical user-defined logic.</td>
</tr>
</tbody>
</table>
Assign

Is used for assigning new values to variables, entity attributes, entity types, entity pictures, or other system variables.

Decide

Allows for decision-making processes in the system. It includes options to make decisions based on one or more conditions or based on one or more probabilities.

Batch

Described as the grouping mechanism within the simulation model. Batches of entities can be permanently or temporarily grouped.

Separate

Used either to copy an incoming entity into multiple entities or to split a previously batched entity.

Record

Used to collect statistics in the simulation model.

Dispose

Is intended as the ending point for entities in a simulation model. Entity statistics may be recorded before the entity is disposed.

II. Advance Modules

<table>
<thead>
<tr>
<th>Module</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ReadWrite</td>
<td>ReadWrite</td>
<td>Used to write data to an output device, such as the screen or a file.</td>
</tr>
</tbody>
</table>

III. Advanced Transfer Modules

<table>
<thead>
<tr>
<th>Module</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route</td>
<td>Route</td>
<td>Used for transferring an entity to a specified station, or the next station in the station visitation sequence defined for the entity.</td>
</tr>
</tbody>
</table>
Station

Defines a station corresponding to a physical or logical location where processing occurs. It receives the entity that comes from any location to go through another location in the model.

**Data Modules:** define the characteristics of various process elements. Only three of them are taken into consideration during the model building:

Table (2.2) Data arena modules (Kelton, et al., 2002; Altio & Melamed, 2007)

<table>
<thead>
<tr>
<th>Module</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entity</td>
<td><img src="Symbol" alt="Entity" /></td>
<td>Defines the various entity types and their initial picture values in a simulation. Initial costing information and holding costs are also defined for the entity.</td>
</tr>
<tr>
<td>Resource</td>
<td><img src="Symbol" alt="Resource" /></td>
<td>Defines the resources in the simulation system, including costing information and resource availability.</td>
</tr>
<tr>
<td>File</td>
<td><img src="Symbol" alt="File" /></td>
<td>Identifies the system file name and defines the access method, formatting, and operational characteristics of the files.</td>
</tr>
</tbody>
</table>
CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction
The main frame of this research will be discussed in this chapter. The major objective is to build a general simulation model for the MSB projects in Gaza strip, to simplify the estimation of durations and resources’ cost with optimum number of required resources. Where it was accomplished by three steps: First, started with using Arena software as a platform for building and testing the simulation model. Second, an appropriate case study was chosen for applying the validation process on the simulation model. Finally, OptQuest for Arena software was used as an optimization tool to find the optimal number of required resources in terms of minimum cost. The research methodology went through the following stages: See Figure (3.1).

3.2 System Definition and Project Preparation
This stage contains two steps: The first step is defined and formulated the overall problem. The second is established the research’s objectives.

3.3 Literature Review
After defining a main objective, a wide range of surveys was made for relevant studies to enhance the background in this topic. Review the previous traditional techniques used for planning and scheduling RAP and their challenges and deficiencies. Then the most focus was laid on the simulation technique as a tool to remedy the deficiencies of the conventional planning and scheduling methods.

3.4 Model Formulation
This stage is the essential stage, which is divided into two sequential steps as follow: See Figure (3.2).

3.4.1 Input data and conceptual model formulation.

3.4.1.1 Data collection and statistical analysis
Data collection is needed for estimating the model input parameters. The data through the model was divided into two types, user input data and simulation input data. Interviews
were done with experts, who have experience in MSB projects in Gaza Strip. By using the Input Analyzer tool, the data was analyzed and used it in the simulation model.

Figure (3.1) Research methodology flowchart
3.4.1.2 Conceptual Model Formulation

After studying all the requirements for planning and scheduling in MSB projects and the simulation consideration, the general framework was developed which reflects the logical relationships between activities and the overall mechanism followed by MSB projects. Then the general workflow mechanism of the simulation model was built for clarifying any assumptions based on interaction between the system components.

3.4.2 Model Building

Once the conceptual model was formulated, the typical simulation model is developed. The developed model was designed for multi-story building projects using Arena simulation software. The model was built through three steps: the first is demonstrates the method of calculating the processes’ durations in Arena. The second step is clarifies the main features for assigning resources in the simulation model. Finally, describes model’s components (modules) and their functions.

3.5 Model Validation and Verification

Verification process was continuous process during the model building to ensure that the model operates as intended with no errors. After the simulation model was developed, validation process was started. The purpose of model validation is to determine whether the model is an accurate representation of real system for the particular objectives of the study.

3.6 User Interface Building

Arena software supports the VBA, which enables the modeler to write custom code that augments Arena model logic and simplifying changing variables during a model. The Visual Basic user interface was developed to facilitate the interaction of the user with Arena software where no previously knowledge with Arena is needed.

3.7 Conclusion and Recommendation

As a final stage, comments on the results of the research, personal recommendations, and further research were introduced.
Figure (3.2) Modeling flowchart
CHAPTER 4: CONCEPTUAL MODEL FORMULATION

4.1 Introduction

The real-world system under investigation is abstracted by a conceptual model. In order to clarify the conceptual model formulation a preliminary model is developed that either graphically (e.g. block diagram or process flow chart) or in code to define the components, descriptive variables, and interactions (logic relationships) (Shannon, 1998). It is recommended that modeling begins simply and that the model grows until a model of appropriate complexity has been developed. The scope of this chapter covers the formulation of the conceptual model to simplify developing accurate general simulation model for MSB projects. Firstly, starts with clarifying the model’s needed input data and analyzed to determine an appropriate distribution functions for resource’s production rates. Thereafter, the conceptual model formulation will be demonstrated through define the Work Breakdown Structure (WBS), developing general flowchart for real life case in MSB-projects and workflow mechanism of the simulation model will be presented.

4.2 Input Data Collection and Analysis

Input data are key ingredients of simulation modeling. Such data are used to initialize simulation parameters and variables. This process involves the collection of input data, analysis of the input data, and uses analyzed data in the simulation model, see Figure (4.1).

Unlike most of the conventional scheduling methods, which deal with activity’s duration as a fixed deterministic input, the simulation technique has the flexibility to operate with the statistical distribution data. Therefore, to develop simulation model valid for planning and scheduling of MSB projects, it is necessary collecting more detailed data regarding productivity of resources, cost rate of resources and quantity for each activity.

![Figure (4.1) Input data collection and analysis](image-url)
4.2.1 Input Data Collection

The collection of input data is often considered the most difficult process involved in conducting a simulation model and analysis of project. The main source of input data was through interviews with experts in construction industry. Preserve complete control over the data is very important. Therefore, through the model the data was classified as follow:

- **User input data**: this data changed according to the nature of the project (variable data); it will be entered through the model using VBI (uses need not to have previous knowledge of simulation), such as quantities, number of resources and their costs.

- **Simulation input data**: in order to simulate a general simulation model for MSB projects, it is important to identify the required data for the simulation software Arena, to adapt Arena with the nature of MSB projects. This data was entered by the developer for one time for all projects (the user cannot change), such as:

  **Production rates**: productivity for resources is considering the most essential input data for any activity to compute the stochastic durations. Eighteenth points for productivity were collected for each activity in 10 working hour, which was as three points (minimum value, most likely value, maximum value) for each reading. Input Analyzer has been used to analyze data and fit the best distribution.

  **Activities’ relationships (logical relationships)**: according to nature of MSB projects, each activity has multiple predecessors and successors. The activity may be linked with more than one activity in different locations. Availability of resources control the start time of the activity. The most recurrent logical relationships were used in the model were given in Table (4.1).
### Table (4.1) Different types of relations between activities

<table>
<thead>
<tr>
<th>Description</th>
<th>Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Finish to Start:</strong> The work of activity B can start only after all the work of activity A is finished (mostly used in model)</td>
<td><img src="image1" alt="Diagram" /></td>
</tr>
<tr>
<td><strong>Start to Start:</strong> The work of activity B cannot start until the work of activity A starts.</td>
<td><img src="image2" alt="Diagram" /></td>
</tr>
<tr>
<td><strong>Finish to Finish:</strong> The work of activity B cannot finish until the work of activity A finishes.</td>
<td><img src="image3" alt="Diagram" /></td>
</tr>
</tbody>
</table>

### 4.2.2 Analysis of the Input Data

As soon as adequate data are collected, a preliminary analysis of the data was performed to assist in the model building. The analysis stage often involves the computation of various empirical statistics from the collected data. One of the most features that distinguish Arena software is to consider the realistic nature of data through providing data analysis facilities via its Input Analyzer tool, shown in Figure (4.2). “Input Analyzer” tool add-in Arena software is located at the tools menu, whose main objective is to fit distributions to a given data. Once after saving some “resources’ productivity” records in text file as “txt” format, the “Input Analyzer” has the ability to fit such records into different random distribution functions, such as, triangular distribution.
According to the local practice for construction industry in Gaza Strip, the numbers of resources in each crew are shown in Table (4.2).

Table (4.2) Number of resources in MSB crews

<table>
<thead>
<tr>
<th>No.</th>
<th>Crew Name</th>
<th>Number of resources in crews</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shutter Crew</td>
<td>2 skilled labor and 2 unskilled labor</td>
</tr>
<tr>
<td>2</td>
<td>Mason Crew</td>
<td>2 skilled labor and 1 unskilled labor</td>
</tr>
<tr>
<td>3</td>
<td>Plastering Crew</td>
<td>2 skilled labor and 1 unskilled labor</td>
</tr>
<tr>
<td>4</td>
<td>Tiling Crew</td>
<td>2 skilled labor and 1 unskilled labor</td>
</tr>
<tr>
<td>5</td>
<td>Painting Crew</td>
<td>2 skilled labor and 1 unskilled labor</td>
</tr>
<tr>
<td>6</td>
<td>Marble Crew</td>
<td>1 skilled labor and 1 unskilled labor</td>
</tr>
<tr>
<td>7</td>
<td>Isolating Crew</td>
<td>1 skilled labor and 2 unskilled labor</td>
</tr>
<tr>
<td>8</td>
<td>Electrical Crew</td>
<td>2 skilled labor and 1 unskilled labor</td>
</tr>
<tr>
<td>9</td>
<td>Plumper Crew</td>
<td>1 skilled labor and 1 unskilled labor</td>
</tr>
<tr>
<td>10</td>
<td>Carpenter Crew</td>
<td>1 skilled labor and 1 unskilled labor</td>
</tr>
<tr>
<td>11</td>
<td>Aluminum Crew</td>
<td>2 skilled labor and 1 unskilled labor</td>
</tr>
</tbody>
</table>
o **Triangular Distribution Function**

The triangular distribution function is one of most common distribution functions. It has only three parameters: the minimum possible value, the most common value, and the maximum possible value. The shape of the triangular distribution does not necessarily have to be symmetric, because the most common value does not have to be equally between the minimum and the maximum value. It is not necessary to collect much data if the developer is willing to assume that the distribution is triangularly distributed. In fact, the developer really needs to know only the three-parameter values by practice through asking a machine operator or experts to provide estimates (Chung, 2004).

According to the nature of collected data, the triangular distribution was the most suitable function for the resources’ production rates. The productivity distribution of each crew for each activity was calculated using Input Analyzer as mentioned above, see Table (4.3).

**4.2.3 Use of Processed Data in the Simulation Model**

After finding, the distribution functions they were used in the simulation model through Assign modules as attributes, which will discussed in (Chapter 5).
Table (4.3) Resources productivity distribution

<table>
<thead>
<tr>
<th>No.</th>
<th>Crew</th>
<th>Process</th>
<th>Unit</th>
<th>Productivity distribution (Per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shutter Crew</td>
<td>Plain concrete works</td>
<td>m³</td>
<td>TRIA(2.5, 3, 14.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Isolated &amp; combined footing works</td>
<td>m³</td>
<td>TRIA(3.5, 5, 7.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Raft foundation works</td>
<td>m³</td>
<td>TRIA(5.5, 8, 12.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ground beam works</td>
<td>m³</td>
<td>TRIA(0.999, 2, 3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ground Slab works</td>
<td>m²</td>
<td>TRIA(54.5, 60, 90.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Columns</td>
<td>m³</td>
<td>TRIA(0.999, 1.6, 3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wall works</td>
<td>m³</td>
<td>TRIA(0.999, 1.18, 3.75)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Staircase works</td>
<td>m³</td>
<td>TRIA(0.38, 1.1, 1.82)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slab works</td>
<td>m²</td>
<td>TRIA(14.5, 20, 30.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inlets works</td>
<td>m³</td>
<td>TRIA(0.37, 1.27, 1.94)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X-Y Grid works</td>
<td>m²</td>
<td>TRIA(300, 350, 400)</td>
</tr>
<tr>
<td>2</td>
<td>Mason Crew</td>
<td>Masonry works</td>
<td>m²</td>
<td>TRIA(34.5, 40, 70.5)</td>
</tr>
<tr>
<td>3</td>
<td>Plastering Crew</td>
<td>Normal plastering (Internal &amp; External )works</td>
<td>m²</td>
<td>TRIA(39.5, 55, 80.5)</td>
</tr>
<tr>
<td>4</td>
<td>Tiling Crew</td>
<td>Ground tilling works</td>
<td>m²</td>
<td>TRIA(14.5, 25, 45.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wall tilling works</td>
<td>m²</td>
<td>TRIA(9.5, 20, 35.5)</td>
</tr>
<tr>
<td>5</td>
<td>Painting Crew</td>
<td>Painting works</td>
<td>m²</td>
<td>TRIA(79.5, 90, 111)</td>
</tr>
<tr>
<td>6</td>
<td>Marble Crew</td>
<td>Marble parapets works</td>
<td>m'</td>
<td>TRIA(24.5, 25, 50.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Marble cupboard works</td>
<td>m'</td>
<td>TRIA(0.999, 1.18, 3.75)</td>
</tr>
<tr>
<td>7</td>
<td>Isolating Crew</td>
<td>Isolated works</td>
<td>m²</td>
<td>TRIA(94.5, 140, 141)</td>
</tr>
<tr>
<td>8</td>
<td>Electrical Crew</td>
<td>Preliminary electrical works</td>
<td>m²</td>
<td>TRIA(29.5, 30, 60.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fix electrical works</td>
<td>m²</td>
<td>TRIA(19.5, 30, 50.5)</td>
</tr>
<tr>
<td>9</td>
<td>Plumper Crew</td>
<td>Sanitary works</td>
<td>m²</td>
<td>TRIA(34.5, 50, 70.5)</td>
</tr>
<tr>
<td>10</td>
<td>Carpenter Crew</td>
<td>Wooden doors</td>
<td>No.</td>
<td>TRIA(4.5, 8, 12.5)</td>
</tr>
<tr>
<td>11</td>
<td>Aluminum Crew</td>
<td>Aluminum windows</td>
<td>m²</td>
<td>TRIA(14.5, 20, 40.5)</td>
</tr>
<tr>
<td>12</td>
<td>Excavator</td>
<td>Excavation</td>
<td>m³</td>
<td>TRIA(150, 190, 250)</td>
</tr>
<tr>
<td>13</td>
<td>Compactor</td>
<td>Backfilling works</td>
<td>m³</td>
<td>TRIA(29.5, 48.8, 60.5)</td>
</tr>
</tbody>
</table>


4.3 Conceptual Model Formulation

Robinson (2010) defined the conceptual model as “the abstraction of a simulation model from the part of the real world it is representing (‘the real system’)”. Constructing a conceptual model will be in terms of; define a hierarchy of a real case for MSB-projects (Work Breakdown Structure), developing flow chart to show the logical relationships for MSB-projects, building workflow mechanism of the simulation model and clarify any assumptions based on interaction between the system components.

4.3.1 Project WBS

WBS is a graphical portrayal of the project, exploding it in a level-by-level fashion, down to the degree needed for effective planning and control. It must include all deliverable end items, and includes the major functional tasks that must be performed. (Hinze, 2008). As with the scope statement, the WBS is often used to develop or confirm a common understanding of project scope. Each descending level represents an increasingly detailed description of the project elements. In order to create representative WBS for MSB-projects was divided into four sequential levels as shown in Figure (4.3). These four levels are summarized as follows:

- **Level 1 (Project)**

  It is the highest level in WBS, which it is concerned with any general information related to the entire project and clarified the nature and scope of the project, for example (building project, bridge project, infrastructure project, etc.).

- **Level 2 (Subproject)**

  Project level is divided into some subprojects, which provide a description of what to be done in certain part of the project. In MSB projects, the subprojects are the different floors in the project (basement floor, ground floor, etc.) Mainly each subproject contains two work packages that are required to complete a subproject.
Multi–story Building Project

Level 1
(Project)

Level 2
(Subproject)

Level 3
(Package)

Level 4
(Activity)

- Roof Floor
- Typical Floors
- Annex Floor
- Ground Floor
- Basement Floor
- Under Ground Works
- Footings Works
- Mobilization & Excavation

- Finishing Works
- Structure Works

- Masonry & Inlets
- Electrical
- Sanitary
- Marble
- Plaster
- Tile
- Aluminum
- Wood
- Paint
- Columns
- Slab
- Staircase
- Wall
- Column Neck
- Isolated works
- Ground Beam
- Backfilling
- X-Y Grid
- Plain Concrete
- Footings
- Mobilization
- Excavation
- Leveling & Compaction

Figure (4.3) WBS for MSB-Project
• **Level 3 (Package)**

  The third level describes how to construct the subprojects in work packages, for example in MSB-projects (structure works and finishing works). Each work package is a single discrete scope of work that is to be performed by a single responsible party. Therefore, it works together according to their logical relationships.

• **Level 4 (Activity)**

  The lowest level of a project is the activity level that contains many tasks, which are essential to accomplish the work in details, in MSB-projects such as (columns works plaster, paint, etc.) The activities are logically connected to each other with various relationships. Through the activity level, it will be possible to assign resources, cost rates, and quantities.

**4.3.2 General Framework of MSB Projects**

  To develop successful and effective simulation model, logical flowcharts must be designed to represent the hierarchy of the entire model, see Figure (4.4). This flowchart must be clearly defined and have correct logic, because it is reflected the real case with all of variables, to give correct output results. It was built through a group of subprojects that are connected in different relationships. It starts with “Mobilization and Excavation Works” subproject, then user must specify the type of foundation whether “Isolated /Combined Footings” or “Mat Foundation”. If there is no basement floor (BF), the entity goes to execute the “Underground Works”, which not exciting in BF works. Otherwise, it goes to execute the Structure Works for the BF. Then, it will work in parallel in Finishing Works for BF and Structure Works for ground floor (GF). If there is mezzanine floor (MF), it can start its Structure Works in parallel with Finishing Works for the GF. Otherwise, it goes to execute the Structure Works for the typical floors (TF). The Finishing Works for the TF can be works in parallel with Structure Works for the TF. If there is roof floor (RF), it will start after finishing all Structure Works for TF. After that, “Staircase and External Finishing” it begins as final step before handing over.
START

Mobilization & Excavation Works

Case I

Type of Foundation?

Isolated & combined Footings

Case II

Mat foundation

Is There Basement Floor?

Underground Works

Yes

Basement Floor structure works (BF) Finishing Works

No

Typical floor structure works (GF) Finishing Works

Is There Mezzanine Floor?

Yes

MF floor structure works (MF) Finishing Works

No

Typical floor finishing Works

Reached No. of required typical floor ??

Is There Roof Floor?

Yes

Roof floor structure works (RF) Finishing Works

No

Staircase & External Finishing

Hand Over

Figure (4.4) MSB-project procedures
4.3.3 General Structure for Simulation Model

Once WBS and the general framework of MSB projects were built, it becomes easy to construct the general hierarchy of the simulation model that describes how the system components will be modeled. The generic model was divided into four sequential levels that are embedded in each other to formulate the final simulation model that suits the logical mechanism previously discussed in section (4.3.2). Figure (4.5) shows the hierarchy of the simulation model from lower level to the highest.

- **Model**

  It represents the generic model that reflects the general system logic for the entire project. It consists of many groups of sub-models (blocks) connected to each other. The model was developed through generating one entity representing the project.

  The entity was transmitted from one block to another until all activities in each block has been executed. Before the entity enters each activity (Process), it is divided by the area of the building into (100m²) as one part and all parts batched again when the process was done.

- **Block**

  It considers the second level in the simulation model, which consists of a group of sub-models that are logically connected to each other (as described in section 4.3.2). Block level in the simulation model represents level two in WBS. For example, ground floor works is considered as simulation block that contains two sub-models (structure works and finishing works).

- **Sub-model**

  A sub-model level consists of number of interrelated activities (modules), which are logically connected to each other. The logical connections were assumed as in practice in Gaza Strip.
• **Module**

It is considered key element for building the simulation model. These modules are considered as flow of logic that simulates different construction activities. Modules were classified into three types: the first type is dedicated to data entry (Assign modules). The user enters this data through VBI (chapter 6) which forwards the data to a specific Assign module. The second type is related to build the logical relationships in the simulation model that contains (Separate, Batch, Decide modules). The last type is (Process module), which represents the activity.
Figure (4.5) General structure of the simulation model
CHAPTER 5: MODEL BUILDING

5.1 Introduction

After determining the needed data, defining the model components and describing the model’s flowchart, the simulation model is developed. The objective of the model building phase is to translate the system into a computer model. The developed model was designed for multi-story building projects using Arena simulation software. The main power of Arena is that it considers the stochastic nature for calculating the processes’ durations as discussed in this chapter. The next section clarifies the main features for assigning resources in the simulation model. Finally, the general layout of Arena simulation model is described in addition to the model’s components (modules) and their functions.

5.2 Processes’ Duration

To achieve the concept of continuous resource utilization, the entity (building) was divided into segments according to the total area, each segment equal (100m²). When the entity enters the Process module, it will seize the resource until the process delay has been finished. So the duration of the process was entered as delay time in the Process module in Arena as an expression, as follows:

\[ D = \frac{Q}{P \times S} \]  

Eq. (5.1)

Where:

\( D \) = activity duration (process delay).
\( S \) = the number of entity (building) segments.
\( Q \) = the quantity of work.
\( P \) = the productivity of resource crew.
As shown in Eq.(5.1), the delay time of the process (activity duration) depends on the number of entity segments (S) according to three cases:

- When the number of idle resources (not seized) is equals the number of segments; all segments will enter the process and each segment will catch one resource. Therefore, all of them will be finished at the same time.
- When the number of idle resources (not seized) is greater than the number of segments; all segments will enter the process and each segment catches one resource. Therefore, all of them will be finished at the same time. Nevertheless, the excess resources will be still idle.
- When the number of idle resources (not seized) is less than the number of segments, the number of segments that enter the process only equal the number of idle resources and the others will wait in queue until the resources are idle. So the process duration will increase.

All start and finish dates for each process were determined in Excel Worksheet via ReadWrite module in Arena, see Figure (5.1). When the entity arrives at the ReadWrite module, the simulation time will be written as (day-month-year) in excel sheet. So this module was used before and after each process to write the start and finish dates for each activity.

![Figure (5.1) Activities’ dates in excel sheet](image-url)
5.3 Resources Pool

The model has two types of resources: human resources and equipment resources. The human resources are assumed as crews and not as individual resources. For example, the shutter crew contains two skilled labors and two unskilled labors as mentioned in (chapter 4, section 4.2.1). The user can enter the number of resources crew and their costs. The resources’ cost does not include the cost of materials. For example, the cost of resources in aluminum works equals the cost of installation only.

Resources’ capacity and cost were inserted in the Arena model via Resource data module that is considered the resources’ pool, see Figure (5.2). Resources may have fixed capacity that does not vary over the simulation run or may operate based on a schedule. In addition, the user can get the optimum number of resources with minimum project cost or minimum project duration (user specify) via OptQuest for Arena tool as optimization technique.

![Resource data module – Recourses pool](image)

Figure (5.2) Resource data module – Recourses pool
5.4 Arena Model Layout

The developed model was especially designed for construction projects (MSB-projects) as example for RAP. The reason of choosing this category of projects is that it has a vital position in construction industry in Gaza Strip at the present time.

The developed model was composed of twelve Arena blocks: project start, mobilization and excavation, footings, underground works, basement floor, ground floor, mezzanine floor, typical floor, roof floor, assemble block, staircase and external finishing and handing over, see Figure (5.3). Through these blocks, all activities of MSB-project will be executed. At the beginning, on the “project start” block, one entity will be created to represent the entire project, also at the same block all required data will be assigned on the entity as attributes. Then the entity will flow through the model according to the general hierarchy for MSB-projects that was discussed in (chapter 4, section 4.3.2). All possible scenarios were simulated to build a general simulation model that satisfies the nature of the MSB-projects. The user will choose between these scenarios according to his case and reflects his choice to Arena model via Decide module. For example, the model was valid for isolated, combined footings and mat foundation.

All floors blocks contain two sub-models: the structure and finishing works. Each sub-model has the same activities and the same logical relationships for all floors (repetitive activities). The next sub sections handle in details, project start block, mobilization and excavation block, footings block, underground works block, typical floor block (as example for repetitive activities), staircase and external finishing block and handing over block. Figure (5.4) shows the layout of the Arena model.
Figure (5.3) Arena blocks flowchart
Figure (5.4) Arena model layout
5.4.1 Start Block

It is considered as starting point for the flow of the entity through the model. It has two basic functions: Create the entity that will be created via Create module in Arena. Assign the required data for the model, which will be through the Assign modules that were designed in “Input data” sub-model, see Figure (5.5).

![Project Start Diagram]

Figure (5.5) Start block

Figure (5.6) shows the Create module panel. In frame, “Time Between Arrivals” choose “constant” option from type menu and set “value” equal (1) to create one entity that represents the entire project. Thereafter the entity will enter “Input Data” sub-model to hold the required data as attribute. As mentioned in (chapter 4, section 4.2.1) data through the model were classified into two types: user input data and simulation input data. All input data were assigned in the entity via Assign module as attributes.
User input data was divided into groups according to the Arena blocks. Insertion of these data could be done in two ways: by using the VBI where no prior knowledge of Arena is required, or by direct insertion of data to the Assign module in Arena as shown in Figure (5.7).

Figure (5.7) demonstrates the Assign module for the “Isolated Footing” activity including the identification of the quantity (concrete volume). For entering all variables related to site conditions and quantity of each activity, 104-assign modules were designed in Arena. To simplify programming of the user interface, each Assign module was designed for one input data. All assign modules (input data) and their functions are presented in Appendix 2.

For the simulation input data, two Assign modules were designed, resources’ productivity and entity segments. As mentioned in (Chapter 4, section 4.2.2), Arena software is a suitable tool to consider the realistic nature of data. After collecting the resources’ productivity and finding the suitable distribution functions for the resources in each activity via Input Analyzer, the function is fed into Arena by Assign module as attributes, see Figure (5.8).
Figure (5.7) Assign module – User data

Figure (5.8) Assign module – Simulation data
5.4.2 Mobilization and Excavation Block

- Activities hierarchy and description
  In this block, the work includes the following activities: mobilization works, excavation works and leveling and compaction works. They are linked together as shown in Figure (5.9).

  ![Diagram](image)

  Figure (5.9) Mobilization and excavation block relationships

  **Mobilization works:** contains all works related to preparation of the project site, that includes preparing site and removing any existing obstacles, preparing construction equipment, material, facilities, project staff, etc. The duration of the mobilization works depends on the project size and the nature of the site. So its duration is left to be specified by the user according to his case.

  **Excavation works:** include all excavation works according to design depth. Its duration depends on the productivity of excavator and the site of the storage area.

  **Leveling and compaction works:** begin after excavation works have been finished. The main purpose of this activity is leveling and compacting the site after excavation. Its duration depends on the productivity of the compactor.
• **Arena modules**

After creating the entity and assigning all input data, the entity goes to perform the project blocks. The first block is mobilization and excavation block, which includes one sub-model that consists of three activities, see Figure (5.10).

![Mobilization and Excavation](image)

Figure (5.10) Mobilization and excavation arena modules

Each activity in the project was represented as “Process Submodel” that contains three modules (Separate, Process and Batch). Figure (5.11) shows “Excavation process” as an example. When the Process type is specified as “Submodel”, all fields in the logic portion of the Process module will disappear and will not be used and converted as sub-model window that has one entry point and one exit point. Through this window, any other modules can be inserted with logical relationships that should be connected to the entry and exit points.
To define the submodel logic, simply right-click on the Process module shape and select “Edit Submodel” option from the menu. A window will appear where the submodel logic may be defined. The submodel window includes an exit point on the left side and an entry point on the right side of the window see Figure (5.12).

Figure (5.11) Submodel processing

Figure (5.12) Excavation modules
**Separate module:** used to copy an incoming entity into multiple entities. When the entity enters this module, it is divided into segments according to the total area; each segment equals $(100\text{m}^2)$.

By choosing “Duplicate Original” option from separate type menu, the entity will be duplicated according to the specified “# of Duplicates” plus the original entity. The original entity will leave the Separate module and continue processing until it reaches a process delay or a queue. Duplicate entities will be sent from the Separate module to their respective modules, no simulation time consumed in Separate module, see Figure (5.13).

The entity was duplicated with “# of Duplicates = Segment – 1”. Where “Segment” is an attribute and defined equals the (total building area /100).

![Separate module diagram](image)

**Figure (5.13) Separate module**

**Process module:** is considered as the main processing method in the simulation model. Via this module, can enter the process delay time and assign the required resources from the recourses' pool.
As shown in Figure (5.14) the process module for the Excavation activity functioned to assign the passing entity with the needed resource crews to perform the work and activity’s duration. After resources were initially fed to the resource data module, which represents the project’s resource pool, the needed resources will be added to the Process module through the resource dialogue. The logic action for assign resources in the process is “Seize Delay Release” which means that the entity seizes the resource until it has finished the work and released it. The priority field for this module is used when multiple entities are waiting to seize the same resource. Processes with priority (1) are allocated the resource before a priority (2) or (3). Entities with the same priorities will be serviced first-in first-out. By checking “Report Statistics” check box all process statistics such as time and cost are collected when the entity leaves the Process module in Processes Report. All parent processes statistics are recorded as the entity goes back through the levels of hierarchy.
To start the “Expression Builder”, click on the field “Expression” in Process module. Then right-click and choose “Build Expression…” from the right-click menu, see Figure (5.14).

In the lower section of the “Expression Builder” window, there is an edit box labeled “Current Expression” where used to build the expression. When pressing “OK” on the “Expression Builder”, the text in “Current Expression” is transferred to the expression in Process module. The duration of each entity will enter as delay time in the Process module that was calculated by applying equation Eq.(5.1), as discussed in Section (5.2). “Expression Builder” was used to formulate the duration equation in the Process module by using previously defined attributes, see Figure (5.15).

![Expression Builder](image)

Figure (5.15) Expression builder

`Exc.vol = excavation quantity
Excavation = excavator productivity
Segment = no. of entity segment`
5.4.3 Footing Block

- **Activities hierarchy and description**

  Through this block, two scenarios were simulated: isolated/combined footings and mat foundation (user specify). Both of them include the same activities as follows: xy-grid, plain concrete and footing works. They are linked together as shown in Figure (5.16).

  ![Diagram of Footing Block Relationships](image)

  **Figure (5.16) Footing block relationships**

  **X-Y Grid works:** related to fixing the columns and walls axes and determining the footings places. It must finish to begin the next activity.

  **Plain concrete works:** include four activities: installing shutters, fixing the reinforcement steel, casting, and curing. The duration of this activity depends on the productivity of shutter crew per cubic meter per day of reinforced concrete plus the curing time.

  **Footing works:** it starts after casting the plain concrete. Its duration varies according to the type of footings (isolated/combined footing and mat foundation) and the productivity of shutter crew.

- **Arena modules**

  Footing block contains two sub-models, the user will choose between them. The first, was designed to perform all activities related to isolated/combined footings, which contains three Process modules. The second was designed to execute all activities related to mat foundation that has the same Process modules as in the first sub-model, see Figure (5.17).
When the entity reaches to Decide module “Type of foundation”, it will check the condition to decide where it will flow. By choosing the type as “2-way by condition” it can build “if statement” to direct the entity according to user choice. If the user chooses (isolated/combined footing) scenario the attribute “Footing” will take a value equals (1) (true), and the entity enters (isolated/combined footing) sub-model, and if the user chooses (mat foundation) scenario the attribute “Footing” will take a value equals (0) (false), and the entity will enter (mat foundation) sub-model, see Figure (5.18).
5.4.4 Underground Block

- Activities hierarchy and description

It is assumed that this block contains one sub-model that has six activities: column necks, isolation sheets (footing and columns neck), backfilling 1\textsuperscript{st} stage, ground beams, backfilling 2\textsuperscript{nd} stage, ground slab that are linked together as shown.

Figure (5.19).

Figure (5.19) Underground block relationships
**Columns necks works:** considered as the first activity after casting the footings. Columns necks are usually defined as the underground portion of the columns. Columns necks works include installing shutters, fixing the steel reinforcement, casting, and curing. The productivity for shutter crew in the columns is less than the footings.

**Isolation:** is usually done for any underground concrete structure. It is assumed for columns necks and footings, which were painted with two coats of hot bitumen.

**Backfilling:** done in two stages. The first stage is filling the site to the ground beams level. The second is filling the site to the required level. It is assumed that the filling will be in layers (each layer = 25cm). The works include watering and compaction for each layer.

- **Arena modules**
  
  The entity will enter this block if there is no basement floor. It contains one sub-model that has six process modules to perform the work, see Figure (5.20).

![Diagram](image)

**Figure (5.20) Underground modules**

### 5.4.5 Typical Floor block

- **Activities hierarchy and description**

  It contains two sub-models: structure and finishing works, which will be repeated in each floor.

  Structure works sub-model consists of six main activities that are responsible to perform all structural works in each floor. It is assumed that the staircase activity will be executed in two stages; the first, as finish-to-finish with columns activity, and the second, as finish-to-finish with slab works, see Figure (5.21).

58
Slab works: include two main activities; the first is structure works for the slab that contains shuttering and fixing steel reinforcement that will be performed by shutter crew. The second is mechanical and electrical works that works in parallel and as finish-to-finish with structure works.

Curing and removing shutters: after casting the slab it must be cured within (3-7) days as in practice. Removing shutters was assumed after (16) days from casting.

Finishing works sub-model contains fourteen activities that are responsible to perform all finishing works in each floor. These activities are linked together as shown in Figure (5.22).
**Masonry and lintel works:** is assumed as the first activity in the finishing works starts after curing and removing the shutters. This activity was assumed to be performed in two stages: internal and external that work in parallel.

**Preliminary works:** it usually contains four activities that work in parallel as shown in Figure (5.22).

**Plastering:** starts after finishing all required preliminary works. Type of plastering is assumed as normal plaster with two coats.

**Tiles works:** the productivity of the tilling crew depends on the type of tiles, so it is assumed as Ceramic or Porcelain tiles for floors and Ceramic tiles for walls.

**Painting works:** the productivity of painting crew depends on the type of paint, so it is assumed as emulsion painting.

- **Arena modules**

  This block contains two sub-models: structure sub-model and finishing sub-model that are repeated for each typical floor in a loop, Figure (5.23).

![Figure (5.23) Typical floor arena modules](image)

**Structure Works modules:** structure works are consider as a repetitive part in each floor, so the entity will go through this sub-model in a loop. Each loop represents one floor. The loop was built in Arena as shown in Figure (5.24).
When the entity enters “Assign1” module it is labeled with attribute “no” equals (0), then this attribute will increase by (1) in the assign module “Assign2”. After that, the entity enters the sub-model “Typical Floor” with attribute “no” equals (1) that represents the first floor. After structures activities for the first floor have been finished, the entity will enter Decide module to check if it reached to the required number of typical floors or not. If the attribute “no” does not equal the number of required typical floors (N), it goes back to “Assign2” to label with attribute “no” equals (2) that represents the second floor to perform structures activities for the second floor, and so on. Except that, the entity will exit from “true” exit point.

Figure (5.24) Typical floor loop
Structure sub-model contains five processes modules to perform all structure activates with their logical relationships that were discussed in Figure (5.21). To simulate a Finish-to-Finish relationship between columns and staircase activities, the arriving entity will be split as two entities; each of them will be performed one process in parallel. After leaving the processes, they grouped again in Batch module. Before the entity enters the curing and removing shutter activity, it will split again as two entities, one of them flows to complete the structure works for the next floor. And the other flows within curing and removing shutter activity. Then it is sent to finishing works via Route module to work in parallel with the entity that has been in structure works in the next floor, see Figure (5.25).
Figure (5.25) Typical floor structure modules
Route module was used to transfer the entity to a specified station (finishing works) that has one entry point and no exit point. When the entity enters the Route module, its station attribute (Station name) is set to the destination station. Then the entity has been sent to the destination station using route time equals zero, Figure (5.26).

![Route module](image)

**Figure (5.26) Route module**

**Finishing Works Modules:** as shown in Figure (5.23), the entity will arrived to finishing sub-model via Station module. The Station module defines a station corresponding to a physical or logical location where processing occurs. The entity will proceed directly from Rout module where the entity transfer is initiated to the corresponding Station module, regardless of the location of the Station module within the model. It has one exit point and no entry point. By setting the “Station Name”, the Station module will received the entity from the Route that has been labeled with the same station name, see Figure (5.27).
The layout of the finishing sub-model contains two modules: the first is “Process submodel” module that contains fourteen processes modules that are responsible to perform all finishing activities with their logical relationships, see Figure (5.29). The second module is Batch module that is responsible to group all entities according to the number of typical floors, to leave the finishing sub-model as one entity, see Figure (5.28). Once the entity leaves the finishing sub-model, it transfers to Assemble Block for grouping with other entities.
Figure (5.28) Batching finishing floors
Figure (5.29) Finishing sub-model contents
5.4.6 Assemble Block

This sub model is designed to re-aggregate the split work streams into one line again and to batch the entity’s duplicates into one entity that holds all of the desired records and information of the performed activities in the project. The layout of the Assemble Block consists of two modules: Station module and Batch module as shown in Figure (5.30).

The Station module is intended to receive all entity’s duplicates within the entire model. The Batch module is intended to group the received entities into one entity in order to be disposed in the next sub model. As shown in Figure (5.30), the batch size is different according to the project's scenarios, for example: batch size is (6) if the project has (basement, mezzanine, and roof floors).

![Assemble Block modules](image)

Figure (5.30) Assemble block modules
5.4.7 Staircase and External Finishing Block

It is the last block in the model, which contains two sub-models: staircases finishing and external finishing works. The two sub-models were designed to work in parallel and were linked with (FF) relationship that was built though Separate and Batch modules as shown in Figure (5.31).

![Staircase and External Finishing Works](image)

Figure (5.31) Staircase and external finishing block

**Staircase finishing sub-model:** The model was designed for more than one staircase, through building a loop in staircase sub-model as typical floors. As shown in Figure (5.32), it contains four processes: preliminary electrical, plastering, marble works and painting that are linked with (FS) relationship. The descriptions of these finishing activities are like the description of finishing activities in floors.

![Staircases Finishing](image)

Figure (5.32) Staircase finishing modules
**External finishing sub-model:** The layout of external finishing was assumed has two processes: plastering and painting, which linked with (FS) relationship and their activities’ description like the description of finishing activities in floors, see Figure (5.33).

![Diagram of External Finishing](image)

Figure (5.33) External finishing modules

### 5.4.8 Handing Over Block

This block represents the final step in the simulation model. It has Dispose module that has one entry point, and no exit points, see Figure (5.34). Its main function is to end the simulation process. The single entry point is to receive the incoming single entity from the Assemble Block. Having no exit points indicates that this block includes the termination point of the simulation process.

![Diagram of Handing Over Block](image)

Figure (5.34) Handing over - Dispose module
Chapter 6: Model Verification and Validation

6.1 Introduction

During the model building phase, it is essential to ensure that the simulation model operates as intended and that the model actually runs. This process is known as model verification. Chung (2004) looks at the verification processes as “Building the model correctly”. So the verification processes were applied for each component of the model. After ensuring that the model was built correctly, validation process was begun. Chung (2004) defines the model validation as “the process of ensuring that the model represents reality at a given confidence level”. In other words, validation can be considered as “Building the correct model”.

This chapter demonstrates the verification and validation processes, which applied to the simulation modules and model. A case study was selected for applying the validation process.

6.2 Model Verification

Verification is the process of ensuring that the simulation model operates as intended. This means that the model should include all of the intended components and that the model is actually able to run without any errors or warnings (Chung, 2004). Verification should be considered as a continuous process rather than a one-shot effort. So the verification process was executed by comparing each block of the model versus the applied traditional schedule (CBM) for the real case. If these results are close to actual results, then this means that the simulation model has a correct logical relationships and probability distribution functions. In addition, the logical relationships between activities were tested by tracking each start and finish dates for each activity using MS-Excel. Furthermore, all activities were drawn in MS-Project to ensure there are no overallocations happening in resources.
6.3 Model Validation

After the entire model has been built and ensured the model was built correctly through verification process, the validation process was started. As mentioned above, the validation process is to determine whether a simulation model is an accurate representation of real system for the particular objectives of the study.

Validation should be done for the entire model (Banks, 2000). There are two major types of validation. The first is face validity, which was achieved with the assistance of domain experts who are considered knowledgeable on the system under study to ensure that the model represents reality. The second is statistical validity that involves a quantitative comparison between the output performance of the actual system and the model (Chung, 2004).

In this research, validation process was performed using both; face validation and statistical validation. Face validation was achieved through a cyclic model review and improvement process with the assistance of a number of project managers and site engineers. For statistical validation, it was achieved through comparing the model’s results with traditional scheduling (CPM) for actual case study using Microsoft Office Project (MS Project) program.

6.3.1 Model Features

The model was built as general model to accommodate the most frequent scenarios for structure projects in Gaza Strip, see (Section 5.4). Moreover, the model handled recourses costs, and neutralized any other costs such as: materials and overhead costs, due to their static effect on the overall cost value. In addition, three types of the used resources were considered as permanent resources that owned by executing company (shutter crew, mason crew and plastering crew), and other resources assumed as subcontractors. All resources’ costs are inserted per hour. Moreover, the model assumed ten working hour per day (common practice) and the total duration expressed as working days.
6.4 Limitations

The limitations on the model adopted are divided into two groups as follow:

6.4.1 General Limitations

The model is generic to its structure, but it is tested on construction activities involved in the erection of a concrete framework casted on-site. The model has been built to suit the nature of the MSB projects in terms of the structural approach in Gaza Strip. The model was built in Arena 12.00.00., which is a commercial software for simulation approach.

6.4.2 Specific Limitations

A. Special logical relationships between activities were used in the model, which are convenient with MSB projects.
B. The model handled resources costs, and neutralized any other costs such as materials and overhead costs, due to their static effect on the overall cost value.
C. The model assumed ten working hour per day and the total duration expressed as working days.
D. Special type of internal and external finishing was used such as (normal plastering and emulsion painting only without decoration).

6.5 Validation Process

A residential multi-story building project was selected to be a representative case study that was modeled by Arena software. The case was appropriate the limitations and the conceptual model. All project data was gathered from a leading engineering company with an extensive experience in this field. The project consists of five typical floors, basement, ground, mezzanine and roof. The area of ground floor = 788 m², the area of typical floors = 861 m², and the area of the roof = 490 m². The basement and ground floors were designed as services places and warehouses. And the other floors were residential floors. The type of foundation was isolated and combined footings. The project includes all internal and external finishing works. All finishing works were assumed to appropriate the limitations of the simulation model as discussed in (Chapter 5). List of activities, their
logical relationships, activities' priorities and resources production rates were considered as fixed input data, which were inserted by the developer as in practice. Bill of quantities, resources’ capacities and their costs were considered as user input data, which are presented in Appendix 1.

The actual plan for this case study was CPM plan that was built using MS-project. The MS-project depends on the deterministic durations for activities. Moreover, the MS-project produces only one simple planning attempt. For instance, the total duration was (290 working days) and the total resources cost equals (204,880 $).

The simulation model was run 100 replications with confidence level 95% using the same number of resources in the actual plan. Table (6.1), shows the results of the simulation model.

<table>
<thead>
<tr>
<th>Table (6.1) Simulation results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration (Working day)</td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
<tr>
<td>Duration (Working day)</td>
</tr>
<tr>
<td>Cost ($)</td>
</tr>
</tbody>
</table>

It is noteworthy that the estimated duration (simulation results) depends on distribution functions for activities durations, which were considered the main power of the simulation technique in planning and scheduling. Moreover, the simulation results have more support, by generates many planning attempts by each replication. In addition, the developed simulation model has the ability to define such uneven levels of priorities for the performed activities. All of the mentioned characteristics of the simulation model input features make it advantageous regarding the outputs quality.
From Figure (6.1), it is clear that the differences between the results of the simulation model and the actual plan results are relatively small (about 2%). In addition, by face validation the simulation result was acceptable. So it is obvious that the model is valid and was designed properly in terms of time.

Figure (6.2) Actual cost vs. simulated cost
Figure (6.2) presents the total resources costs for actual plan and simulated plan. It is clear that the resources’ costs of the simulation model are close to the actual resources’ costs (about 2%). In addition, by face validation the simulation results were acceptable. So it is obvious that the model is valid and was designed properly in terms of cost.
CHAPTER 7: OPTIMIZATION PROCESS

7.1 Introduction

In terms of finding an optimum number of resources crew with minimum cost and sophisticated constraints, the optimization process is a valuable tool. The designed model integrates simulation and optimization engines using OptQuest for Arena program. OptQuest is an optimization tool that enhances the analysis capabilities of Arena by searching for optimal solutions within simulation model to satisfy the defined constraints. This chapter demonstrates the optimization process by OptQuest for Arena, to get the optimum number of resources crew with minimum cost.

7.2 Setting up an Optimization Process

OptQuest is add-in tool in Arena, which is located at the tools menu. When OptQuest starts, it will check the Arena model, which will able to run without any errors. It can define new optimization or open existing optimization file by Browse button. There are four steps to identify the optimization process: define controls, select required responses, define constraints (if needed) and define the required objective.

7.2.1 Define Controls

The optimization process begins with the identification of the resources constraints, which is called controls in the OptQuest environment. The optimization process will be controlled by the selected controls (resources), and their values provided to the Arena model. Three resources were selected as controls in optimization process (shutter crew, mason crew, plastering crew) that are considered as permanent resources that an owned by executing company. After selecting the required resources, it can specify the capacities for each resource (upper and lower bounds) that will be used in the optimization. See Figure (7.1) and Figure (7.2).
Figure (7.1) Selection optimization controls

Figure (7.2) Controls’ editor
7.2.2 Select Responses

The objective function and constraints may depend on the outputs of the simulation, and therefore, they are based on responses. The Responses node of the OptQuest tree displays the hierarchical structure of responses in Arena. Any selected response can be used to create constraint and objective expressions. In addition, all selected responses will be shown in the solution details view, which can be displayed after an optimization process completes, see Figure (7.3). The selected responses in the model were:

**System.Total Cost** (for objective expressions) that equals all entities costs plus all resources costs (idle and busy costs).

**All Entities.Total Cost** (for view in the results) that equals entity value added costs (busy resources cost) plus waiting cost.

**Entity.Total Time** (for constraint expression) that means the entire simulation time.

![Responses System]

Figure (7.3) Selection responses
7.2.3 Define Constraints

The optimization can run without defining any constraint. However, including constraints (if appropriate), which define relationship among controls (resources) or responses, increases the efficiency of the search for optimal solutions. By Constraints Editor can add new constraint, which are represented in terms of the controls that have been selected for optimization. The main constraint in the model was the total time as in contractual requirements (less than or equal 290 day). A feasible solution is one that satisfies all constraints. Infeasibility occurs when no combination of values of the controls can satisfy a set of constraints. The infeasible solution occurs when failing to satisfy the problem constraints and this does not imply that the problem or model itself is infeasible.

7.2.4 Define Objective

In OptQuest, only one objective can be defined for the optimization process representing the model’s goal in terms of the assumptions and controls. The objective is either to minimize or maximize the quantity. OptQuest’s job is to find the optimal value of the objective by selecting and improving different values for the controls. The model objective was minimizing the total costs of the project. Table (7.1) summarizes the OptQuest input data.

<table>
<thead>
<tr>
<th>Controls</th>
<th>Lower bound</th>
<th>Suggested Value</th>
<th>Upper bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shutter Crew</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Mason Crew</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Plastering Crew</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

Table (7.1) OptQuest input data

<table>
<thead>
<tr>
<th>Constraints</th>
<th>(Entity1) Total Time &lt;= 290</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>Minimize Total Cost</td>
</tr>
</tbody>
</table>

The other resources capacities still as entered in Arena and does not change during the optimization process. See Appendix 1.
All of the previously mentioned steps were a preparation for the optimization process. Before starting the optimization, the optimization options that are located in Options Editor must be specified. At the first section in Options Editor is related to stop the optimization process, see Figure (7.4).

![OptQuest options panel](image)

Figure (7.4) OptQuest options panel

The number of simulations depends on the number of controls. OptQuest user’s guide specifies the general guidelines for the minimum number of simulations required for a given number of controls in the model to find high-quality solutions, as shown in Table (7.2) (Bradley, 2007). So stopping the optimization was according to the number of simulations, which was set equal to 100 simulations run.
In addition, the quality of the optimization results depends on the number of replications per simulation. By chosen “Vary the number of replications” option in the second section from Options Editor, OptQuest uses the given numbers as bounds on the number of replications per simulation. This option allows OptQuest to test for the statistical significance between the mean of the objective function in the current simulation and the best value found in previous simulations, which is to weed out inferior solutions without wasting too much time on them, see Figure (7.4). The number of replications was varying between 2 and 6 replications per simulation.

### 7.3 Optimization Results

Once the optimization process has been defined completely, the optimization can run. OptQuest evaluates the responses from the current simulation run, analyzes and integrates these with responses from previous simulation runs and determines a new set of values for the controls, which are then evaluated by running the Arena model. This is an iterative process that successively generates new sets of values for the controls. The process continues until the optimization has been stopped. When an optimization completes or stops, the best solution will be displayed. The best solution shows the optimum number of resources in terms of the selected objective and defined constraints.

Table (7.3) demonstrates the results of simulation run number 45 that represents the best solution.
Table (7.3) Optimization solution

<table>
<thead>
<tr>
<th>Resources Name</th>
<th>Lower</th>
<th>Solution</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shutter Crew</td>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Mason Crew</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Plastering Crew</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Total Duration (days)</th>
<th>288</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Cost ($)</td>
<td>189,454</td>
</tr>
</tbody>
</table>

The new resources capacities that resulted from the optimization were inserted again in Arena model to run the simulation and find the dates (start and finish date) for each activity. After that, the start and finish dates for each activity were entered into MS-project that directly plots the project’s schedule to ensure that no overallocations happened in recourses. Table (7.4) presents a comparison between the optimization results and the actual plan.

Table (7.4) Optimization results vs. actual plan

<table>
<thead>
<tr>
<th>Resources Name</th>
<th>Optimization results</th>
<th>Actual plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shutter Crew</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Mason Crew</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Plastering Crew</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Total Duration (days)</th>
<th>288</th>
<th>290</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Cost ($)</td>
<td>189,458</td>
<td>204,880</td>
</tr>
</tbody>
</table>

As shown in Table (7.4), the optimization process achieved decreasing in the total cost (about 7.5%) from the actual cost and the total duration still around the actual.
Moreover, the optimum number of resources crew is less the actual plan, which is due to two reasons: The first reason is to obtain good exploitation of the resources by integration between simulation and optimization using the optimum number of resources with maximum utilization and minimum idle cost. The second reason is the divergence in managing the resources between simulation and MS-Project. The simulation depends on the concept of resources perform activities sequentially, which means that the whole simulation process deals with the available resources that were predefined in the resources’ pool without any overallocations of any resource. While Ms-project used the recourse-leveling concept, which means “the logical relationships control the works”.
CHAPTER 8: VISUAL BASIC INTERFACE

8.1 Introduction

Arena interoperates with Visual Basic for Applications (VBA) technology that is designed to enhance the user interaction with the Arena model. VBA allows custom proceedings to be inserted into a model. These proceedings may be used to allow for the manipulation of variables or delay times, change the number of replications, the number of resources and many other useful functions. A simple user interface was designed through this chapter for data entry. The user interface was developed to facilitate the interaction of the user with Arena software where no previously knowledge with Arena is needed.

The interface screen was divided into nine forms; eight of them were used for entering all input data and the last form was used for specifying the required simulation option.

8.2 General Project Data Form

The first form appears only when the user open Arena. This form contains the general project data that was divided into two groups: simulation options and resources sheet as shown in Figure (8.1).

8.2.1 Simulation Options

The user should choose the suitable simulation options from the three options according to his case. The first option is “Use Simulation” that means, the user can run the simulation model with specific number of replications without optimization. The second option is “Use Simulation and Optimization” which enables the user to run the OptQuest program for optimization process. The final option is “Simulation with One Replication” that is used when the user needs to find the tasks form (start and finish dates for each activity) in Excel sheet.
8.2.2 Resources Sheet

The user can define the available resources through this sheet by three items:

**Resources’ capacities**: the number of resource units of a given name that are available to the system for processing.

**Resources’ busy cost**: cost per hour of a resource that processes an entity. The resource becomes busy when it is originally allocated to an entity and becomes idle when it is released. During the time when it is busy, cost will accumulate based on the busy cost rate.
**Resources’ Idle cost:** cost per hour of a resource that is idle. The resource is idle while it is not processing an entity. During the time when it is idle, cost will accumulate based on the idle cost rate.

The user can upload previously saved data file by clicking “Upload Data File” button.

### 8.3 Earth Works Form

The main aim of this form is to facilitate the data entry for the modules related to “Earth Works”. The data required by the user was divided into three groups: mobilization and excavation, footings and underground works, see Figure (8.2)

![Earth Works Form](image)

Figure (8.2) Earth works form – Mobilization and excavation

**Mobilization and excavation group:** In the first text box, the user should define the required duration for the mobilization activity in days. The second text box is dedicated to enter the volume of excavation in cubic meters, see Figure (8.2).
**Footings works group:** As shown in Figure (8.3) the user should choose one of the two scenarios. In both scenarios, the user should define the volume of plain concrete and reinforced concrete volume for the footings in cubic meters.

**Underground works group:** It is considered as the third group in the “Earth Works” form. This group is related to underground works that may not exist in some projects. The user can enable the below text boxes by checking the check box in “Is There Underground Works”. In this case, the user should define the required data as shown in Figure (8.4).
8.4 Basement Floor Form

This form was designed for the data entry for the modules related to “Basement Floor”. For entering the required data, the user should check the box “Is there Basement Floor” and define the total area of the basement floor. As shown in Figure (8.5), the “Basement Floor” form was divided into two groups: structure and finishing works.

Structure Works group: In this group, the user should specify the required data for the structure works in basement floor. The used should enter the volume of the reinforced concrete for the columns, walls and staircases (between two slabs) in cubic meters. In addition, the user should define the area of the slab in square meters, see Figure (8.5).
Finishing Works group: It is considered as the second group for the “Basement Floor” form, which is related to enter the required data in finishing works, see Figure (8.6).

In the “Masonry Area” part, the user should define the area of internal and external masonry in square meters. The internal masonry area was defined as the area of internal partitions. And the external masonry area was defined as the external partitions. In the “lintels Volume” part, the user can enter the volume of reinforced concrete for internal and external lintels in cubic meters.
Figure (8.6) Basement floor form – Finishing works

The last section in the data entry for finishing works group consists of eight variables: wooden doors, plaster area (slabs and walls), floor tiles area, wall tiles area, aluminum windows area, marble parapets length, marble cupboard length and painting area (slabs and walls).

In the same way, four forms were developed that related to data entry for the ground floor, mezzanine floor, typical floor and roof floor, which are presented in Appendix 3.
8.5 Staircase and External Finishing Form

It is considered as the final form related to data entry in the model that was designed for the modules related to Staircase and External Finishing. In the “No of Staircase” text box, the user should enter the number of stairwells in the building.

As shown in Figure (8.7), the required data in this form was divided into two groups: staircase finishing works and external finishing works.

Figure (8.7) Staircase and external finishing – Staircase finishing works

**Staircase finishing works group:** In this group, the user should define the area of plastering, painting and aluminum windows for one stairwell. In “Marble Length” box, the user should define the total length of the marble related to staircase steps and handrail.
External finishing works group: the user should define the total area for plastering and painting for one staircase.

Through the buttons “Back” and “Next” the user can navigate between interface forms.

8.6 Start Simulation Form

In this form, there are three options for running the model: run simulation, run optimization and run simulation with one replication, see Figure (8.9).

Run simulation: the user can enable the button “Run Simulation” by choosing the first option in simulation option group in “General Project Data” form (section 8.2.1). By clicking on “Run Simulation” button, the user can run the simulation model for multiple replications (user specified). Then the user can find the results of the simulation from Arena reports.
Run optimization: the user can enable the button “Run optimization” by choosing the second option in simulation option group in “General Project Data” form (section 8.2.1). By clicking on “Run optimization” button, the user can run the OptQuest to start the optimization process. After that, the user can find the results of the optimization process from view the best solution (section 7.3).

Run simulation with (one replication): the user can enable the button “Run simulation (one replication)” by choosing the third option in simulation option group in “General Project Data” form (section 8.2.1). By clicking on “Run simulation (one replication)” button, the user can run the simulation model for one replication. Then the user can find the activities’ dates (start and finish dates) for each activity by clicking on the button “Tasks Form”, see Figure (8.9).

The button “Save Data File” was designed to save all input data to reuse it at a later time in running the model.

Figure (8.9) Start simulation form
CHAPTER 9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

Multi-story building projects are classified as repetitive activities projects “RAP” that have vital position in construction industry in Gaza Strip at the present time. The main challenges of planning and scheduling RAP are getting the optimum project duration subject to resource continuity constraints and minimum resource cost, considering the complex relationships in how resources are managed to keep resources working without idle time, and the stochastic approach for activities duration.

Many research attempts have been carried out in order to develop suitable planning and scheduling strategies for RAP. However, the repetitive project scheduling problems are still a challenge as most attempts did not consider the stochastic nature of construction activities, and could not ensure the resource continuity constraints.

The integration between simulation and optimization is the key solution to plan RAP in terms of time, cost with the optimum number of resources. Additionally, their mathematical power could afford numerous planning alternatives, and optimize such cases according to any specified constraints. Moreover, they have a massive and detailed output reports that can build a complete planning vision.

This research attempted to solve planning and scheduling problems of repetitive projects by developing the general simulation model suitable for the MSB-projects as example for the RAP.

Two types of data were gathered regarding MSB projects. The first was “simulation input data” that was used to build the model; including a list of the performed activities, their logical relationships, the productivity of the resources, a list of the used resources, and the number of resources in each crew. According to the nature of collected data, the triangular distribution was the most suitable function for the resources’ production rates. The productivity distribution of each crew for each activity was calculated using “Input Analyzer”, which is Add-in tool in Arena software.
The second type of data was “user input data”. It consisted of work quantity for each process, number of required resources, resources cost rates, the project’s objective and resources’ constraints. In a leading local engineering and construction companies, experts engineers and skilled labors were interviewed, details of a typical built-story building projects were gained, and the related records of the achieved projects were utilized.

The conceptual model was constructed in terms of defining a hierarchy of a real case for MSB-projects “WBS”, developing flow chart to show the logical relationships for MSB-projects, building workflow mechanism of the simulation model and clarifying any assumptions based on interaction between the system components.

The typical simulation model was developed using (Arena software) as a simulation tool. Through this step, the general layout of Arena simulation model components (modules) and their functions were described.

The model was built to suit the nature of the MSB projects in terms of the structural approach in Gaza Strip. The most frequent possible scenarios was considered in the model. In addition, the developed model is limited to special logical relationships between activities, handled recourses costs only, assumed ten working hour per day, and special type of internal and external finishing.

The designed model was verified and validated. The verification process was executed to ensure that the simulation model operates as intended and no syntax or logical errors exist in the model. In addition, all activities were drawn in MS-Project to ensure there are no overallocations happening in resources. The validation process was executed to determine whether the simulation model is an accurate representation of real system for the particular objectives of the study. Two types of validation were done; face validity and statistical validity. Face validation was achieved through a cyclic model review and improvement process with the assistance of a number of project managers and site engineers. The statistical validation was achieved through comparing the model’s results with traditional scheduling (CPM) for actual case study using MS-Project. The results of
the verification and validation processes demonstrated that these modules work properly and they gave sound output results (time and cost).

The developed model empowers the users to optimize any of the applied case parameters using OptQuest for Arena. The objective of the optimization was minimizing the total costs of the project through finding the optimum number of required resources. The optimization process achieved decreasing in the total cost of about 7.5% from the actual cost and the total duration still around the actual. Moreover, the optimum number of resources crew is less than the actual plan, which is due to the good exploitation of the resources by integration between simulation and optimization.

Finally, the designed model facilitated the interaction of the user with Arena software by developing the user interface for the project’s data entry.

9.2 Recommendations
For increasing the efficiency of planning in the construction projects, simulation should be used by the planners and decision makers, as it was proven that simulation is a powerful tool in forecasting the behavior of projects.

For effectual planning in construction projects, optimization should be considered as well as could produce several solutions from a group of predefined constraints against a specified objective and achieve minimum overall project time and cost.

To enhance using simulation in the construction industry, it is good to perform educational courses for the engineers and the decision-makers in the field.

The commandment to the Ministry of Public Works and Housing to pay more attention to archiving the resources’ productivity in construction projects as it was hard to revive historical data.
9.3 Further Studies

However, this research developed the general simulation model for the MSB-projects, there is a need to develop analogous models with more scenarios for “Finishing Works” in the MSB-projects. In addition, insert the cost of material and the overhead cost in overall cost.

Implementing an external algorithm as optimization tool as (Genetic Algorithms), to assist the simulation system to solve the planning and scheduling problems in RAP.
References


Al-Helou, M. F., 2006. The impact of continuous resource utilization on cost and duration of projects with repetitive activities using simulation. Master of Science, Department of Civil Engineering, The Islamic University-Gaza.


List of Appendices

Appendix 1: Case Project Gathered Information
Appendix 2: Arena Input Data (Attributes Modules)
Appendix 3: Visual Basic Interface
Appendix 1

Case Project Gathered Information

1- Bill of Quantity

<table>
<thead>
<tr>
<th>Item</th>
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<tr>
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**Basement Floor Works**

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<tbody>
<tr>
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<tr>
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**Mezzanine Floor Works**

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</table>

**Typical Floor Works**

| Column Works (Reinforce concrete volume) | m³   | 28.5 |
| Staircase Works 1st stage(Reinforce concrete volume) | m³   | 0.82 |
| Slab Works(Reinforce concrete area)     | m²   | 861.34 |
| Staircase Works 2nd stage(Reinforce concrete volume) | m³   | 0.93 |
| External Masonry area                   | m²   | 360  |
| Internal Masonry area                   | m²   | 750  |
| External lintels concrete volume        | m³   | 5.2  |
| Internal lintels concrete volume        | m³   | 6.1  |
| Marble parapets length for windows      | m'   | 46   |
| No. of wooden doors                     | No   | 24   |
| Plastering area                        | m²   | 2205 |
| Floor Tiles area                       | m²   | 723  |
| Walls Tiles area                       | m²   | 364  |
| Aluminum works area                    | m²   | 51.4 |
| Painting area                          | m²   | 2205 |
| Marble cupboard length                 | No   | 24   |

**Roof Floor Works**

<p>| Column Works (Reinforce concrete volume) | m³   | 16.4 |
| Slab Works(Reinforce concrete area)     | m²   | 490  |
| External Masonry area                   | m²   | 193  |
| Internal Masonry area                   | m²   | 345  |</p>
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### 2- Resources’ capacities and cost rate

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<td>Shutter crew</td>
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<tr>
<td>Vibrator</td>
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<td>Mason crew</td>
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## Appendix 2

### Arena Input Data (Attributes Modules)

#### Footing Block

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<tr>
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<th>Attribute Name</th>
<th>Description</th>
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<tr>
<td>Type of foundation</td>
<td>Footing</td>
<td>Choose type of foundation (isolated/combined footings or mat foundation)</td>
</tr>
<tr>
<td>IF Plain Concrete vol m³</td>
<td>IF Plain Concrete</td>
<td>Enter the volume of plain concrete under isolated footings (m³)</td>
</tr>
<tr>
<td>IF Concrete vol m³</td>
<td>IF Concrete Vol</td>
<td>Enter the concrete volume for isolated footings (m³)</td>
</tr>
<tr>
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<td>MF Plain concrete vol</td>
<td>Enter the volume of plain concrete under the mat foundation (m³)</td>
</tr>
<tr>
<td>MF Concrete vol m³</td>
<td>MF Concrete vol</td>
<td>Enter the concrete volume for mat foundation (m³)</td>
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#### Underground Works Block

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<thead>
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<th>Attribute Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
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<td>Column neck volume m³</td>
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<td>Enter the concrete volume for column neck (m³)</td>
</tr>
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<td>Isolated Footing</td>
<td>Enter the required isolating area for footings, columns and wall (m²)</td>
</tr>
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<td>Enter the backfilling volume for first stage (m²)</td>
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<td>Ground beam vol</td>
<td>Enter the concrete volume for ground beam (m³)</td>
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<tr>
<td>Backfilling 2nd volume m³</td>
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<td>Enter the backfilling volume for second stage (m²)</td>
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<td>Ground slab area</td>
<td>Enter the ground slab area (m²)</td>
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<td>Enter the duration for mobilization works (day)</td>
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<tr>
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#### Basement Floor Block

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<th>Description</th>
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<td>Determines the existence of basement floor or not</td>
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<td>Enter the basement floor area (m²)</td>
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<td>BF column volume m³</td>
<td>BF col vol</td>
<td>Enter the concrete volume for column (m³)</td>
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<td>BF wall volume</td>
<td>Enter the concrete volume for walls (m³)</td>
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<td>BF Staircase volume m³</td>
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<td>BF external masonry area m²</td>
<td>BF external masonry area</td>
<td>Enter the external masonry area (m²)</td>
</tr>
<tr>
<td>BF Internal masonry area m²</td>
<td>BF internal masonry area</td>
<td>Enter the internal masonry area (m²)</td>
</tr>
<tr>
<td>BF Number of wooden doors</td>
<td>BF No doors</td>
<td>Enter the number of wooden doors</td>
</tr>
<tr>
<td>BF Plaster area m²</td>
<td>BF plaster area</td>
<td>Enter the plastering area (m²)</td>
</tr>
<tr>
<td>BF Ground tiles area m²</td>
<td>BF Ground tiles area</td>
<td>Enter the floor tiles area (m²)</td>
</tr>
<tr>
<td>BF Aluminum Windows Area m²</td>
<td>BF Window area</td>
<td>Enter the Aluminum Windows Area (m²)</td>
</tr>
<tr>
<td>BF Walls tiles area m²</td>
<td>BF wall tiles area</td>
<td>Enter the wall tiles area (m²)</td>
</tr>
<tr>
<td>BF Marble parapets length m</td>
<td>BF Parapets length</td>
<td>Enter the length of marble parapets (m')</td>
</tr>
<tr>
<td>BF Marble Cupboard length m</td>
<td>BF Cupboard length</td>
<td>Enter the length of marble cupboard (m')</td>
</tr>
<tr>
<td>BF Painting area m²</td>
<td>BF Paint area</td>
<td>Enter the painting area (m²)</td>
</tr>
</tbody>
</table>

**Ground Floor Block**

<table>
<thead>
<tr>
<th>Assign Module Name</th>
<th>Attribute Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GF Area m²</td>
<td>GF Area</td>
<td>Enter the ground floor area (m²)</td>
</tr>
<tr>
<td>GF column volume m³</td>
<td>GF col vol</td>
<td>Enter the concrete volume for column (m³)</td>
</tr>
<tr>
<td>GF Staircase volume m³</td>
<td>GF Staircase vol</td>
<td>Enter the concrete volume for staircases (m³)</td>
</tr>
<tr>
<td>GF slab area m²</td>
<td>GF slab area</td>
<td>Enter the slab area (m²)</td>
</tr>
<tr>
<td>GF internal lintels volume m³</td>
<td>GF internal inlets vol</td>
<td>Enter the concrete volume for internal lintels (m³)</td>
</tr>
<tr>
<td>GF external lintels volume m³</td>
<td>GF external inlets vol</td>
<td>Enter the concrete volume for internal lintels (m³)</td>
</tr>
<tr>
<td>Assign Module Name</td>
<td>Attribute Name</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>GF external masonry area m²</td>
<td>GF external masonry area</td>
<td>Enter the external masonry area (m²)</td>
</tr>
<tr>
<td>GF Internal masonry area m²</td>
<td>GF internal masonry area</td>
<td>Enter the internal masonry area (m²)</td>
</tr>
<tr>
<td>GF Number of wooden doors</td>
<td>GF No doors</td>
<td>Enter the number of wooden doors</td>
</tr>
<tr>
<td>GF Plaster area m²</td>
<td>GF plaster area</td>
<td>Enter the plastering area (m²)</td>
</tr>
<tr>
<td>GF Ground tiles area m²</td>
<td>GF Ground tiles area</td>
<td>Enter the floor tiles area (m²)</td>
</tr>
<tr>
<td>GF Aluminum windows area m²</td>
<td>GF Window area</td>
<td>Enter the aluminum windows Area (m²)</td>
</tr>
<tr>
<td>GF Walls tiles area m²</td>
<td>GF wall tiles area</td>
<td>Enter the wall tiles area (m²)</td>
</tr>
<tr>
<td>GF Marble parapets length m</td>
<td>GF Parapets length</td>
<td>Enter the length of marble parapent (m')</td>
</tr>
<tr>
<td>GF Marble Cupboard length m</td>
<td>GF Cupboard length</td>
<td>Enter the length of marble cupboard (m')</td>
</tr>
<tr>
<td>GF Painting area m²</td>
<td>GF Paint area</td>
<td>Enter the painting area (m²)</td>
</tr>
<tr>
<td>Mezzanine Floor Block</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is there mezzanine Floor</td>
<td>Annex</td>
<td>Determines the existence of mezzanine floor or not</td>
</tr>
<tr>
<td>AF Area m²</td>
<td>AF Area</td>
<td>Enter the mezzanine floor area (m²)</td>
</tr>
<tr>
<td>AF column volume m³</td>
<td>AF col vol</td>
<td>Enter the concrete volume for column (m³)</td>
</tr>
<tr>
<td>AF Staircase volume m³</td>
<td>AF Staircase vol</td>
<td>Enter the concrete volume for staircases (m³)</td>
</tr>
<tr>
<td>AF slab area m²</td>
<td>AF slab area</td>
<td>Enter the slab area (m³)</td>
</tr>
<tr>
<td>AF internal lintels volume m³</td>
<td>AF internal inlets vol</td>
<td>Enter the concrete volume for internal lintels (m³)</td>
</tr>
<tr>
<td>AF external lintels volume m³</td>
<td>AF external inlets vol</td>
<td>Enter the concrete volume for internal lintels (m³)</td>
</tr>
<tr>
<td>AF external masonry area m²</td>
<td>AF external masonry area</td>
<td>Enter the external masonry area (m²)</td>
</tr>
<tr>
<td>AF Internal masonry area m²</td>
<td>AF internal masonry area</td>
<td>Enter the internal masonry area (m²)</td>
</tr>
<tr>
<td>AF Number of wooden doors</td>
<td>AF No doors</td>
<td>Enter the number of wooden doors</td>
</tr>
<tr>
<td>AF Plaster area m²</td>
<td>AF plaster area</td>
<td>Enter the plastering area (m²)</td>
</tr>
<tr>
<td>AF Ground tiles area m²</td>
<td>AF Ground tiles area</td>
<td>Enter the floor tiles area (m²)</td>
</tr>
<tr>
<td>Assign Module Name</td>
<td>Attribute Name</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------</td>
<td>----------------</td>
<td>-------------</td>
</tr>
<tr>
<td>AF Aluminum Windows Area m²</td>
<td>AF Window area</td>
<td>Enter the Aluminum Windows Area (m²)</td>
</tr>
<tr>
<td>AF Walls tiles area m²</td>
<td>AF wall tiles area</td>
<td>Enter the wall tiles area (m²)</td>
</tr>
<tr>
<td>AF Marble parapets length m</td>
<td>AF Parapets length</td>
<td>Enter the length of marble parapets (m')</td>
</tr>
<tr>
<td>AF Marble Cupboard length m</td>
<td>AF Cupboard length</td>
<td>Enter the length of marble cupboard (m')</td>
</tr>
<tr>
<td>AF Painting area m²</td>
<td>AF Paint area</td>
<td>Enter the painting area (m²)</td>
</tr>
</tbody>
</table>

**Typical Floor Block**

<table>
<thead>
<tr>
<th>Assign Module Name</th>
<th>Attribute Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of typical floors</td>
<td>N</td>
<td>Enter the number of typical floors</td>
</tr>
<tr>
<td>TF Area m²</td>
<td>TF Area</td>
<td>Enter the typical floor area (m²)</td>
</tr>
<tr>
<td>TF column volume m³</td>
<td>TF col vol</td>
<td>Enter the concrete volume for column (m³)</td>
</tr>
<tr>
<td>TF Staircase volume m³</td>
<td>TF Staircase vol</td>
<td>Enter the concrete volume for staircases (m³)</td>
</tr>
<tr>
<td>TF slab area m²</td>
<td>TF slab area</td>
<td>Enter the slab area (m²)</td>
</tr>
<tr>
<td>TF internal lintels volume m³</td>
<td>TF internal inlets vol</td>
<td>Enter the concrete volume for internal lintels (m³)</td>
</tr>
<tr>
<td>TF external lintels volume m³</td>
<td>TF external inlets vol</td>
<td>Enter the concrete volume for internal lintels (m³)</td>
</tr>
<tr>
<td>TF external masonry area m²</td>
<td>TF external masonry area</td>
<td>Enter the external masonry area (m²)</td>
</tr>
<tr>
<td>TF Internal masonry area m²</td>
<td>TF internal masonry area</td>
<td>Enter the internal masonry area (m²)</td>
</tr>
<tr>
<td>TF Number of wooden doors</td>
<td>TF No doors</td>
<td>Enter the number of wooden doors</td>
</tr>
<tr>
<td>TF Plaster area m²</td>
<td>TF plaster area</td>
<td>Enter the plastering area (m²)</td>
</tr>
<tr>
<td>TF Ground tiles area m²</td>
<td>TF Ground tiles area</td>
<td>Enter the floor tiles area (m²)</td>
</tr>
<tr>
<td>TF Aluminum Windows Area m²</td>
<td>TF Window area</td>
<td>Enter the Aluminum Windows Area (m²)</td>
</tr>
<tr>
<td>TF Walls tiles area m²</td>
<td>TF wall tiles area</td>
<td>Enter the wall tiles area (m²)</td>
</tr>
<tr>
<td>TF Marble parapets length m</td>
<td>TF Parapets length</td>
<td>Enter the length of marble parapets (m')</td>
</tr>
<tr>
<td>TF Marble Cupboard length m</td>
<td>TF Cupboard length</td>
<td>Enter the length of marble cupboard (m')</td>
</tr>
<tr>
<td>TF Painting area m²</td>
<td>TF Paint area</td>
<td>Enter the painting area (m²)</td>
</tr>
</tbody>
</table>

**Roof Floor Block**

<table>
<thead>
<tr>
<th>Assign Module Name</th>
<th>Attribute Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attribute Name</td>
<td>Description</td>
<td>Unit</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Is there roof Floor</td>
<td>Determines the existence of roof floor or not</td>
<td></td>
</tr>
<tr>
<td>RF Area m²</td>
<td>Enter the roof floor area (m²)</td>
<td></td>
</tr>
<tr>
<td>RF column volume m³</td>
<td>Enter the concrete volume for column (m³)</td>
<td></td>
</tr>
<tr>
<td>RF slab area m²</td>
<td>Enter the slab area (m²)</td>
<td></td>
</tr>
<tr>
<td>RF internal lintels volume m³</td>
<td>Enter the concrete volume for internal lintels (m³)</td>
<td></td>
</tr>
<tr>
<td>RF external lintels volume m³</td>
<td>Enter the concrete volume for internal lintels (m³)</td>
<td></td>
</tr>
<tr>
<td>RF external masonry area m²</td>
<td>Enter the external masonry area (m²)</td>
<td></td>
</tr>
<tr>
<td>RF Internal masonry area m²</td>
<td>Enter the internal masonry area (m²)</td>
<td></td>
</tr>
<tr>
<td>RF Number of wooden doors</td>
<td>Enter the number of wooden doors</td>
<td></td>
</tr>
<tr>
<td>RF Plaster area m²</td>
<td>Enter the plastering area (m²)</td>
<td></td>
</tr>
<tr>
<td>RF Ground tiles area m²</td>
<td>Enter the floor tiles area (m²)</td>
<td></td>
</tr>
<tr>
<td>RF Aluminum Windows Area m²</td>
<td>Enter the Aluminum Windows Area (m²)</td>
<td></td>
</tr>
<tr>
<td>RF Walls tiles area m²</td>
<td>Enter the wall tiles area (m²)</td>
<td></td>
</tr>
<tr>
<td>RF Marble parapets length m</td>
<td>Enter the length of marble parapets (m')</td>
<td></td>
</tr>
<tr>
<td>RF Marble Cupboard length m</td>
<td>Enter the length of marble cupboard (m')</td>
<td></td>
</tr>
<tr>
<td>RF Painting area m²</td>
<td>Enter the painting area (m²)</td>
<td></td>
</tr>
</tbody>
</table>

**Staircase and External Finishing Block**

<table>
<thead>
<tr>
<th>Assign Module Name</th>
<th>Attribute Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of Staircase</td>
<td>Staircase</td>
<td>Enter the number of staircases in the project</td>
</tr>
<tr>
<td>Stair Plaster area m²</td>
<td>Stair plaster area</td>
<td>Enter the staircase plastering area (m²)</td>
</tr>
<tr>
<td>Stair Paint area m²</td>
<td>Stair paint area</td>
<td>Enter the staircase painting area (m²)</td>
</tr>
<tr>
<td>Stair Marble length m</td>
<td>Stair Marble Length</td>
<td>Enter the marble length for stairs (m')</td>
</tr>
<tr>
<td>Stair Aluminum Windows Area m²</td>
<td>Stair Window area</td>
<td>Enter the Aluminum Windows Area (m²)</td>
</tr>
<tr>
<td>External Plaster area m²</td>
<td>External plaster area</td>
<td>Enter the external plastering area (m²)</td>
</tr>
<tr>
<td>External Paint area m²</td>
<td>External painting area</td>
<td>Enter the external painting area (m²)</td>
</tr>
</tbody>
</table>
Appendix 3

Visual Basic Interface

1- VBI Forms

Ground Floor Structure Works
Ground Floor Finishing Works

Ground Floor Area

Structure Works  |  Finishing Works

Masonry Area
  Internal
  External

Lintels Volume
  Internal
  External

Wooden Doors
Plaster Area
Floor Tiles Area
Wall Tiles Area
Aluminum Windows Area
Marble Parapets length
Marble Capboard length
Painting Area

Back  |  Next
Mezzanine Floor Structure Works

- **Is There Mezzanine Floor**
  - Mezzanine Floor Area: 0.0 m²

- **Structure Works**
  - Column Volume: 0.0 m³
  - Staircase Volume: 0.0 m³
  - Slab Area: 0.0 m²
### Mezzanine Floor Finishing Works

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry Area</td>
<td></td>
</tr>
<tr>
<td>- Internal</td>
<td>0.0 m²</td>
</tr>
<tr>
<td>- External</td>
<td>0.0 m²</td>
</tr>
<tr>
<td>lintels Volume</td>
<td></td>
</tr>
<tr>
<td>- Internal</td>
<td>0.0 m³</td>
</tr>
<tr>
<td>- External</td>
<td>0.0 m³</td>
</tr>
<tr>
<td>Wooden Doors</td>
<td>0.0 No.</td>
</tr>
<tr>
<td>Plaster Area</td>
<td>0.0 m²</td>
</tr>
<tr>
<td>Floor Tiles Area</td>
<td>0.0 m²</td>
</tr>
<tr>
<td>Wall Tiles Area</td>
<td>0.0 m²</td>
</tr>
<tr>
<td>Aluminum Windows Area</td>
<td>0.0 m²</td>
</tr>
<tr>
<td>Marble Parapets length</td>
<td>0.0 m'</td>
</tr>
<tr>
<td>Marble Capboard length</td>
<td>0.0 m'</td>
</tr>
<tr>
<td>Painting Area</td>
<td>0.0 m²</td>
</tr>
</tbody>
</table>
Typical Floor Structure Works

- Number of Typical Floors: 0.0
- Typical Floor Area: 0.0 m²

Structure Works

- Column Volume: 0.0 m³
- Staircase Volume: 0.0 m³
- Slab Area: 0.0 m²
Typical Floor Finishing Works

![Typical Floor Form]

- Number of Typical Floors: 0.0
- Typical Floor Area: 0.0 m²
- Masonry Area:
  - Internal: 0.0 m²
  - External: 0.0 m²
- Lintels Volume:
  - Internal: 0.0 m³
  - External: 0.0 m³
- Wooden Doors: 0.0
- Plaster Area: 0.0 m²
- Floor Tiles Area: 0.0 m²
- Wall Tiles Area: 0.0 m²
- Aluminum Windows Area: 0.0 m²
- Marble Parapets length: 0.0 m
- Marble Capboard length: 0.0 m
- Painting Area: 0.0 m²
Roof Floor Structure Works

- Is There Roof Floor
  - Roof Floor Area: 0.0 m²

- Structure Works
- Finishing Works

- Column Volume: 0.0 m³
- Slab Area: 0.0 m²
# Roof Floor Finishing Works

![Diagram](image)

<table>
<thead>
<tr>
<th>Description</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry Area</td>
<td>0.0 m²</td>
<td>0.0 m²</td>
</tr>
<tr>
<td>Wooden Doors</td>
<td>0.0</td>
<td>No.</td>
</tr>
<tr>
<td>Plaster Area</td>
<td>0.0 m²</td>
<td></td>
</tr>
<tr>
<td>Floor Tiles Area</td>
<td>0.0 m²</td>
<td></td>
</tr>
<tr>
<td>Wall Tiles Area</td>
<td>0.0 m²</td>
<td></td>
</tr>
<tr>
<td>Aluminum Windows Area</td>
<td>0.0 m²</td>
<td></td>
</tr>
<tr>
<td>Marble Parapets length</td>
<td>0.0 m'</td>
<td></td>
</tr>
<tr>
<td>Marble Capboard length</td>
<td>0.0 m'</td>
<td></td>
</tr>
<tr>
<td>Painting Area</td>
<td>0.0 m²</td>
<td></td>
</tr>
</tbody>
</table>
2- Visual Basic code for the interface

- Resources Sheet

'choose simulation only or optimization

Private Sub CommandButton2_Click()
Dim mdl As Model
Dim modu As Module
Dim idx As Long
Dim idx2 As Long
Dim sub_mdl As Submodel
    Set mdl = ThisDocument.Model
    idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
    Set sub_mdl = mdl.Submodels.Item(idx2)
    idx = sub_mdl.Model.Modules.Find(smFindTag, "sim")
    Set modu = sub_mdl.Model.Modules(idx)
    If OptionButton1.value = True Then
        modu.Data("Value") = 1
        End If
    If OptionButton2.value = True Then
        modu.Data("Value") = 1
        End If
    If OptionButton3.value = True Then
        modu.Data("Value") = 0
        End If
End Sub

'Number of replications
ThisDocument.Model.NumberOfReplications = TextBox1.value

'resources sheet

'shutter crew capacity

Dim a As Model
Dim b As Module
Dim c As Long
    Set a = ThisDocument.Model
    c = a.Modules.Find(smFindTag, "shutter")
    Set b = a.Modules(c)
    b.Data("Capacity") = TextBox2.value
    b.Data("Busy") = TextBox3.value
    b.Data("Idle") = TextBox4.value

'Mason crew capacity
Dim a2 As Model
Dim b2 As Module
Dim c2 As Long

    Set a2 = ThisDocument.Model
    c2 = a2.Modules.Find(smFindTag, "mason")
    Set b2 = a2.Modules(c2)
    b2.Data("Capacity") = TextBox5.value
    b2.Data("Busy") = TextBox6.value
    b2.Data("Idle") = TextBox7.value

'Plaster crew capacity
Dim a4 As Model
Dim b4 As Module
Dim c4 As Long
    Set a4 = ThisDocument.Model
    c4 = a4.Modules.Find(smFindTag, "plaster")
    Set b4 = a4.Modules(c4)
    b4.Data("Capacity") = TextBox8.value
    b4.Data("Busy") = TextBox9.value
    b4.Data("Idle") = TextBox10.value

'Tilling crew capacity
Dim a6 As Model
Dim b6 As Module
Dim c6 As Long
    Set a6 = ThisDocument.Model
    c6 = a6.Modules.Find(smFindTag, "tilling")
    Set b6 = a6.Modules(c6)
    b6.Data("Capacity") = TextBox11.value
    b6.Data("Busy") = TextBox12.value
    b6.Data("Idle") = TextBox13.value

'Painting crew capacity
Dim a8 As Model
Dim b8 As Module
Dim c8 As Long
    Set a8 = ThisDocument.Model
    c8 = a8.Modules.Find(smFindTag, "paint")
    Set b8 = a8.Modules(c8)
    b8.Data("Capacity") = TextBox14.value
    b8.Data("Busy") = TextBox15.value
    b8.Data("Idle") = TextBox16.value

'Marble crew capacity
Dim a10 As Model
Dim b10 As Module
Dim c10 As Long
    Set a10 = ThisDocument.Model
    c10 = a10.Modules.Find(smFindTag, "marble")
Set b10 = a10.Modules(c10)
b10.Data("Capacity") = TextBox17.value
b10.Data("Busy") = TextBox18.value
b10.Data("Idle") = TextBox19.value

'Isolating crew capacity
Dim a12 As Model
Dim b12 As Module
Dim c12 As Long
Set a12 = ThisDocument.Model
    c12 = a12.Modules.Find(smFindTag, "isolation")
Set b12 = a12.Modules(c12)
b12.Data("Capacity") = TextBox20.value
b12.Data("Busy") = TextBox21.value
b12.Data("Idle") = TextBox22.value

'Electrical crew capacity
Dim a14 As Model
Dim b14 As Module
Dim c14 As Long
Set a14 = ThisDocument.Model
    c14 = a14.Modules.Find(smFindTag, "electrical")
Set b14 = a14.Modules(c14)
b14.Data("Capacity") = TextBox23.value
b14.Data("Busy") = TextBox24.value
b14.Data("Idle") = TextBox25.value

'Plumber crew capacity
Dim a16 As Model
Dim b16 As Module
Dim c16 As Long
Set a16 = ThisDocument.Model
    c16 = a16.Modules.Find(smFindTag, "plumber")
Set b16 = a16.Modules(c16)
b16.Data("Capacity") = TextBox26.value
b16.Data("Busy") = TextBox27.value
b16.Data("Idle") = TextBox28.value

'Carpenter crew capacity
Dim a18 As Model
Dim b18 As Module
Dim c18 As Long
Set a18 = ThisDocument.Model
    c18 = a18.Modules.Find(smFindTag, "carpenter")
Set b18 = a18.Modules(c18)
b18.Data("Capacity") = TextBox29.value
b18.Data("Busy") = TextBox30.value
b18.Data("Idle") = TextBox31.value
'Aluminum crew capacity
Dim a20 As Model
Dim b20 As Module
Dim c20 As Long
    Set a20 = ThisDocument.Model
    c20 = a20.Modules.Find(smFindTag, "aluminum")
    Set b20 = a20.Modules(c20)
    b20.Data("Capacity") = TextBox32.value
    b20.Data("Busy") = TextBox33.value
    b20.Data("Idle") = TextBox34.value

'Lintel crew capacity
Dim a22 As Model
Dim b22 As Module
Dim c22 As Long
    Set a22 = ThisDocument.Model
    c22 = a22.Modules.Find(smFindTag, "lintel crew")
    Set b22 = a22.Modules(c22)
    b22.Data("Capacity") = TextBox35.value
    b22.Data("Busy") = TextBox36.value
    b22.Data("Idle") = TextBox37.value

'Excavator capacity
Dim a24 As Model
Dim b24 As Module
Dim c24 As Long
    Set a24 = ThisDocument.Model
    c24 = a24.Modules.Find(smFindTag, "excavator")
    Set b24 = a24.Modules(c24)
    b24.Data("Capacity") = TextBox38.value
    b24.Data("Busy") = TextBox39.value
    b24.Data("Idle") = TextBox40.value

'Vibrator capacity
Dim a26 As Model
Dim b26 As Module
Dim c26 As Long
    Set a26 = ThisDocument.Model
    c26 = a26.Modules.Find(smFindTag, "Vibrator")
    Set b26 = a26.Modules(c26)
    b26.Data("Capacity") = TextBox41.value
    b26.Data("Busy") = TextBox42.value
    b26.Data("Idle") = TextBox43.value

'Compactor capacity
Dim a28 As Model
Dim b28 As Module
Dim c28 As Long
    Set a28 = ThisDocument.Model
    c28 = a28.Modules.Find(smFindTag, "compactor")
Set b28 = a28.Modules(c28)
b28.Data("Capacity") = TextBox44.value
b28.Data("Busy") = TextBox45.value
b28.Data("Idle") = TextBox46.value

- Basement Floor Structure Works Code (as Example)

Dim mdl As Model
Dim modu As Module
Dim idx As Long
Dim idx2 As Long
Dim sub_mdl As Submodel
Private Sub CheckBox1_Click()
If CheckBox1.value = False Then
    MultiPage1.Enabled = False
    TextBox1.Enabled = False
    Label13.Enabled = False
    Label14.Enabled = False
    TextBox1.BackColor = &H80000016
Else
    MultiPage1.Enabled = True
    TextBox1.Enabled = True
    Label13.Enabled = True
    Label14.Enabled = True
    TextBox1.BackColor = &H80000005
End If
End Sub
Private Sub CommandButton1_Click()
Form3.Hide
Form2.Show
End Sub
Private Sub CommandButton2_Click()
Form3.Hide
Form4.Show
    Set mdl = ThisDocument.Model
    idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
    Set sub_mdl = mdl.Submodels.Item(idx2)
    idx = sub_mdl.Model.Modules.Find(smFindTag, "Basement")
    Set modu = sub_mdl.Model.Modules(idx)
    If CheckBox1.value = True Then
        modu.Data("Value") = 1
    Else
        modu.Data("Value") = 0
    End If
'Basement Area
    Set mdl = ThisDocument.Model
idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl = mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFArea")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox1.value

'Basement Column
Set mdl = ThisDocument.Model
idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl = mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFColumn")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox2.value

'Basement Wall
Set mdl = ThisDocument.Model
idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl = mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFWall")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox3.value

'Basement Stair
Set mdl = ThisDocument.Model
idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl = mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFStair")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox4.value

'Basement Slab
Set mdl = ThisDocument.Model
idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl = mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFSlab")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox5.value

'Basement Internal Lintels
Set mdl = ThisDocument.Model
idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl = mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFIternalLintel")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox8.value

'Basement External Lintels
Set mdl = ThisDocument.Model
idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl = mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFExternalLintel")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox9.value

'Basement Internal Mason
Set mdl = ThisDocument.Model
idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl = mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFInternalMason")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox6.value

'Basement External Mason
Set mdl = ThisDocument.Model
idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl = mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFExternalMason")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox7.value

'Basement Wooden Doors
Set mdl = ThisDocument.Model
idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl = mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFNoDoor")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox10.value

'Basement Plaster
Set mdl = ThisDocument.Model
idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl = mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFPlaster")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox11.value

'Basement Floor Tiles
Set mdl = ThisDocument.Model
idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl = mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFFTiles")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox12.value

'Basement Wall Tiles
Set mdl = ThisDocument.Model
idx2 =mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl =mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFWTiles")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox13.value

'Basement Aluminum Windows
Set mdl = ThisDocument.Model
idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl = mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFAWindows")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox14.value

'Basement Marble Parapets
Set mdl = ThisDocument.Model
idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl = mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFMarbleP")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox15.value

'Basement Marble Capboard
Set mdl = ThisDocument.Model
idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl = mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFMarbleC")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox16.value

'Basement Painting
Set mdl = ThisDocument.Model
idx2 = mdl.Submodels.Find(smFindTag, "inputdata")
Set sub_mdl = mdl.Submodels.Item(idx2)
idx = sub_mdl.Model.Modules.Find(smFindTag, "BFPaint")
Set modu = sub_mdl.Model.Modules(idx)
modu.Data("Value") = TextBox17.value
End Sub