AN APPROACH FOR BUILDING INFORMATION MODELING AND SIMULATION INTEGRATED LOOK-AHEAD PLANNING

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AN APPROACH FOR BUILDING INFORMATION MODELING AND SIMULATION INTEGRATED LOOK-AHEAD PLANNING

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To My Family,

To My Home; Palestine,

To Jerusalem,

ABSTRACT

Look-ahead planning has a key role for construction management as an intermediary between master schedules and site production. Its effective implementation can improve construction management and production control for a specific time period, while considering site performance, work sequencing, and matching tasks to resources. However, it remains a highly manual process, it is not integrated with Building Information Modeling (BIM), and it is hard to consider process alternatives at this level. In addition, there is a gap between Look-ahead Scheduling (LAS) process and site production in terms of information such as design changes, site progress, and resources availability. BIM and simulation have potential for improving look-ahead planning processes.

This thesis presents techniques to make look-ahead scheduling process work within a structured BIM and resource-integrated simulation approach. It integrates and analyzes necessary information from planning and site using BIM. This information includes a coding structure for BIM entities, tasks and work sequence for scopes of work, available resource data, construction constraints and site progress information are integrated with BIM. The necessary information is integrated in a unified platform for look-ahead planning using an existing simulation tool called GSimX for analysis.

The building test case presented in this thesis demonstrates the approach with simulation support to generalize its use within lean construction context. The results show alternatives of look-ahead schedule considering the crews and equipment status, site progress and constraints. Results also demonstrate updating of master schedules. As a result, planners will be able to effectively generate look-ahead tasks and match them with resources all within a BIM environment using simulation.

ÖZETÇE

İleriye dönük planlama, inşaat yönetiminde master iş programı ile saha üretimi arasında aracı olarak önemli bir role sahiptir. İleriye dönük planlamanın etkin uygulanması, saha performansını, iş sıralamasını, ve işlerle kaynakların eşleştirilmesini göz önünde bulundurarak inşaat yönetimi ve üretim kontrolünü belirlenen ileriye dönük süre için iyileştirebilir. Bununla birlikte, bu süreç elle hazırlanan bir süreç olmaya devam etmektedir, Bina Bilgisi Modellemesi (BIM) ile entegre değildir ve süreç alternatiflerini bu seviyede değerlendirilmesi zordur. Buna ek olarak, ileriye dönük planlama (LAS) süreci ve saha üretimi arasında tasarım değişiklikleri, saha ilerleme durumu ve kaynakların kullanılabilirliği gibi bilgiler açısından bir boşluk mevcuttur. BIM ve simülasyon, ileriye dönük planlama süreçlerini iyileştirme potansiyeline sahiptir.

Bu tez, ileriye dönük planlama sürecini yapısal BIM ve kaynak entegrasyonlu simülasyon yaklaşımı içinde çalıştırma amaçlı teknikler ortaya koymaktadır. Bu teknikler BIM kullanımı ile planlama ve saha ile ilgili gerekli bilgileri bütünleştirir ve analiz eder. Bu bilgiler, BIM elemanları için bir kodlama yapısı, çalışma kapsamı için işler ve iş sırası, mevcut kaynak verileri, inşaat kısıtlamaları ve BIM ile entegre saha ilerleme bilgilerini içerir. Gerekli bilgiler analiz için GSimX isimli mevcut bir simülasyon platformunu kullanarak ileriye dönük planlamayı entegre bir platformda bütünleştirilmiştir.

Bu tezde sunulan bina örneği, simülasyon desteğiyle ve yalın inşaat yaklaşımı altında, bu yaklaşımın genel olarak kullanımını ortaya koymaktadır. Sonuçlar, ekip ve ekipman durumu, saha çalışma ilerlemesi ve kısıtlamaları değerlendirerek ileriye dönük iş programı alternatiflerini göstermekte ve master iş programını güncellemektedir. Sonuç olarak, planlamacılar, etkin bir şekilde ileriye dönük iş programlarını üretebilecek ve bunları simülasyon kullanarak BIM ortamında kaynaklarla eşleştirebilecektir.

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ABBREVIATIONS

ARC	: Architectural work discipline
BIM	: Building Information Modeling
BIM-BOQ	: BIM Bill of Quantities
BOQ code	: Unique code assigned to each BOQ item
CPM	: Critical Path Method
GSimX	: Geometry Simulation Software Approach
LAP	: Look-ahead Planning
LAS	: Look-ahead Scheduling
LC	: Lean Construction
LBS	: Location Based Scheduling
LPS	: Last Planner System
MEP	: Mechanical, Electrical and Palming work discipline
ObjectCode	: Logical BIM-Entity Unique ID
SiteProgress	: Logical BIM-Entity Site Progress Status
STR	: Structural Work Discipline
Tag	: List of Parameters Attached to Each BIM Object
Task Code	: Unique Combination Code of ***ObjectCode*** and ***Task-Component*** Code for Each Individual BIM-Entity at ***BIM-BOQ***
Task-Component	: Task and Component Data Base
WBS	: Work Breakdown Structure

CHAPTER I

INTRODUCTION

In construction, poor planning usually leads to poor management of processes. Because of poor management, many problems occur throughout construction stages including design, estimating, planning, and site management, leading to time delays, ineffective resources distribution, materials waste, and sometimes incomplete projects. In contrast, effective planning approaches lead to better construction process and control, on-time project delivery, ideal resource consuming, better construction quality, and decrease construction cost.

Construction planning process is the transformation link between design and on-site construction works. Planning aims to move project from design drawings and specifications to actual physical building within planned budget, scheduled time, and designed specifications. Planning process has multiple levels that extend from the beginning to the end of a project; starting from high level; called master planning, and reaching detailed planning. However, there are some gaps in the link between master planning and detailed planning.

Look-ahead Planning LAP is a mid-level between master and detailed planning levels. Look-ahead scheduling aims to coordinate and link various construction activities to crews and resources working on-site for a specific look-ahead period, ranging from two to eight weeks. It has a potential to fill the gap in planning process. Most of planning and control problems can be improved though effective look-ahead planning approach using recent construction and control technologies such as BIM and simulation.

Poor information management between planning levels usually leads to poor resource distribution and planning, on-site work conflicts, missing site works and others. As a result, site management may face construction delivery delays and significant waste of project resources and cost.

This thesis work defines techniques to enable implementation of a BIM and resource integrated look-ahead planning approach. This includes developing a methodology for building look-ahead schedules using BIM-based simulation that satisfies project goals. The presented approach aims to integrate with current construction planning technologies, satisfy look-ahead planning information management needs between design and construction, and provide ability to test alternatives in order to get full value out of look-ahead scheduling process.

1.1 Importance of Look-ahead Planning

Look-ahead planning (LAP) has a key role for construction and it recently attracted increased attention. It is a phase of planning where planners identify what specific construction works they can do during upcoming period considering identified construction resources and constraints. LAP is a process to create and manage construction look-ahead schedules; it is a planning phase where planners break down the master schedule into look-ahead work schedules.

Good look-ahead scheduling (LAS) leads to better project performance in meeting the objectives of time, cost, quality, and safety. Look-ahead scheduling is a link between the master scheduling and detailed work plans for a time span between 2-6 weeks (Lindhard and Wandahl 2015). Look-ahead scheduling is a process to prevent work conflict, ensure the correct work sequence, facilitate a fluent workflow for crews and equipment, and prevent rework. Look-ahead scheduling process identifies work that can be done by matching workflow to capacity, maintains a balance of work to minimize downtime, and develop plans for how the work will be completed.

Look-ahead schedules focus decision makers’ attention on activities and actions that supposed to happen within a specific time frame in the look-ahead future. It ensures that present actions will lead to identified target objectives within look-ahead planning. Look-ahead scheduling is also used to perform production control to meet goals in higher level (phase) plans, and ensure that there are no constraints will affect a short-term (weekly) plans.

1.2 Challenges of Current Look-ahead Scheduling

Current look-ahead scheduling approaches have a lot of practical problems and challenges. There is a gap between LAS process and work ongoing at site in terms of information such as design changes, site progress, and resources availability. Therefore, some potential improvements in scheduling reliability, productivity and workflow are unrealized. The presented approach aims to achieve high level of integration between as-built site status and LAS process. Look-ahead scheduling is a periodic process which depends on latest status of site progress. LAS process aims to identify the uncompleted site works in order to identify the target works that can be done within specific look-ahead time.

Current LAS approaches have limited information transfer between different information sources. During LAS process, some required information is missing because of disconnect between LAS process and information sources. For example, some of design changes or pending RFIs are not integrated into LAS process, since there is no central shared information repository for the whole design and construction process. Limited information transfer and inadequate information management throughout design and construction processes are a few of the main causes for poor planning schedule, time delay, and resources waste (Bhatla, Pradhan et al. 2016).

Look-ahead scheduling process aims to match activities with proper resources such as material quantities, required crews and equipment. Incorrect material estimation leads to on-site material shortage or waste. Current LAS approaches are rarely use modern technologies for material take-off such as Building Information Modeling (BIM), therefore, they may lack material quantity information.

Moreover, current LAS approaches are highly manual. Users or planners depend on their experience and skills to manually describe look-ahead activities from master activities. This process becomes more complicated for mega and large complex projects. It is very hard to evaluate schedules for the whole project with many related trades and resources manually. Results will likely contain errors and will be less efficient than one that is automated.

1.3 Last Planner System

Last Planner System (LPS) is a method of production planning and control that gets down to the daily planning level in attempt to improve construction performance. Research done over the years show that LPS improves predictability and reliability of construction process (Porwal, Fernandez-Solis et al. 2010). LPS manages relationships, conversations, and commitments that together enable production planning decisions to be made collaboratively at site during construction process.

In LPS, weekly work plans need to be made by the people doing the work, such as site engineers or on-site foremen. LPS is a control and planning approach where team; as last planners, can identify and remove construction constraints that can delay or stop site works. LPS introduces discipline and accountability to achieve measured performance target.

Last Planner System is the most common technique in practice to perform look-ahead and short-term scheduling, coordinating, and directing various trades to crews working on the job (Pellicer, Cerveró et al. 2015). LPS is a tool to achieve lean construction philosophy at multiple levels of planning and scheduling. Figure 1.1 summarizes various planning levels of LPS, namely master scheduling, phase planning, 2-6 weeks look-ahead scheduling and weekly planning. Chapter 2 discusses LPS in more detail.

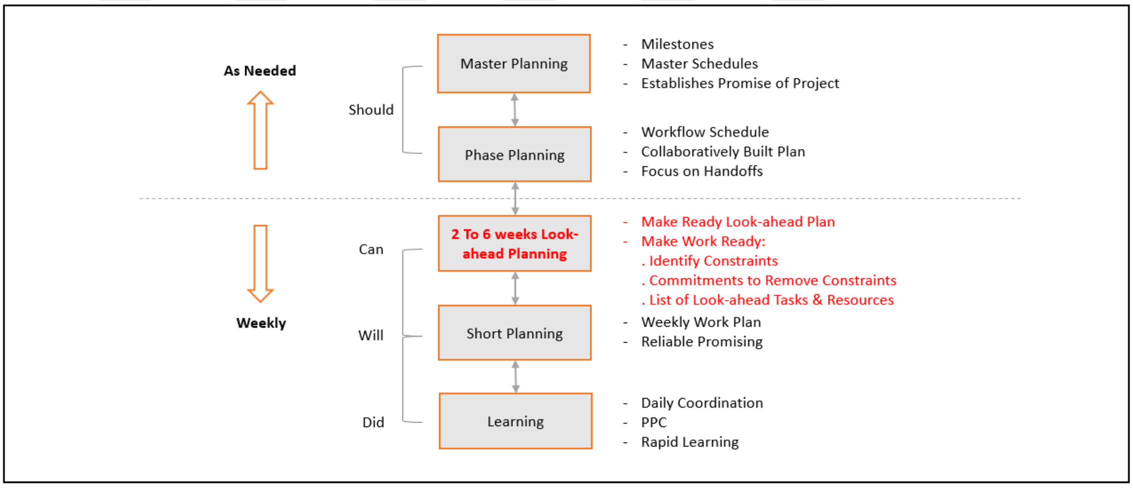

Figure 1.1 Planning Levels Based on LPS

Due to data coming from separate project sources and the need to evaluate data in a structured way, it is challenging for planners and site engineers to consider feasible alternatives to create best alternative schedule. In complex projects, determining tasks that can be performed and matching them with resources, while satisfying requirements of master schedules given the current project status, still proves to be challenging. Moreover, this process needs to be repeated throughout the project and performing LAS manually is prone to loss of information and inefficiencies. However, Last Planner

System is a highly manual scheduling approach and it is not integrated with BIM model. This thesis presents an approach that integrates LPS principles within a BIM and simulation environment for LAS purposes.

1.4 Automation in Construction

Two main tools can help automate look-ahead scheduling: Building Information Modeling (BIM) and simulation. Recently, BIM has become the standard approach for project information coordination and automation. BIM has demonstrated potential to resolve most construction problems. BIM is becoming a central repository for managing all project information such as design information, budget, construction schedule, project status and more, all in one composite model.

BIM can also enable lean construction systems to support planning production and daily control production on construction sites (Sacks, Radosavljevic et al. 2010). A set of requirements has been defined for BIM based lean production management systems for construction planning and management. These requirements include integration of on-site progress status into design BIM phase, integration of work methods into design BIM model, and improvement of planning production phase; especially the look-ahead planning.

BIM has potential to improve various aspects of planning and construction management processes. Without connecting to the BIM model, planners cannot realize full benefits of the look-ahead scheduling process. However, practical gaps between design BIM and on-site construction works makes BIM implementations limited for LAS processes. Sometimes, site progress information has poor connection with design BIM, therefore, site progress has limited integration with look-ahead planning process. Other times, poor information management for design changes, construction process and others, leads to inefficient LAS process.

Simulation is the second toolset that can help automation for look-ahead processes. Despite of many research and studies discussing construction planning production, use of simulation for practical construction planning production is not very common. Simulation has potential to support decision making process related to construction during the design and construction phases. Simulation models can be used to simulate tasks, resources, and specific constraints of construction process, therefore, planners can optimize resource use, and project planning process.

Simulation has been applied to many aspects of construction including (i) studying construction logistics, (ii) planning construction processes and analyze construction workflow relative to project cost plan, (iii) optimizing planning of activities and tasks for building construction, and (iv) managing supply chains, reducing site storage and material shortages. Current simulation approaches have some practical shortcomings such as not being integrated into look-ahead planning processes.

This thesis builds on a new multi-method simulation platform called GSimX for simulation. GSimX is particularly suited for look-ahead planning using BIM, since it is BIM and resource-integrated and specifically designed and developed for construction processes. GSimX simulation platform implements discrete-event and agent-based approaches at the same time and naturally represents construction processes. Construction crews and equipment become part of simulation as agents on BIM and simulated based on activity and resource parameters on geometric model. GSimX calculates resource, location and activity states after simulation. Moreover, since the simulation process and construction status are linked to the geometric model, visualization of construction status is automatic. The user is able to update model parameters such as construction resource assignment and behavior, construction methods, and constraints. After modelling updates, the user is able to re-simulate to consider alternative scenarios.

1.5 Research Questions

As discussed, look-ahead planning has a critical role in construction stage and it leads to better construction management and control systems. Better look-ahead planning approach leads to better construction resources management by achieving better work backlog construction activities and their resources. While current LAS approaches can be integrated with BIM, they are still highly manual. There are limited BIM and simulation implementations to improve LAS process.

The main goal of this thesis work is to enable effective look-ahead planning through BIM and resource-integrated simulation. To support this, it should describe information workflow and management to effectively support LAS simulation process. Various information coming from design BIM model, construction constraints, site progress, resources and master schedule have to be managed through design BIM approach. Then, this set of information is analyzed within look-ahead scheduling process using BIM and simulation platform.

Design BIM model provides a central work space for all construction stakeholders to share and manage information in order to make planning decisions. Also, simulation provides better automation system for information analysis for thousands of construction activities, hundreds of crews and on-site equipment. This thesis work has two main research questions:

1- How can information be managed between design and construction BIM to perform effective look-ahead planning through simulation?

In current practical approaches, the available on-site resources have limited integration with LAS process. They also have a manual master schedule breaking down to achieve look-ahead schedules. Current practical approaches have limited constraints integration into LAS process. Current approaches have limited integration with on-site progress status; it is still manual process. Moreover, current approaches poorly include BIM material take-off within look-ahead scheduling process. The presented approach discusses these problems and describes an integrated approach to solve them. Figure 1.2 summarizes research questions development.

Information coming from various sources needs to be integrated for simulation analysis approach. Furthermore, this information needs to be periodically updated during the project for updated analysis. In traditional construction, the design phase is not fully integrated with on-site construction process. Design phase has variety of information; such as design specifications and design changes, that are very important to be integrated into construction LAS process and that need to managed well in order to achieve better results of LAS process. Moreover, on-site construction process forms the basis for upcoming LAS process. Information such as on-site progress status and available resources need to be fully integrated into LAS process in order to achieve better results for construction look-ahead planning process.

BIM can help improve look-ahead planning process. This thesis discuss how BIM can improve look-ahead scheduling processes throughout construction process. It also discusses how to use BIM as central workspace to automatically manage the required information; these requirements include design BIM work breakdown structure of BIM entities and geometry, actual and accurate BIM bill of quantities (BOQ), on-going construction site works, and master schedule activities breakdown into detailed tasks. Chapter 4 discusses these requirements in detail.

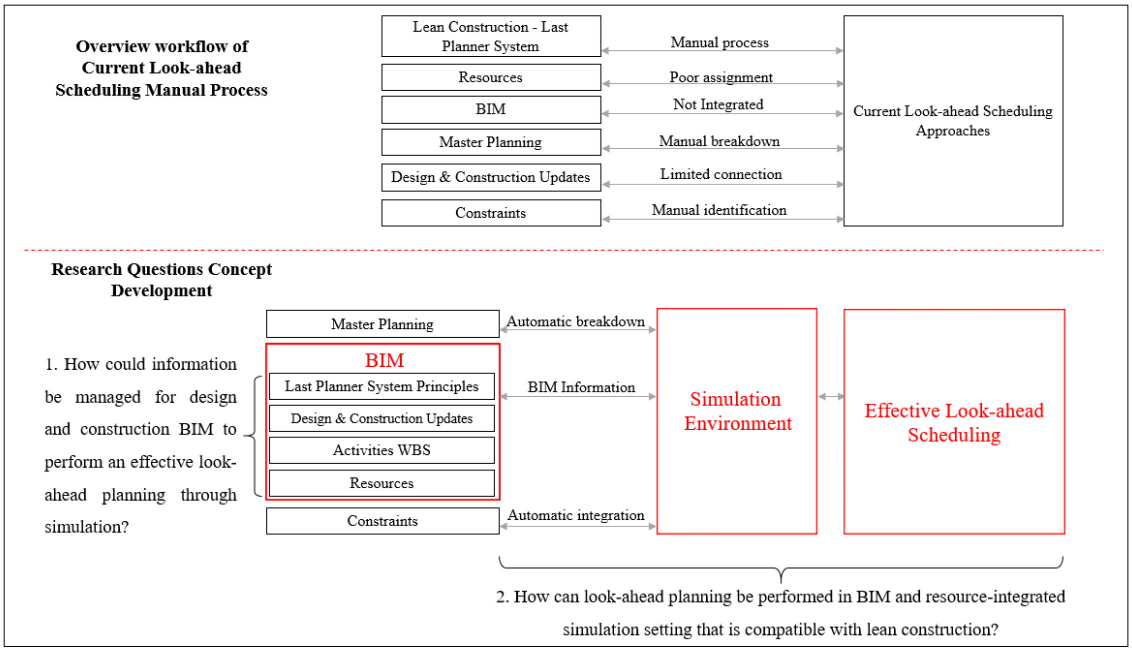

Figure 1.2 Research Questions Development

2- How can look-ahead planning be performed in BIM and resource-integrated simulation setting that is compatible with lean construction?

Following up the research questions development in Figure 1.2, and once the first question has been achieved to identify and manage required information, BIM model with its all managed information will be ready for simulation process. Design information, construction updates, in addition to constraints and other required information for LAS simulation will be transferred to GSimX simulation platform.

Look-ahead scheduling function is to establish WHEN and HOW each task should proceed without violating any constraints. As such, an effective LAS process needs to consider all critical construction constraints. Look-ahead planning process includes analysis, work to remove constraints and make sure that all prerequisites and activity resources (crews, equipment and materials) are available for tasks to be able to assign them into look-ahead schedules.

Once planning participants run the LAS simulation process and provide the resources are needed during LAS period; in order to achieve the target schedule, the project management team need to work to avail these resources. In the event that providing required resources is impossible due to any reason such as continued on-site constraints, that time, a new forecast alternative schedule need to be developed based on the capacity of resources that can be achieved; this capacity needs to be entered in the simulation process for defining the new target dates and revised schedule.

1.6 Aim and Objectives

Based on above description, this thesis aims to enable a BIM and resource integrated look-ahead scheduling approach. Using this approach, the planning participants will be able to generate alternative look-ahead schedules given site progress, plans for crew, equipment, construction constraints, and material availability to satisfy master schedule requirements. Therefore, they will be effectively generating work backlog as look-ahead tasks, and match them with resources all within a BIM environment, taking into consideration lean construction principles.

In order to achieve the general aim discussed above, the objectives are determined as follows:

(1) To identify the requirements for BIM and simulation planning systems to support multiple-level construction schedules,

(2) To describe the project information management process at design BIM and construction phases in order to support look-ahead scheduling process. This information management process should include properly identifying BIM elements, extracting appropriate quantities for each process, relating to master schedules, site progress, and

(3) To discuss integration process into BIM and resources-integrated simulation approach for LAS.

Using BIM and simulation can lead to stability of construction workflow and eliminate idle time during construction process, planner will be able to assign all required project resources on-site-on-time.

This thesis work enables BIM-resources integrated simulation approach that supports planners to generate effective workflow plans and reliable LAS. This helps fill the gap between LAS process and required information sources by implementing the LC principles, LPS techniques, BIM and simulation advantages.

The presented approach describes a methodology of constraints identification and integration into LAS process. Some constraints effect a specific activity within construction process, others effect on specific activity by zone, others effect on specific BIM entity (construction component).

Moreover, in order to ensure target cost and time of the construction process, the presented approach supports lean construction principles by simulating tasks within the target look-ahead period (could be 2-6 weeks or more) in relation to the master schedule. Later on, the generated LAS can achieve successful workable weekly planning; as an integrated construction planning process.

1.7 Scope of Work

This thesis work focuses on look-ahead planning for construction of residential and commercial buildings with various types of structural systems, and of small, medium or large project scale. The discussed approach requires that design BIM, construction constraints and a master schedule using Critical Path Method (CPM) exists to assign required resources to look-ahead work tasks.

This thesis work provides an approach to help participants generate alternative set of simulated LAS. This includes developing and integrating databases for different required information during LAS simulation process. It also includes an automated management approach for different design and construction information, project resources capacity, construction conditions and constraints and master schedule information, in order to achieve better value of LAS process, this valuable look-ahead schedule supports project management to secure target time and cost factors of the project. More details are discussed in Chapter 3.

1.8 Research Methods

To achieve the objectives above, the presented research work has followed steps of literature review; identification of practical problems; description of required BIM information management system, which includes design of information workflow and construction constraints; and developing an experimental test case. Figure 1.3 shows the research method steps for this thesis. Literature survey identifies current construction planning standards and approaches related to look-ahead planning. The gaps between planning process and other project design process, and the gaps between planning process and construction process have been identified. Lean construction, BIM, Last Planner System, location-based and simulation approaches are discussed and reviewed; the requirements of their implementation for LAS uses has been identified; the relations between these approaches, their advantages and limitations are discussed in Chapter 2.

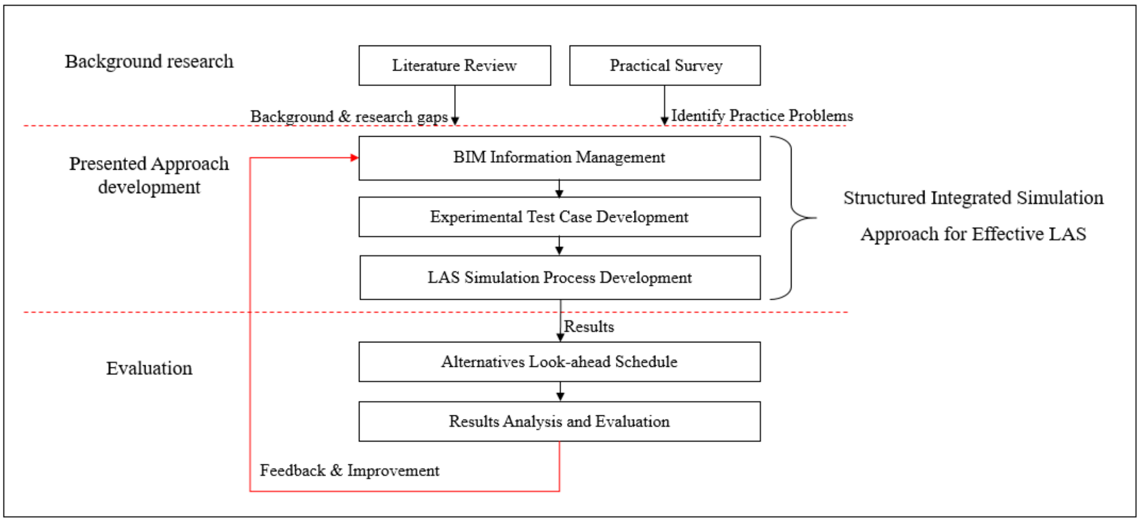

Figure 1.3 Proposed Research Method

Literature survey provides the practical problems related to look-ahead scheduling process from different perspectives. It focuses on look-ahead scheduling procedure and its gaps related to duration, resources integration procedure, and the required information to perform LAS. Current approaches are not fully adopting on BIM material take-off for look-ahead scheduling process. The presented approach discusses these problems and describes an integrated approach to solve them.

During look-ahead planning process, information coming from different sources are integrated for simulation analysis approach. In this thesis, information management for look-ahead scheduling using BIM technology has been described, which includes design of information workflow and describe multiple information elements for LAS simulation process. Afterwards, this managed information is part of a general LAS simulation approach, through integration between described BIM data flow and GSimX; an existing simulation tool, to support look-ahead planning phase compatible with the Last Planner System and within lean construction environment.

An experimental test case has been created to test and evaluate the presented approach. The information flow for look-ahead planning is demonstrated on a hypothetical 10 floor building, which consists of structural and architectural components. Figure 1.4 summarizes the steps for test case implementation. Test case describes the information workflow from design drawings to design BIM, then to GSimX simulation tool for analysis and look-ahead level simulation.

3D BIM model based on design drawings and specifications has been created. Afterwards, design BIM and other simulation process requirement has been imported GSimX, that automatically matched master-level activities with detailed tasks within location flows. Available crews and equipment are defined for the project and requirements for each activity were updated in GSimX. Constraints are integrated into simulation process. The generated LAS alternatives have been tested and evaluated, the simulation parameters have been changes and the simulation process has been repeated to get more LAS alternatives.

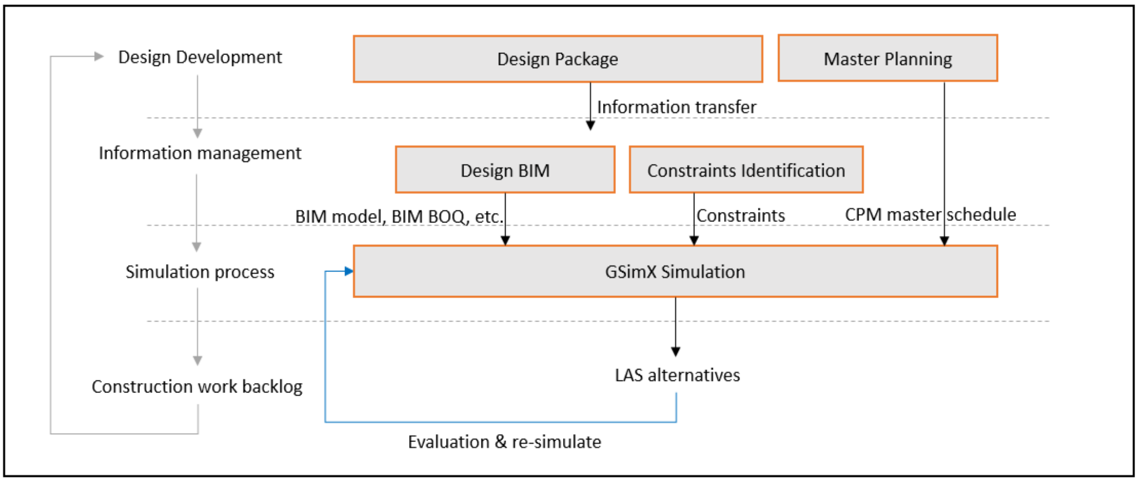

Figure 1.4 Test Case Summary

In this test case, the simulation process has been formed to identify the target work of 2-6 weeks look-ahead related to the master schedule, in order to achieve target project time. As a result of simulation process, the list of look-ahead tasks, list of any additional required resources and look-ahead materials are identified. All are discussed in detail in Chapter 4.

Finally, an evaluation from many perspectives has been discussed; planning participants, BIM coordinators, construction team, and project management. Construction constraints such as design changes, site progress, material status and others, have been integrated into simulation process. This will allow flexible and customized LAS simulation approach, better consideration of resources within the simulation process, therefore, better updates for look-ahead schedules.

1.9 Organization of Thesis

The remainder of this thesis is organized as follows. Chapter 2 discusses background information for lean construction philosophy; definition, impacts, and tools. It also includes a general description on Last Planner System as a modern look-ahead planning tool with its definition, principles, and planning procedure. This chapter also covers the BIM technology and simulation approach with their benefits, implementations, and current limitations. In addition, it introduces geometry-based planning approach and GSimX as a tool for BIM and resource-integrated simulation approach for look-ahead scheduling. Chapter 3 discusses the research methodology for information management at design BIM process and the LAS simulation procedure. Chapter 4 includes the test case, technical information of test case development, LAS simulation procedure, and results discussion. Finally, concluding remarks, summary of findings, thesis contributions, and further research are discussed in Chapter 5.

CHAPTER II

LITERATURE REVIEW

This thesis particularly focuses on improving the look-ahead scheduling process within a lean construction environment using BIM and simulation technologies. As a result, it aims to have easily generated and more reliable look-ahead schedules. In this research, techniques to implement look-ahead scheduling process on a BIM and simulation integrated platform are developed. This supports improvement of productivity and construction workflow by improving LAS process within lean construction environment.

This chapter provides a background discussion for techniques related to this thesis. It includes lean construction philosophy; definition, impacts, and tools. It also includes a general description of Last Planner System as a modern look-ahead planning approach, which includes definition, technique, and planning procedure. It also discusses location based planning approach with its definition, planning process, limitations and potentials. Furthermore, this chapter presents the BIM and simulation as related automation approaches for construction process control and planning. In addition, this chapter presents GSimX as a tool for BIM and resource integrated location-based simulation approach for workflow improvement and look-ahead schedule generation.

2.1 Lean Construction Philosophy

Lean Construction (LC) philosophy has been derived and developed based on Toyota manufacturing system’s principles and methodologies that are mainly care about waste of time, quality and cost throughout production process (Alarcón 1997). LC aims to decrease waste while increasing the added value of the construction process. In order to enhance process quality and ensure client satisfaction, LC improves two main principles which are (Forbes and Ahmed 2010):

(1) Eliminate construction wastes as much as possible, and

(2) Just-in-Time; is a technique to afford required resources on-site-on-time.

This section discusses LC definition and principles, its concept development, a comparison between LC and traditional construction approach, and LC tools.

2.1.1 Lean Construction Definition

Ballard and Howell (1994) define Lean Construction as a philosophy to manage construction process. The Construction Industry Institute defines lean construction as "a system of decreasing wastes, matching the customer specific requirements, and perfect pursuing in construction process " (Tommelein 1998). Ballard, Tommelein et al. (2002) define lean construction as "a construction system which aims to reducing material, efforts, and time to generate and achieve the best required output value".

Ballard and Howell (1994) integrate the lean construction's objectives, principles and techniques into new project delivery process. LC improves the foundation of the activity-based construction delivery system; it is an approach for construction improvements in all construction projects; especially uncertain, and complex projects.

2.1.2 Concept Development of Lean Construction

Historically, lean production management principles were developed by Toyota manufacturing. Toyota's engineering and development team worked on auto production development approach called 'Lean' to reduce the manufacturing waste of Toyota manufacturing process, and make it more flexible for craft and mass manufacturing (Alarcón 1997). Influenced by Total Quality Management (TQM) and based on structured system to reduce machine set up time, Toyota's engineering team identified the new system objectives:

(1) Manufacture a car matching to the specific requirements of customer
(2) Deliver on time
(3) No cars in stores and no intermediate stores

Lean Construction philosophy was developed based on Toyota lean production system as an ideal standard (Ballard, Tommelein et al. 2002). However, construction approach is different from manufacturing one, the manufacturers produce components of a machine or a project. In contrast, construction industry deals with a unique and complex project, within uncertain conditions, under a specific time schedule, and more complicated pressure factors.

Lean work structuring approach throughout construction process is different from typical traditional practical approach because (Howell and Ballard 1998, Ballard, Tommelein et al. 2002):

(1) Lean approach identifies the objectives of construction process to improve construction delivery system,
(2) Lean approach has a goal to maximizing performance of the construction process,
(3) Lean approach designs project and the construction process at the same time, and
(4) Lean approach applies planning and production control during the whole life of the project; started from design, planning, construction, delivery, project operation, and facility management.

Lean construction (LC) describes a practical construction approach for better matching of customer needs while considering planned cost, quality and time schedule

(Bertelsen and Koskela 2004). Lean construction is a translation of lean production management philosophy to construction. Lean construction is a project delivery system that is flexible to match of the assigned construction requirements.

2.1.3 Lean Construction Benefits

Lean construction has many effective benefits and tangible impacts onto construction planning and delivery process. Lean design and construction applies lean method, principles and techniques into construction delivery process (Bertelsen and Koskela 2004). Therefore, project management can achieve the identified benefits in lean construction process, which include decreased costs, time, wastes, and uncertainty, better workflow and planning efficiency, and better users and construction participant satisfaction.

The implementation of lean construction principles leads to better distribution and utilization of project resources; especially materials and crews (Ballard, Tommelein et al. 2002). It also improves the construction quality in completed projects. Delivery project with less time and better resources distribution means more profit benefits for all stakeholders. Lean construction helps to improve the construction process of uncertain, and complex projects (Tommelein 1998).

2.1.4 Lean Construction vs Traditional Construction

Traditional construction process has many problems of planning control (Dave, Boddy et al. 2013). Typically, construction management subdivides project into master and phases activities; activities' resources requirements and their time frame are managed throughout Critical Path Method (CPM) chart. Generally, project activities are assigned into master schedule by work discipline such as structural, architectural and mechanical works. Once the on-site construction work starts, construction management follows up and controls their process by comparing actual progress with pre-planned progress throughout weekly meetings, therefore, project management team makes corrections, performs updates re-plans and other actions in order to improve the construction process. The following are some of those traditional construction control actions (Forbes and Ahmed 2010):

(1) By using specific equipment and better construction methods, increase in production could be achieved, therefore, costs are reduced,
(2) By adjusting on-site crews and resources, the duration of construction activities could be adjusted, and
(3) By site inspection and pursuance, construction workflow and construction quality could be improved.

However, previous traditional construction control actions have limited impact on productivity improvement for overall construction projects. Construction management is usually in reactive mode in order to control and follow up the schedule in case of the progress is off track; in most cases, construction management adjusts construction crews, resources, or change sequencing to maintain the schedule. However, many construction and planning problems can happen because of poor communication and poor information management. Sometimes, poor management leads to construction delay and the project become behind the schedule, therefore, construction management forced to make a decision to accelerate the project in order to get back on schedule, which may lead to cost overrun, decrease in quality, or gaps in safety management.

Traditional construction approach has limited ability to decrease construction variability (Forbes and Ahmed 2010). It implements CPM to create and develop overall construction schedule, it keeps tracking based on it; whatever progress is on schedule or behind of it. The critical path schedule (timeline) is shown using Gantt chart. Construction milestones, zones, and tasks are defined by this master schedule. However, traditional planning approach via CPM master schedule does not push crews to incentive each other and improve productivity.

Lean construction aims to have the resources on hand for a construction team and crews to proceed with activities steadily and without interruption (Howell and Ballard 1998). Matching labor and resources to pending work is a sensitive practical problem of traditional construction management approach, traditional approach distributes the crews as a mini-contractor with a charge responsible for resources, organization and direction of each crew. Each crew could be more or less independent of other construction works.

Lean construction supports and improves the concept of team work (Forbes and Ahmed 2010). The integration of lean thinking between design engineers and construction people; such as crews, engineers and planning participants, improves the construction information workflow, thus, better construction performance will be achieved. On the other hand, in traditional construction approach, each crew tries to optimize and improve their production and performance without considering how their actions affect the whole construction process.

Lean construction approach aims to improve construction workflow reliability (Ballard and Howell 1994, Alarcón 1997, Bertelsen and Koskela 2004). Planning is a key to achieve reliable construction workflow. Ballard and Tommelein (1999) defined workflow as “the movement of information and materials through networks of interdependent specialists”. Kalsaas and Sacks (2011) defined workflow as “The flow of project resources throughout construction work locations in process that crews and equipment work to achieve direct and indirect works”. Under lean, crews and construction workflow are perfectly matched if the resources supply is under control. In LC, as in most of production lines or networks, planning and control should be integrated and applied throughout the project construction process (Ballard, Tommelein et al. 2002):

(1) Planning: to define criteria of construction strategies in order to achieve the construction objectives, and
(2) Control: is an action of measuring, evaluating, learning and re-planning, in order to improve the workflow of construction process.

According to Ballard, Tommelein et al. (2002), lean construction philosophy has two main applicable principles to construction schedules, which are "(i) limit master schedules to phase milestones, special milestones, and long lead items, and (ii) produce phase schedules with the team that will do the work, using a backward pass, making float explicit, and deciding as a group how to use float to buffer uncertain activities".

Lean construction approach works to deliver project construction under pre-defined time schedule (Ballard and Howell 1994, Howell and Ballard 1998). Planning system; under lean philosophy, aims to reduce the on-site construction problems, manage on-site construction resources within site constraints to improve the workflow reliability. On the other hand, in complex project, the traditional construction approach has less reliability than lean approach, therefore, an effective planning and control system is required to improve the reliability of workflow and construction process within lean environment.

2.2 Last Planner System (LPS)

Last Planner System is a planning system to implement lean construction philosophy and ensure its goals (Ballard 2000). LPS has potential to control and manage project variability to improve construction workflow and increase crews and material resources productivity (Pellicer, Cerveró et al. 2015). Usually, in traditional construction planning, construction management and planners assign work activities to crews beyond their ability in hope to deliver project on-time. However, because of bad resources distribution for assigned activities, and because of different types of construction constraints, some of assigned activities do not get completed, which cause a gap between actual and pre-planned progress. Howell and Ballard (1998) present a statistical data related to workflow variability throughout traditional construction planning efficiency; the results show around 50% of traditionally scheduled work plan got failure.

Last Planner System is most commonly used technique in practice to perform short-term scheduling coordinating and direct various trades and crews working on the job (Pellicer, Cerveró et al. 2015). Due to available data from separated project sources and evaluating the data in a structured way, it is challenge for planners and site engineers to create much better alternative schedule; especially in complex projects, it also challenges to determine tasks that can be performed and matching them with resources, while satisfying requirements of master schedules given the current project status still proves to be challenging. Moreover, this process needs to be repeated throughout the project and performing look-ahead scheduling manually, this is prone to loss of information and inefficiencies.

Last planner system is about planning the work; breaking it down into manageable pieces dealing with construction constraints, thus, the trades can do the work and check progress against plan, and improving the process to eliminate waste through a close circle Plan-Do-Check-Improve (Ballard 2000):

(1) <u>Plan</u> the lean projects delivery system includes milestone on phase planning, pull planning; a process of involving materials into workflow plans throughout look-

ahead process (Ballard 2000), to meet phase plans and utilizing a look-ahead schedule,

(2) Do manage production based upon establishing shortly work plans coordinating the work on a daily basis,

(3) Check the progress against plan, and make adjustments if required, and

(4) Improve the workflow and develop the operating procedures that provide consistency to the way of work.

2.2.1 Last Planner System Structure

Last Planner concept has been structured based on 'Should-Can-Will-Did' planning approach (Ballard 2000). LPS improves planning and control of traditional construction management by identifying what SHOULD we do as a target objective into what CAN we do throughout look-ahead time. Crews, foremen, and site engineers; as last planners, identify a promises weekly work plans for what WILL we do. Last Planner procedure has weekly measurements and evaluation of actions for what we DID, in order to perform learning and further improvement steps into construction work.

Last Planner System utilizes lean techniques to give enhanced construction control (Ballard 2000). It is a system for production planning and control in construction projects that is a particular implementation of lean construction. It focusses on improving the productivity and workflow by having quality assignments. The LPS includes four levels of planning processes (Seppänen, Ballard et al. 2010, Hamzeh and Langerud 2011, Hamzeh, Ballard et al. 2012):

(1) Master scheduling process is used to determine the likely duration of the project, to set milestones, and identify phase plans needed to deliver the project to an estimated target completion date. At this stage, a planning team will look at long

lead times and deal with any design or construction constraints that affect the feasibility of delivering the project,

(2) Phase planning; which is more level of details than master scheduling. It covers each project phase by identifying the trades doing the work. Working backwards from the milestone dates and up downstream, trades pull the task needed for the completion of the work, establishing commitments, and hand-off dates for upstream work. This network of tasks and commitments establishes a high-level work plan, which is based on the available capacity and commitments to complete the work to a collaboratively developed phase plan,

(3) Look-ahead planning is used for construction workflow control to meet the phase plans and ensure that there are no constraints will affect a short work plan. It identifies the work that CAN be done by matching the workflow to capacity, maintaining a balance of work to minimize downtime, and develop plans for HOW the work will be completed during look-ahead time period, and

(4) Weekly planning is prepared by the foreman or site engineer; as last planners, in a weekly meeting with all of the trades; where they collaboratively establish the work that will be done daily according to look-ahead schedules, and they track the work that is getting done according to their weekly schedules.

Last Planner System improves continuous communication between different crews during construction process; a lot of construction activities require a high and direct coordination between in-charge crews (Porwal, Fernandez-Solis et al. 2010). For example, in concrete slab construction work, structural crew can’t proceed with concrete casting activity before checking and getting confirmation from mechanical crew about supposed mechanical shaft openings. Also, architectural finishing crew can’t precede with false ceiling works before confirmation that all pipes, cable tray, and other mechanical works has been done. If structural or mechanical crew fails to complete their activities as per design and schedules, the architectural works will be delayed with wasted money. In other words, completing individual activities without caring or coordination to other related activities could definitely cause a time delay, and uncoordinated site work, therefore, material and resources waste.

2.2.2 Last Planner System Principles

In the Last Planner system, the reliability of workflow is measured in terms of percent planned complete (PPC); the percentage of tasks completed at the end of a certain period relative to tasks planned at the beginning of the same period (Ballard 2000, Hamzeh, Zankoul et al. 2015, Pellicer, Cerveró et al. 2015). Based on measuring and evaluating PPC, the planners work to improve construction workflow reliability and planning efficiency in order to get better results through upcoming construction works.

Last Planner System aims to reduce and manage project variability. Ballard (2000) identify the criteria and principles of effective implementation of LPS approach as follows:

(1) Accurate PPC measurement will improve planning efficiency,

(2) Planners should identify and analyze the reasons of plan failure,

(3) The look-ahead process has the express purpose of effective scheduling production, workable construction workflow plans preparation, and construction value improvement,

(4) Pulling technique is required for improving generated assignment quality by improving make-ready function; which is a process of taking needed actions to remove constraints for assign look-ahead works to make them ready to start on site (Ballard 2000), function performance throughout look-ahead process. Ballard (1997) define LAS performance term as “the successful performance of LAS

process can be measured using two metrics, tasks anticipated (TA) and Tasks Made Ready (TMR). TA measures the success of look-ahead planning in successfully anticipating tasks that will take place in the future. TMR measures the ability of look-ahead planning to identify/ remove constraints and to make tasks ready for execution",

(5) LPS considers construction process as a temporary production process,

(6) The sharing decision making is required for work assignments acceptance, and it also required for workflow plan control throughout look-ahead process, and

(7) Task sequencing is required to improve both of look-ahead and weekly work assignments efficiency.

2.2.3 Traditional Planning vs LPS Planning

Traditional construction planning has many limitations (Forbes and Ahmed 2010). Usually, construction managers; based on their experience, identify the planning and control system, and an estimated material take-off (MTO) is used in creating the master schedules. Project management manually identifies the activities that SHOULD be done in order to meet planned master schedule; without considering what CAN be done. In this master level of planning, the planners or construction managers are disconnected from crews' productivity in order to achieve project delivery target date, thus, their schedules will not be secured by on-site crews' capability. Sometimes, managers and decision makers assume that on-site crews will complete the planned work on-time, which is unmistakably over crews' capacities, therefore, many of traditionally planning schedules are delayed, even if managers and decision makers motivate on-site crews to achieve better performance (Howell and Ballard 1998).

On the other hand, Last planner system depends on an activity driven approach to improve crews' performance and construction workflow reliability to assure that assigned activities are capable of completion within identified resources and time (Ballard 2000). By on-site planning, crews and last planners; foremen and site engineers, are able to improve their skills and performance by involving them into decision making process based on site working conditions increase the reliability of work plan and better construction performance (Pellicer, Cerveró et al. 2015). This process enables planning participants to create better resource distribution, and better match the on-site required resources and supply, which leads to better efficiency in planned schedules.

2.3 Look-ahead Planning (LAP)

Look-ahead planning has a key role for construction process and it is attracting attention of construction management research and practice (Ballard 1997, Hamzeh, Ballard et al. 2012). LAP is an approach for workflow controlling and managing throughout the construction planning system.

Look-ahead planning process is the mid-level process within construction planning systems (Tommelein 1998, Chua, Jun et al. 1999, Ballard 2000). It is the process that links master schedule and weekly work plans, a process where planners create construction workflow plans, identify all construction constraints to analyze and remove them, create an effective distribution of resources to assign tasks within look-ahead window. Also, LAP is a process of maintaining a balance of work to minimize downtime, and develop plans for how the work will be completed.

2.3.1 Planning vs Scheduling

Construction planning and scheduling are two main parts of construction workflow control process in general. Planning is characterizing criteria for progress and creating techniques for accomplishing objectives (Ballard 2000). It is a process to identify the activities that need to be done, the required time and resources such as crews, equipment, and materials, in addition to identifying all constraints throughout construction process.

On the other hand, scheduling is a process to assign activities and tasks to required amount and time of resources by showing the working plan in graphical frame (Forbes and Ahmed 2010). CPM Gantt chart represents each construction activity in horizontal time bar. The bar length (scale) represents the activity duration.

2.3.2 Look-ahead Planning Structure

Look-ahead planning is a process of activities breakdown from master schedule to look-ahead schedule, and creating the construction workflow sequence for look-ahead scheduling process; which represents the construction work backlog within 2-6 weeks (or more) time frame (Ballard 2000, Hamzeh, Ballard et al. 2012).

Look-ahead planning is commonly used to focus construction management attention on what is supposed to happen at some time in the future, and to encourage actions in the present that cause the desired future (Ballard 1997). The following are purposes of LAP process (Ballard 2000, Ballard, Tommelein et al. 2002):

(1) Create construction workflow sequence,

(2) match construction workflow with capacity,

(3) Identify and analysis the construction constraints,

(4) Identify look-ahead schedules (workable backlog activities), and

(5) Create a detailed work plan; identify the criteria for progress and creating techniques that describe how site works will be performed in order to achieve objectives.

2.3.3 Construction Constraints

In construction planning process, construction constraints are a hindrance that prevent the execution of an assignment that is required in the construction planning process; especially look-ahead planning process (Dong, Fischer et al. 2013). Site foremen, construction managers, planners, engineers and other decision makers work together to identify construction constraints throughout construction process.

Poor constraints identification, analysis and removing process are one of construction planning deficiencies (Hamzeh, Zankoul et al. 2015). There are many sources of constraints that negatively affect LAS process and make LAS process harder, some possible constraints are: lack of design information such as open RFIs, shortage of equipment, crews, and materials, missing completion of predecessor tasks, unfavorable weather conditions, unsafe working condition, incorrect site progress status and others (Koskela 1999, Hamzeh, Zankoul et al. 2015).

Constraints analysis improves the efficiency of planning scheduling process (Wang, Shou et al. 2016). Analysis process allows the planners to check and ensure that assigned activities could be ready when assigned into look-ahead schedules. Later on, planners work to be sure that there are no remaining on-site constraints to assign activities into weekly planning schedules. The following are some of constraints analysis benefits

(1) Early constraints identification improves the decision-making process,
(2) It supports the needed corrective actions throughout look-ahead planning,
(3) It is an effective tool for LAS improvement; it works to make tasks ready,
(4) It improves tasks and resources matching by resources re-allocate in case of un-removed constraint, and
(5) It includes a reference cases during future planning and learning for similar constraints cases.

2.3.4 Look-ahead Scheduling (LAS)

Look-ahead scheduling is a process of planned workflow control and work reliability improvement by linking the identified list of detailed work plan that CAN be done on-site with identified on-site resources; taking consideration the on-going construction constraints within specific look-ahead window (Ballard 1997, Ballard 2000, Hamzeh, Ballard et al. 2008, Hamzeh, Ballard et al. 2012). Ballard (2000) define the look-ahead window as "how far ahead of scheduled start activities in the master schedule are subjected to explosion, screening, or make ready. Typically, construction processes have look-ahead windows extending from 2-6 (or more) weeks into the future".

Look-ahead scheduling is weekly updating process based on coordination and discussion between all planning participants of different disciplines in construction planning system; those planners may be construction managers, planning engineers, site engineers, foremen, BIM coordinator or others (Ballard 2000). LAS works to eliminate construction uncertainty by creating work assignments which have high probability of successful completion (Hamzeh, Abi Morshed et al. 2012).

Look-ahead scheduling helps teams achieve successful project performance in meeting the objectives of time, cost, quality, and safety. LAS is a process to prevent work conflicts, ensure the correct work sequence, facilitate a fluent workflow for crew and equipment, and prevent re-work (Dong, Fischer et al. 2013).

Planners aim to create an effective LAS throughout the following main concepts (Ballard 1997, Ballard 2000, Hamzeh, Saab et al. 2015):

(1) Screening tasks; identify activities and tasks relative to their constraints such as missing prerequisites of design, materials, equipment, crew, prerequisites work etc. Once constraints have been identified, planners and decision makers work to analysis, evaluate and remove them. Constraints analysis aims to push tasks to be

ready for construction assignment; it aims to ensure that assigned activities could be ready when assigned into look-ahead schedules. Those tasks with removed constraints are transferred into list called 'workable backlog' in order to be used into LAS process (Hamzeh, Ballard et al. 2008, Kalsaas and Sacks 2011). Work backlog list includes all activities from look-ahead planning that are ready to enter next step of planning; weekly work planning (Hamzeh, Zankoul et al. 2015). In other words, work backlog describes activities that have met quality criteria, which are not urgent activities, and have no require other essential work to be done before they can be begun. For the weekly planning phase, once there are some constraints that prevent completing an activity, work backlog allows available crew and resources to continue working with other backlog activities, and

(2) Introducing resources such as materials, crews, equipment or other information into planning and construction process by pulling process, which is a method to pull construction input items into construction process based on assigned activities and target scheduled dates. However, pulling integrates resources into assigned look-ahead construction activities only if there is a capability to do that work.

However, planning participants have to re-do look-ahead scheduling process more than one time in order to match best workable look-ahead scenario that meet the following criteria (Forbes and Ahmed 2010, Mubarak 2015):

(1) Scheduled activities and tasks should be small enough with a manageable size, so planners can detail and clarify them to accelerate and improve on-site construction work, and

(2) On-site work progress quantities and duration should be measureable; these measurements will be considered as a baseline into upcoming scheduling process.

2.3.5 Current Look-ahead Scheduling Problems

Traditional look-ahead scheduling approaches have practical problems, challenges, limitations, and gaps that prevent realizing their full benefits (Bhatla, Pradhan et al. 2016). LAS still highly manual process and it's lacking a proper underlying model and automation (Hamzeh, Ballard et al. 2012). In general, traditional LAS process relies on engineers' experience and skills in estimation, calculation, and resources distribution with limited automation. It also has limited connection between planning levels; such as the limited relationship with master level schedules and weekly schedules.

Current LAS approaches have construction management related, construction resources related, and project information related problems in practice (Bhatla, Pradhan et al. 2016). The unnecessary information such as too much detailed tasks breakdown, incorrect information such as incorrect BOQ, poor and manual work resources distribution (crews, equipment, material, cost, etc.), in addition to limited information management leads to poor and complicated look-ahead scheduling, therefore, the project will face time delays and cost overrun problems (Hamzeh, Zankoul et al. 2015, Bhatla, Pradhan et al. 2016).

Building and updating look-ahead schedules requires detailed and reliable project information; even as the process remains manual and prone to error. Complex projects contain many interrelated work performed by many different trades and resources, and can potentially have many design changes during construction (Lindhard and Wandahl 2015). Design changes, contractual updates, and other uncontrolled project information such as on-site progress status, all can affect negatively LAS process.

Current look-ahead scheduling problems and challenges can limit the performance of LPS, therefore, manually generated look-ahead schedules may not perfectly achieve the desired improvements in scheduling reliability, productivity and construction workflow performance.

2.4 Location-based Scheduling Approaches

Critical Path Method (CPM) scheduling is the traditional way of planning construction; which includes scheduling, resources distribution and activities tracking (Akbaş 2003, Mubarak 2015). Historically, CPM is part of construction management process as an effective tool for controlling and planning since 1950 (Kenley and Seppänen 2009). However, practical implementations of CPM have limitations and gaps during complex projects such as limited on-site work activities management, not fully tracking of design changes, and not fully changes tracking of on-site resources flow. Therefore, an alternative scheduling approach has been implemented, which is called location-based approach, which has shown better efficiency and suitability for repetitive nature and complex projects (Seppänen, Ballard et al. 2010).

2.4.1 Location-Based Scheduling (LBS) Definition

Jongeling and Olofsson (2007) define Location-based Scheduling as "a visual scheduling technique that allows the planner to explicitly account for flow of a project". LBS is an alternative scheduling approach that adopts on continuous crews' working throughout the identified work locations in the project (Kenley and Seppänen 2006).

Location-based Scheduling is flexible approach that could be customized for workflow planning and control. The following are some elements that make LBS effective scheduling approach (Kenley and Seppänen 2006):

(1) Location-based approach relies on plan, analyze, control the construction workflow activities, and distribute resources into physical work locations,

(2) Work activities and resources can be visualized through flow-line output, and

(3) LBS is better than CPM regarding schedules implementations for better communications between construction stakeholders, since it can show resources distributions for assigned tasks per location.

2.4.2 Location-Based Scheduling Process

Location-based scheduling approach is not a modern or new construction scheduling approach. There are many research developments and scheduling techniques that support LBS approach with different names such as line of balance, time location matrix model, velocity diagrams, flow-line, linear scheduling, vertical production method, disturbance scheduling and others (Kenley and Seppänen 2006, Jongeling and Olofsson 2007).

Line of balance is the common technique for LBS approach (Andersson and Christensen 2007). Line of balance is a visual graphical scheduling technique to following up the construction project flow. Line of balance is a linear diagram that shows different work crews assigned to various types of work on specific work location in the project. Figure 2.1 shows an example of LBS.

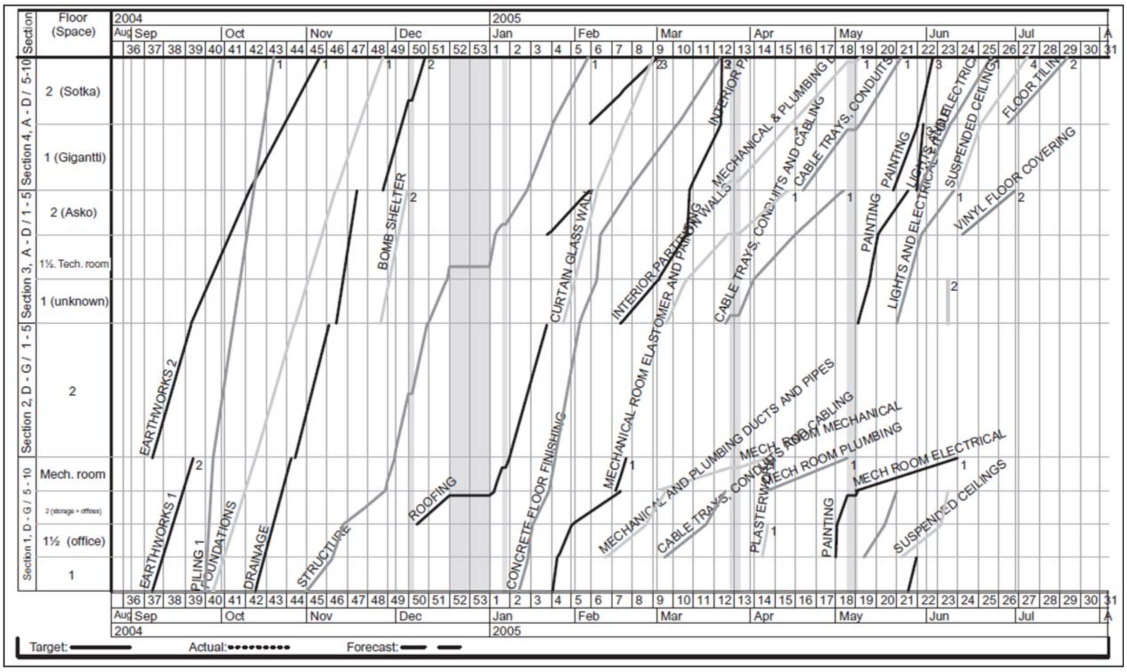

Figure 2.1 Sample of Location-Based Schedule (Kenley and Seppänen 2006)

The following are steps of LBS approach to create a construction schedule (Kenley and Seppänen 2006, Jongeling and Olofsson 2007):

(1) Work breakdown structure; breaking down project into specific work locations such as <Project A- Block 1- floor 3>,

(2) Linear task creation; a process of using Bill of Quantities (BOQ) and cost estimation plan to assign work tasks as linear diagrams into identified work location. For example, the above-mentioned location has a concrete work into project BOQ, this will be translated into linear diagram chart as per following sequencing tasks: formwork installing task, rebar installing task, concreate pouring task, and formwork removing task. Therefore, the planners will be able to identify a specific work amount as per location and per crew,

(3) WHAT and WHEN should be done; based on BOQ and cost estimation plan the planner will be able to identify WHAT work should be done, thus, he has to show WHEN work should be done into linear diagram schedule, and

(4) Crews assigning; based on work amount, location, and tasks description, the planner will be able to define size of required crews,

Location-based scheduling approach defines the construction activities workflow chart within assigned activities' relations that often not supported by CPM approach (Jongeling and Olofsson 2007). However, too much detailed relations and tasks leads to unmanageable schedule and make control process harder. Moreover, as shown in figure 2.1, LBS approach could have some scheduling deviations through scheduling process (Jongeling and Olofsson 2007); (1) same activity in several locations at the same time, (2) crossing of activities, (3) no time and spacing buffer, (4) several activities start at the same day, (5) and (6) Inefficient use of time.

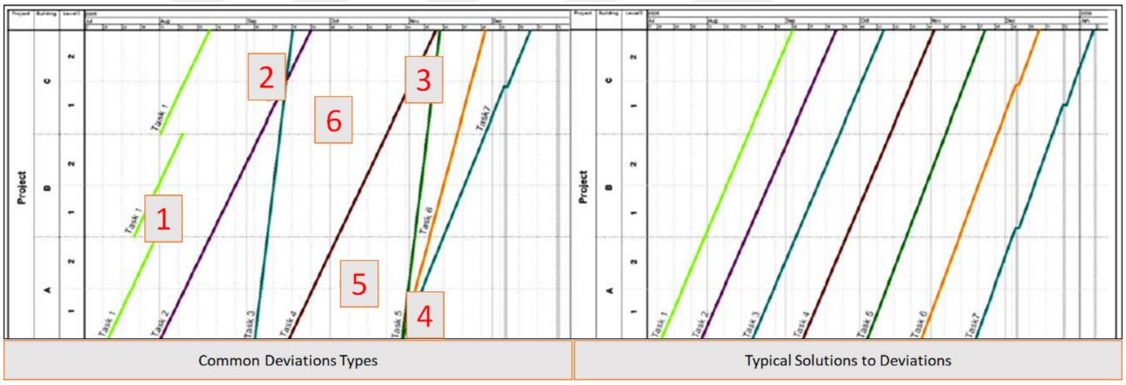

Figure 2.2 Sample of Location-Based Schedule Deviations (Jongeling and Olofsson 2007)

There are two main principles could be applied in order to eliminate those kinds of deviations (Jongeling and Olofsson 2007). First, synchronization; planner aims to get close production rate for various work tasks. As a result, a synchronized schedule will include parallel lines which represent a close time buffer between various tasks. Second, pacing; all scheduled work activities and tasks have to continue and move on from location to another consecutively without breaking-off, unless if breaking is necessary.

2.4.3 Limitations of Location-Based Scheduling

Although location-based scheduling approach includes useful mechanisms for master workflow planning; such as on-site tasks tracking as per location and crew's types, LBS has many limitations throughout look-ahead scheduling. The following are some of them (Jongeling and Olofsson 2007, Seppänen, Ballard et al. 2010):

(1) Traditional implementation of LBS approach has limited automation; typically, planners depend on 2D drawings to identify and analysis activities' locations, which usually leads to different construction workflow paths as long as different planners read and analysis 2D drawings though different ways,

(2) In complex projects, LBS diagrams include many complex activities, in addition to a complex resources distribution for identified activities, therefore, the scheduling process become more complicated with hard tracking,

(3) The real on-site work locations are more complex than planned locations diagram; on site, there is limited physical identification space control for each location, and

(4) The level of location breakdown structure in LBS is not detailed enough to serve look-ahead tasks. On other words, LAS required high detailed level of work location throughout project construction.

In conclusion, location-based scheduling approach improves lean construction principles for lean resources distribution throughout construction planning and scheduling process (Kenley and Seppänen 2006). Seppänen, Ballard et al. (2010) discuss the integration between LBS and LC. Results show that LBS can improve better construction resources distribution; Lean approach can provide effective resources through various locations that have been defined by LBS, which leads to eliminate time waste and resources usage during project cycle.

Location-based scheduling approach ensures that crew can progress and move from activity to next in defined sequence, and it aims to keep resources busy as much as possible (Jongeling and Olofsson 2007). However, scheduling process using LBS become complicated in complex and complicated project.

2.5 Automation in Construction Planning and Control

In complex project construction, traditional planning approach has limited information sharing and limited information management. It adopts on manual individual or team analysis skills to arrange construction workflow. Therefore, traditional planning approach has many discrepancies related to the way of analysis between different planners, construction managers and engineers. This leads to more complicated planning process, thus, scheduling improvement and reliably become harder to achieve.

In current planning approaches, LPS can supplement CPM for better planning and control approach. Although LPS is characterized by sharing of planning information by different decision makers throughout construction process, LPS is still a highly manual approach, as well as it still has limited integration with BIM technology.

Two main tools that can help to automate look-ahead scheduling: BIM and simulation. Recently, BIM has become the standard approach for project information coordination and automation (Azhar, Khalfan et al. 2012). BIM is an intelligent 3D model based process to manage detailed project information. In modern projects, BIM is a place where all project information is managed in one composite model; such as design, budget, schedule, and site progress.

BIM has a key role for resolving most construction problems such as LAS problems, and without connecting to the BIM model, planners cannot realize full benefits of the look-ahead scheduling process (Saffarini and Akbaş 2017). In addition, simulation has become an effective decision making tool for construction projects; considering resource behavior, minimize human mistakes, and evaluating alternatives. (Dave, Boddy et al. 2013, Hamzeh, Saab et al. 2015).

Incorporating BIM with simulation process helps professionals to improve different construction processes; since BIM can provide take-off data, all design changes, all project information and updates, in addition to WBS of construction design and others (Wang, Shou et al. 2016).

This section discusses BIM technology; definition, potential, BIM-based scheduling approach, and BIM as lean approach. Also, it discusses previous simulation implementations for construction control and management; this includes opportunities, potentials, and limitations.

2.5.1 Building Information Modeling (BIM) for Project Construction

Building Information Modeling is xD virtual prototyping technology for the physical and functional attributes of facility components that consolidates learning and information (Eastman, Eastman et al. 2011). BIM can be viewed as an effective digital technology in view of the computerization of the complex structure of the facility, construction work sequencing, cost estimation, facility management, project life-cycle evaluation and others (Azhar, Khalfan et al. 2012).

In construction sector, BIM has a potential to improve various stages of construction starting from design concept, and construction workflow as a smart BIM objects (Eastman, Eastman et al. 2011). BIM is 3D based technique for project design, coordination, improvement, visualization, on-site progress and design changes tracking, communication, control, and management (Azhar 2011). BIM is a place to create all structural, architectural, mechanical and other project components with their information and design parameters into one integrated computerized environment. It supports design coordination, improvements and it offers a continues updating workspace for design work.

BIM has a potential to generate material take-off related to identified WBS (Dave, Boddy et al. 2013), therefore, BIM has a capability to link construction resources; such as crews and equipment, with project components within lean construction environment.

BIM is a technique to improve project construction planning process by attaching all required design and on-site information into BIM model; crews, materials, equipment and other resources can be included in BIM model. (Sacks, Koskela et al. 2010).

In addition, BIM may be integrated with on-site construction status (Azhar 2011, Dong, Fischer et al. 2013). BIM is applicable to receive and attach construction work properties and status. The construction reports can be automatically integrated and reflected into BIM model in order to use real and correct data throughout look-ahead scheduling process.

BIM allows users to generate visual simulation process for construction tasks, improve production quality, eliminate time and cost during construction process, improve coast and planning control, and viably share project information with all stakeholders (Eastman, Eastman et al. 2011, Malsane and Sheth 2015).

2.5.2 BIM for Lean Construction

BIM technology supports construction control system to be more efficient in eliminating waste that may occur during construction process (Eastman, Eastman et al. 2011). Using BIM for construction planning helps to deliver material on-site-on-time, while increasing the value of quality throughout construction process (Büchmann-Slorup and Andersson

2010). according to Eastman, Eastman et al. (2011) BIM can improve lean construction approach by:

(1) Eliminate waste of construction works, construction mistakes, and re-construct actions; BIM implementation improves the collaboration between different project teams; either at office teams or on-site teams, during different levels of project construction life-cycle. For example, using BIM at early design level leads to better communications and evaluation process, better detection for design problems, better clash detection, more accurate MTO calculation, and it helps in material fabrication before on-site installation works, and

(2) Deliver on-site resources just on-time; an effective BIM can improve construction look-ahead planning process. Detailed construction activities and tasks in right sequencing can be easily integrated into BIM process as a project database. Also, BIM provides a central place for construction information transformation, tracking and management. BIM eliminates loss of information, duplication, and other risk related project information. Therefore, it helps to decrease the waiting and idle time throughout construction process, and construction workflow become more effective and reliable.

2.5.3 4D BIM for Construction Planning

4D BIM has a visual enhancement for 3D BIM. The main concept of 4D BIM model relies on better visualization of construction schedules; it is a visualization of on-site activities' relations before real on-site construction process (Forbes and Ahmed 2010, Lin and Golparvar-Fard 2016). 4D models are created by linking the schedule activities; such as CPM, with 3D BIM model. Each BIM physical component has an activity that should be linked with.

However, current 4D BIM has some limitations for construction planning and control (Malsane and Sheth 2015). Current 4D BIM is closer to animation approach more than simulation approach. 4D BIM shows a visualization of provided schedule throughout available BIM model; even if there are many of discrepancies in activities' duration, sequencing and resources distribution. In other words, there is gap in current 4D BIM planning approach, it is not a simulation scheduling approach; it has limited ability to evaluate the on-going construction schedule according to construction workspace constraints, in addition to resources capacity and their production rate, tasks and activities sequencing. Therefore, 4D BIM has no ability to simulate alternatives and revised construction schedules; especially look-ahead schedules.

2.5.4 BIM-Based Scheduling

BIM implementation for look-ahead scheduling aims to improve the efficiency of construction planning process; planning process become easier and flexible, also, BIM can support to automate LAS process (Hamzeh, Ballard et al. 2012). BIM provides a structured approach for construction planning based on identified WBS into 3D physical components.

BIM provides an integrated structured environment for simulation approach; which helps to present the resources distribution during scheduled construction process (Liu, Al-Hussein et al. 2015). The following are some of BIM potentials for BIM-based construction scheduling (Azhar 2011, Eastman, Eastman et al. 2011):

(1) <u>Central design coordination</u>; BIM is a central sharing environment, project staff and engineers can be involved at early stage of design, this leads to better decision making, and better design understanding; if construction team has been involved. This involvement makes planning and scheduling process more effective; it's a direct communication for better understanding for WBS. Moreover, clash-free

and fully coordinated design means decreasing of on-site material waste as well as decreasing of on-site re-work actions,

(2) Accurate bill of quantities (BOQ); BIM provides an accurate and updated project BOQ. Based on design status, new items maybe added, others may be removed from BOQ,

(3) Design tracking throughout construction process; BIM helps for design changes tracking during construction and design process. Early detection and analyzing of design changes leads to better actions for on-site resources distribution and re-allocation; some design changes require new construction activities; thus, new resources are required as well,

(4) On-site progress tracking; It is hard to integrate on-site progress status manually into look-ahead scheduling approach. BIM has a potential to automate integration of on-site progress information into as-built BIM model. Latest on-site progress status considers as base line for upcoming look-ahead schedules,

(5) Effective WBS; using BIM, planners are able to define high detailed level of workable WBS for project components. therefore, BIM supports construction WBS in more details than LBS approach. Moreover, BIM can help to define the construction tasks database, which includes a structured sequencing system for all required construction activities and tasks, and

(6) Effective information management system; all above mentioned information can be well managed into BIM environment. BIM provides an updated managed model with latest design and construction information. This updated BIM model can be integrated into structured simulation approach; which supports construction workflow of look-ahead scheduling.

2.5.5 Simulation-Based Scheduling

Simulation approach for planning helps planners to control and manage a huge number of activities at the same time (Hamzeh and Langerud 2011). Simulation approach helps planning process to reduce sequencing problems of construction activities, and it can show better resources distribution throughout project life cycle (Dong, Fischer et al. 2013). Simulation is powerful analysis tool; it has ability to involve uncertainty and variability for better and much reliable results. Simulation can desired improvements in productivity and construction workflow will be achieved (Dave, Boddy et al. 2013, Malsane and Sheth 2015).

Look-ahead scheduling simulation approach has a potential to efficiently react for system changes (Wang, Weng et al. 2014). This requires a structured simulation system which is able to analysis whole system, capture changes, and update accordingly, therefore, the system parameters changes and their impacts will be taken in consideration for LAS simulation process.

2.5.6 Previous Work in LAS Automation

Simulation implementations integrated with BIM for construction planning are still not very common. However, many researchers have applied BIM and simulation for construction processes; including some BIM and simulation implementations for LAS process.

Chua, Jun et al. (1999) presented a scheduling tool called ‘The Integrated Production Scheduler System’. The presented system employs a methodology to incorporate integrated information into look-ahead activities. However, the presented system is not linked with BIM. Also, it has many challenges such as limited information management, obtaining schedule reliability, and obtaining smooth construction workflow.

Mikulakova, König et al. (2010) discussed integration of BIM and a knowledge-based approach for generation and evaluation construction schedules. Through their study, they integrated identified constraints during planning process into BIM components; BIM entities and their attributes. These constraints describe construction conditions. Then, a case-based reasoning system was implemented to improve construction process using similar past construction execution data. Then, all generated construction activities define a construction schedule. However, this approach focuses on master schedules.

Liu, Al-Hussein et al. (2015) discussed a BIM-based integrated scheduling approach that supports automatic generation of tasks considering resource constraints; integrating with BIM construction data, and using simulations and algorithms. Results show that BIM helps improve construction scheduling process. Büchmann-Slorup and Andersson (2010) discussed current construction scheduling approach in a relation to BIM-based scheduling. Results show that BIM has to be more integrated into current traditional scheduling approach to become more efficient. In addition, analysis shows that current traditional scheduling approach has a gap between master and detailed scheduling levels.

Shi (1999) reviewed the benefits and potentials of simulation throughout planning process. His research discusses potentials of simulation approach to improve construction process performance such as ability of simulation to model resources, describe a dynamic process, and control change of instances through set of alternatives.

Hamzeh, Saab et al. (2015) presented a simulation approach to analyze relation between improving task anticipated in LAP phase and total project construction time. The used methodology includes direct actions with planning participates in a weekly meeting. Site visits for production planning allows better understanding of practical problems that cause work plans failures in order to improve the planning process. The presented simulation study includes three phases (i) modeling a conceptual system of LAP process, (ii) developing a mathematical base for a computer simulation approach, and (iii) developing a set of experiment test cases, run the simulation, and evaluate results. The results show that increasing task anticipated can have a positive impact on minimizing the overall project duration. However, the presented simulation approach is not connected with design BIM. Also, it is not applicable for directly integrating with design changes or constraints. In other words, there is still a gap between look-ahead planning process and other project elements such as design changes and site progress.

Another approach has been presented by Dong, Fischer et al. (2013) to automate look-ahead schedule based on generation process model transforms the operation instances to operations using a constraint-based approach. The automated LAS generation addresses the commonly found constraints on site such as precedence constraints, crew and room availability, operation specific spatial constraints and provides sufficient detail to guide crews' daily work. However, this approach assumes that material, equipment, and engineering documents are always available, which makes LAS output less integrated with current site status, as well as it will be limited in solving specific problems during construction process. Moreover, the presented LAS approach is still depending on a highly manual resources distribution process, and lacking a proper underlying model and automation. However, the used approach is closer to automated calculation approach more than simulation approach. It has poor data updating to support on-site changes, and its integration with BIM is limited.

Other research applied simulation for various areas of construction planning. Vanegas, Bravo et al. (1993) used simulation to improve construction workflow. They used it through planning process of heavy civil projects, results show that simulation has a potential for workflow analysis and improvement with low overall implementation cost. Huang, Chen et al. (2004) used simulation for formwork activities planning in construction process. Simulation has been used for re-allocates resources, and improves formwork uses. Results shows that project cost and time can improve through simulation approach. Wales and AbouRizk (1996) used simulation for site logistics and planning process. They used simulation model to improve construction scheduling by eliminating the weather impacts on construction workflow and productivity of bridge construction project. Hamzeh, Tommelein et al. (2007) used simulation model to improve the construction material supply by gathering on-site material stores throughout logistics locations. Simulation shows better materials distribution and control, therefore, eliminating material shortages. Draper and Martinez (2002) used simulation to generate and evaluate different alternatives designs of production system. They discussed that most of traditional construction process have resources wastes and time constraints, which making the traditional control process much difficult.

AbouRizk and Dozzi (1993) used simulation to evaluate multiple alternatives through multiple projects. By identifying construction cost changes, it could be able to improve resolving construction disputes. Also, results show that simulation is successful tool for construction process improvement. Lu, Dai et al. (2007) used DES model throughout real-time decision making system to plan and control concrete work activities, while as, the actual site information used to update simulation model, therefore, achieve more efficient alternative selection.

Tommelein (1997) used Discrete Event Simulation (DES) model to show the flow of construction materials. She identified the gap between uncertainty and flow within lean construction. Moreover, she concludes that simulation has potential to represent lean construction strategies, and supporting materials flow throughout construction process.

Schramm, Silveira et al. (2007) used DES model to improve decision making process throughout construction works, design, and operation. Results show that simulation has a potential to help in defining reliable process duration, and determine the changes impacts on construction production process.

Choo, Tommelein et al. (1999) presented a database tool which adopts LPS methodology and LC principles. The presented tool helps planners to improve planning process throughout "spelling out work packages, identifying constraints, checking constraint satisfaction, releasing work packages, allocating resources and collecting field progress data and reasons for plan failure". However, the presented tool is not integrated with BIM environment. Similar concept has been integrated in this thesis work, but here it is completely integrated into BIM environment.

2.6 GSimX Simulation Platform

The rapid expansion of Building Information Modeling (BIM) in construction project improves design process, project management, and project delivery process (Eastman, Eastman et al. 2011). As discussed before, the integration of project information such as cost, time, design specifications, etc. into BIM model, helps project participants share information, also contributes to project management. However, the most common application of BIM in the construction planning process is 4D CAD, which in a basic sense is to visualize plans by combining project work schedules with BIM models.

Recently, researchers have used simulation and BIM for construction analysis during planning, but due to a lack of common modelling structure and easy implementation, the practical use of these approaches has been limited.

GSimX is a prototype simulation platform that has been used in this thesis work. It realizes a simulation-based analysis of construction projects entirely through BIM in order to solve the problems of current approaches. The difference from traditional approaches is that the simulation model is created automatically through BIM components, crews, equipment, basic workflow, and efficient incorporation of resources into the dynamic simulation of the 3D model.

2.6.1 GSimX Definition

GSimX is a new general purpose resource-integrated simulation platform on 3D building information models (Akbas 2016). GSimX generates simulation structures from related work on BIM called location flows, and analyses construction site processes as a whole. All primary resources (crews and equipment) are individually tagged and become part of the simulation process.

Once resources are assigned to an activity, they behave as agents in 3D building model. BIM elements are directly part of discrete-event simulation as work locations and their processing by resources are simulated as queueing networks. During simulation, each activity can be active only if their prerequisite tasks are complete, all required resources are ready on location, and there are no other construction constraints. Simulation is complete when all location flows are completed.

2.6.2 GSimX Approach Description

In order to create a general GSimX simulation model, a master schedule and 3D BIM model must be included in the system. Then a few basic steps are followed (Akbas 2016):

(1) Define location flows; activities are systematically linked with BIM components. The BIM components connected in the simulation model that is generated as a result of the connection form the work locations and the activities form the work crews (servers),

(2) Identification of resources; the crews, equipment, and materials requirements that will be used throughout construction process. The crews are organized according to their work items and the number of workers included in each crew is determined. The equipment is also organized according to its type and its properties such as capacities and costs are defined,

(3) Link resources with activities; the crews, equipment, and material needs of the activities are determined. Each activity requires at least one crew. It also defines in which order the crew will complete the activity, the production rate function, and how many crews can work on an activity at the same time. Other sources are defined on demand,

(4) Performing the simulation; the simulation process can be visualized on 3D BIM in the tool workspace. The simulation process starts by the first crew (server). All work locations (customers) pass to the network and get a place in queue of first crew. At the same time, the work locations are automatically preferred throughout first crew workflow sequencing. Once a crew is active and not busy, it can process a work location, and other available work locations are waiting in crew's queue. By multiplying the production rate function with provided work quantities, the serving time can be calculated. Once a specific crew completes serving a work location:

    a. The served work location will be transferred to the queue of the next crew in the network with take in consideration any time buffer between crew. However, if the work location served by the last crew, that's means the work process is complete and work location leaves the network,

    b. The crew becomes available to serve next work location in its queue. If crew's queue is empty, the crew becomes idle,

c. Crews and work locations' status are continuously updated. Once all work locations are served completely, that's mean the simulation is complete, and

(5) Analysis of results; project activities and their relations, construction time, cost, and resource usage are visualized in various forms with graphics. It is possible to compare the simulation results with the planned master schedule on an activity basis. The changes can be done easily and parametrically. For example, adding new equipment or determining how a crew processes an activity is easily applicable through simulation workspace. At the same time, a parametric value can be changed in series to compare the results of a full-scale simulation.

In conclusion, GSimX approach offers considerable advantages in terms of planning. The usage of resources, constraints and BIM information are part of the overall workflow analysis. This allows analysis to be easily incorporated into traditional construction workflows and any change in the project elements can be monitored for the entire project.

2.7 Literature Review Conclusion

Lean Construction (LC) implementation helps to manage construction process. LC improves the foundation of the activities based construction delivery system; it is an approach for construction improvements in all construction projects especially uncertain, complex, and fast-track projects.

Last Planner System (LPS) helps to improve construction planning and control; especially look-ahead planning, but it is still manual scheduling approach, and it is normally not integrated with Building Information Modeling (BIM).

In complex project, Location-Based Scheduling (LBS) approach has limited information integration and presentation. LBS diagrams are less flexible to manage look-ahead scheduling activities and their resources.

BIM implementation can support lean construction principles and improves look-ahead scheduling processes throughout construction process. BIM could be integrated into construction planning and control system for better and more effective management of materials delivery and site logistics.

Throughout construction process of complex project, the manual control process of tasks sequencing become harder and more complicated. BIM affords a digital system for more reliable information presentation. Using BIM for scheduling process improves better control system for project resources, therefore, the schedules and workflow plans become more workable and reliable. BIM helps to create and easily manage a high detailed location breakdown structure, even per room, per individual defined entity such as wall or stair.

Through BIM and simulation integrated structure approach, simulation leads to stability of construction workflow and helps to descries waste time during construction process. Planner will be able to assign and manage all required project resources and construction site logistics. The gap between LAS process and required information sources can be filled through structured BIM-resources integrated simulation approach. This will allow implementation of LC principles, LPS techniques, as well as BIM and simulation advantages to support planners to generate effective workflow plans and reliable LAS.

CHAPTER III

METHODOLOGY

The goal of this thesis is to enable BIM and resource-integrated look-ahead scheduling approach. As a result, planners should be able to generate alternatives of look-ahead schedules given site progress, plans for crew, equipment, construction constraints, and material availability to satisfy master schedule requirements; using BIM and simulation within lean construction environment. This chapter discusses the steps performed to achieve the goals of this research:

(1) Identify the required information for BIM and resource-based planning systems to support multiple-level construction schedules,

(2) Describe project information management at design BIM process, this includes bill of quantities (BOQ), master schedule tasks and activities, site progress status, design BIM work breakdown structure (WBS) and construction constraints, and

(3) Discuss GSimX enabling process into presented LAS process; defining the simulation requirements, relations between them, and constraints analysis.

3.1 Overall Information Flow

For construction planning process, information coming from various sources needs to be integrated into simulation analysis approach within BIM environment. Furthermore, this information needs to be periodically updated during the project for updated analysis. Figure 3.1 shows the integration between BIM environment (Design BIM and GSimX) to support planning phases compatible with the Last Planner System. Although this thesis focuses on look-ahead planning, master scheduling, phase planning and weekly work plan also should be integrated into the general construction planning approach. Also, other information is received from different sources such as design and engineering information, in addition to different types of constraints and feedback coming from construction site, all are integrated within presented approach. For all received information from different sources, the presented approach discusses the information management approach integrated within BIM environment, which aims to analyze this information in order to improve construction workflow, planning reliability and to generate the list of LAS tasks and required resources for these tasks.

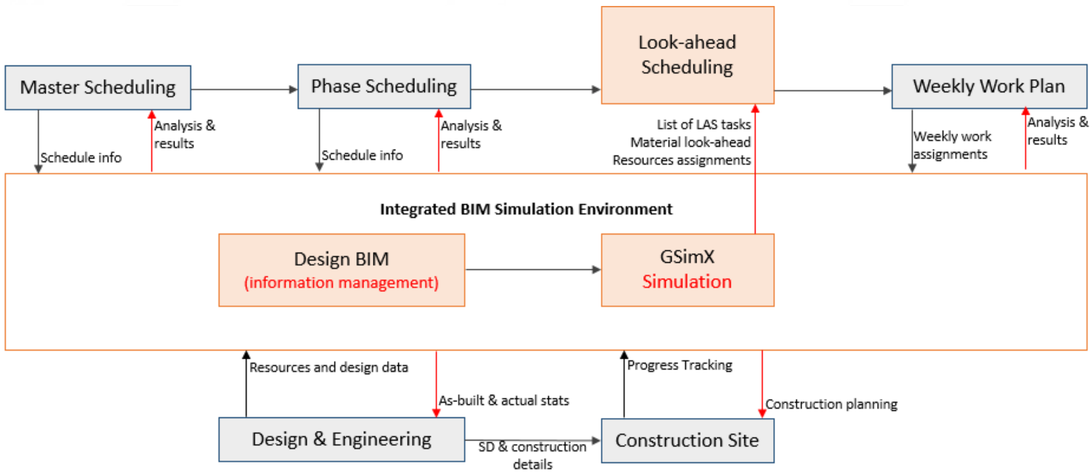

Figure 3.1 Overall Information Management Environment Related to Planning Process

In this thesis work, Figure 3.2 summarizes the proposed information flow for the look-ahead scheduling process through design BIM and the GSimX platform. Design and engineering data with process information forms the basis for generating the master schedule, detailed method, and resources information for construction process. GSimX needs information including master schedule, 3D BIM entities and their quantities for each necessary task to build them. In addition, available resources, construction constraints database, and activity requirements should be defined as well. As a result of GSimX simulation process, a list of LAS tasks and required resources are generated.

These resource requirements include any additional resources for LAS time period. This will also lead to a revised master schedule if necessary.

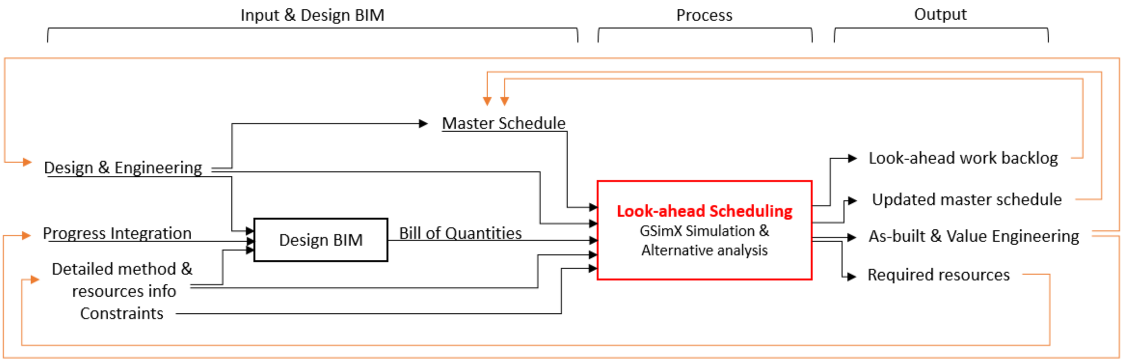

Figure 3.2 General Structure for the Overall Information Flow for LAS process

During the project, look-ahead schedules are periodically updated. There can be various changes for the project between each update including project design changes, completed work, resource availability and master schedule updates. All these changes should be supported as information coming into the platform, and should be synced with the existing data. Within a closed loop, GSimX simulation results are help control the project and update master schedule information.

3.2 Information Management for Design BIM

This section describes information management for identified different sources of information for BIM-based look-ahead scheduling as part of the overall goal of building an integrated platform for performing LAS using GSimX.

In this thesis work, to realize the proposed structure for performing look-ahead scheduling within integrated BIM simulation environment, Figure 3.3 summarizes various types of required information that is generated by researcher and their sources. This includes tagged information within design BIM platform and generated information that flow into the GSimX platform.

During design, an ***ObjectCode*** is generated for each entity on BIM using a defined breakdown structure. This ***ObjectCode*** works as a unique ID to link each individual BIM entity to its work location in GSimX.

Another key element for the process is the ***Task-Component*** database, which includes the sequences of tasks, their production rates, and their associations with BIM entities. ***Task-Component*** database is built based on design and engineering specification, and construction method information. This database includes main construction activities and their sub-task sequence for construction process and serves as a template for construction methods.

Also, construction constraints have a key role into LAS simulation process, therefore, they have to be transferred and identified using constraints database that has been integrated into presented simulation process.

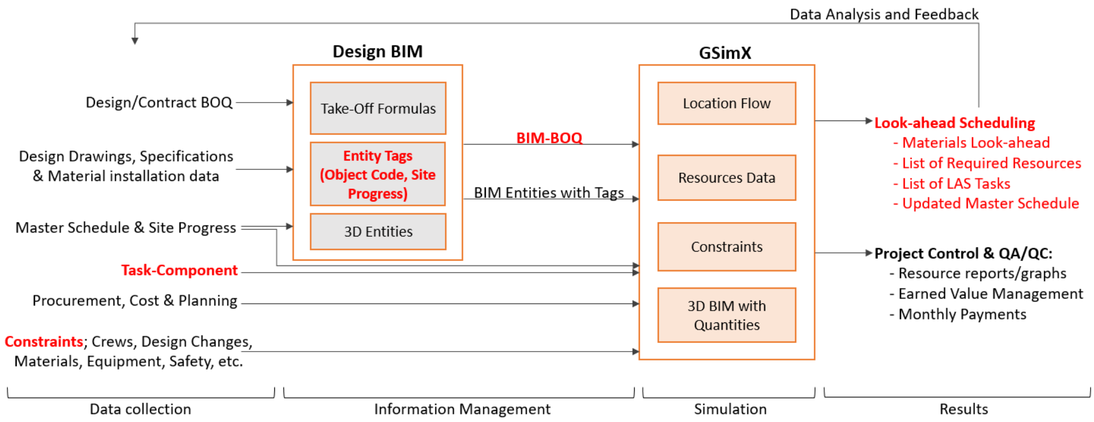

Figure 3.3 Information Workflow for Look-ahead Scheduling Simulation Process

Using the BIM tool in the presented approach, a detailed Bill of Quantities (BOQ) is generated called ***BIM-BOQ***, which includes the quantity for each task at ***Task-Component*** database related to BIM entities. When design BIM is updated, quantities in the ***BIM-BOQ*** are automatically updated. Furthermore, during each project status update, the site progress status for each individual BIM entity in design BIM is checked and updated by a tag named ***SiteProgress***.

3.1.1 Coding Structure for BIM Entities

Breakdown structures are very effective in managing a large amount of data and structuring information, which directly applies to BIM and construction project management and increasingly utilized in recent research and practice (Rischmoller, Dong et al. 2017). BIM Work Breakdown Structure (WBS) is a deliverable oriented hierarchy for a project that organize the project's team work into manageable sections. It is composed of several levels and is customized according to the project, functions, disciplines and task’s needs.

This thesis defines a specific code structure for BIM entities stored under a tag called ***ObjectCode***. Based on the WBS, a unique code is automatically assigned to each BIM entity among the entire project which combines seven levels breakdown structure. Figure 3.4 summarizes a sample for ***ObjectCode*** for a BIM entity. In this case, levels are composed of <Project/Area/Sub-area/Category/Activity/Object/Entity ID>. Sub-areas divide areas into smaller zones or spaces. Categories describe main work categories such as structural and architectural works. For example, structural category contains rebar, formwork, and concrete activities, these activities are assigned to structural BIM entities such as wall, column, beam, and slab. Within the same floor, there can be column objects such as column1, column2, column 3, etc. This seven levels of breakdown structure provides each individual BIM entity with unique ***ObjectCode***.

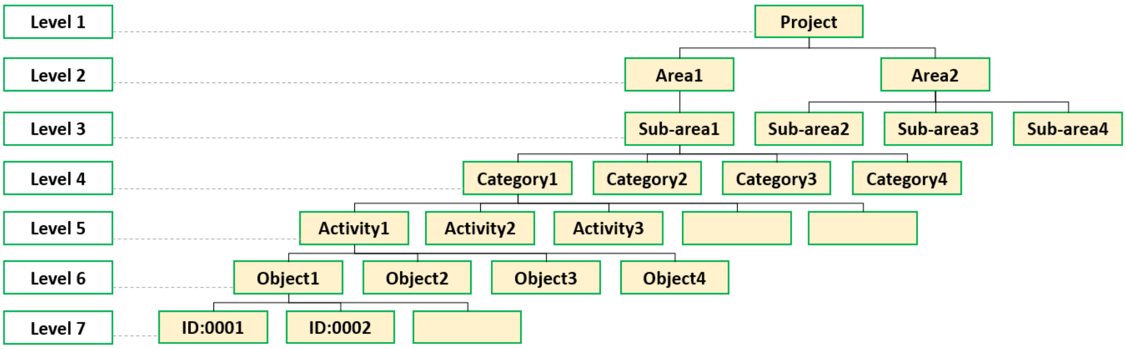

Figure 3.4 Sample WBS of BIM Entities for Object Naming

Each BIM entity is automatically tagged by a unique ***ObjectCode***. Figure 3.5 shows an example of ***ObjectCode*** for an entity: <OZU_BE_L02-B_STR-CON_WALL_12563>, which refers to a structural concrete wall number 12563, which is located in Zone B of floor 2 of Engineering building at project named OZU. These levels of WBS are parsed within the simulation environment to obtain relevant information.

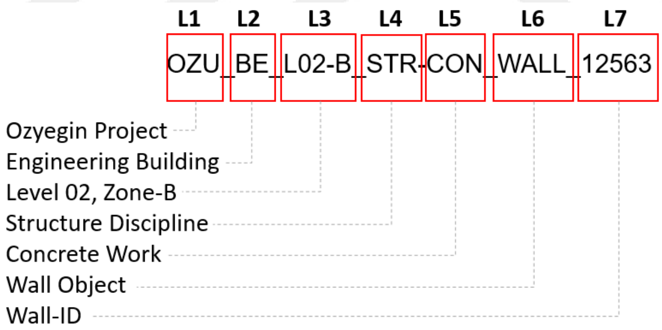

Figure 3.5 ***ObjectCode*** Sample

3.1.2 Task-Component Database

Task-Component database has a key importance in providing necessary information for simulation to perform look-ahead scheduling. It defines the link between design BIM model and bill of quantities, while relating master schedule activities and detailed tasks. ***Task-Component*** database includes the main construction activities and their tasks series at right sequencing for construction process for each entity category. It also contains the production rate of a standard crew performing the particular task. In addition, it includes the formulas and equations for material take-off extraction process from design BIM.

Each entry in ***Task-Component*** database is a common code shared among each BIM entity, bill of quantities, and GSimX platform. Figure 3.6 shows the five levels hierarchy and a sample for ***Task-Component*** database breakdown structure. First three levels of this structure has been built based on Uni-format (1999); it is an element classification for building specifications, cost, estimation, and cost analysis, which has been approved by U.S. National Institute of Standards and Technology, and Canadian Construction Specifications Institute (Charette and Marshall 1999). In this sample, the code <STR-100_01_LAS-BOQ_2> refers to edge formwork tasks of structural foundation footing. This task is the second in line sequence of detailed tasks for foundation footing. For BIM construction component require a set of tasks to complete the construction process on-site, these tasks get the code 'LAS' as level 4, which designates that it will use resources and time to be constructed at LAS level. In contrast, BIM components that are parts of design changes and construction tracking and with no direct task in LAS level gets the code 'BOQ'.

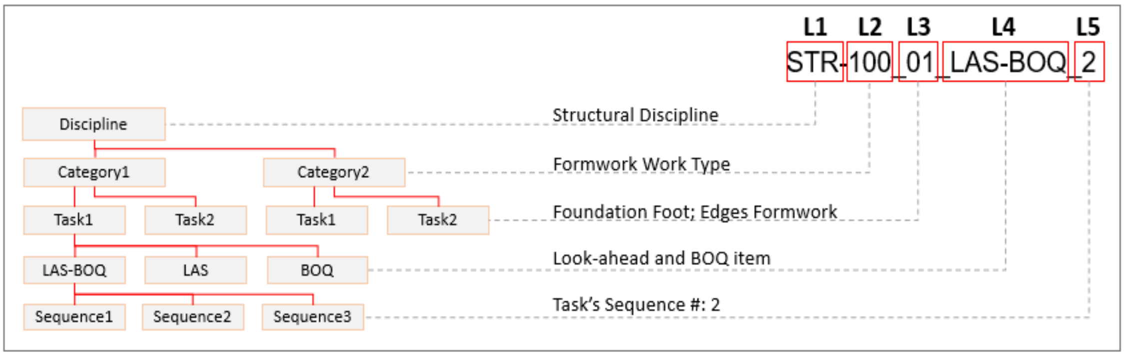

Figure 3.6 ***Task-Component*** Breakdown Structure

Figure 3.7 shows a sample set of items from a ***Task-Component*** database. ***Task-Component*** database includes data from various sources including (i) design specifications, (ii) information from site personnel, (iii) material installation data, and (iv) planning schedule. ***Task-Component*** database works together with the design BIM library to generate automated ***BIM-BOQ*** from design BIM. As such, design BIM should be created in parallel with ***Task-Component*** creation. Each particular task type within ***Task-Component*** has a unique key called 'component code' column in the ***Task-Component*** database. Note that ***Task-Component*** has many-to-many relationship with BIM entities: One ***Task-Component*** code can be assigned to many BIM entities, and one BIM entity could be tagged with multiple ***Task-Component*** codes to represent its tasks series. 'Discipline' column refers to the main trades at site, which typically define how activities are organized in the master schedule. 'Component Code' column includes a unique ID for each task. 'Sequence' column includes the sequences ranging of tasks for each activity. 'Element Type', 'Formula' and 'Unit' columns describe the equations that have been used into design BIM process in order to create ***BIM-BOQ***. Master category column refers to detailed task types appropriate for look-ahead schedules. One discipline item can contain one or more master category item. For example, *wall finish* discipline includes plaster-work, wall lining, wall tiling, and painting task family.

Discipline	Component code	Sequence	Description	Element type	Formula	Unit	Master category
Formwork	STR-100_01_LAS-BOQ	2	Foundation foot edges formwork	FF	SA-ST-SB	m2	Formwork
Formwork	STR-100_02_LAS-BOQ	2	Under ground beam formwork	LF	SL+SR	m2	Formwork
Formwork	STR-100_05_LAS-BOQ	2	Column formwork	FF	SA-ST-SB	m2	Formwork
Rebar	STR-101_01_LAS-BOQ	1	Foundation foot steel (estimated, depends on design)	FF	VOL*250	kg	Rebar
Rebar	STR-101_02_LAS-BOQ	1	Under ground beam steel (estimated, depends on design)	LF	VOL*200	kg	Rebar
Rebar	STR-101_09_LAS-BOQ	1	Shear wall steel (estimated, depends on design)	LF	VOL*70	kg	Rebar
Concrete	STR-102_01_LAS-BOQ	3	Concrete B300 for foundation foot	FF	VOL	m3	Concrete
Concrete	STR-102_03_LAS-BOQ	3	Concrete B300 for under ground beam	LF	VOL	m3	Concrete
Concrete	STR-102_04_LAS-BOQ	3	Concrete B250 for slab on grade	FF	VOL	m3	Concrete
Floor Finish	ARC-100_05_LAS-BOQ	2	Ceramic type FL401	FF	ST	m2	Floor Finish
Floor Finish	ARC-100_07_LAS-BOQ	3	Ceramic type FL412	FF	ST	m2	Floor Finish
Floor Finish	ARC-100_08_LAS-BOQ	1	Stone tile type FL660	FF	ST	m2	Floor Finish
Ceiling Finish	ARC-101_01_LAS-BOQ	3	Gypsum board 12mm thick type CLG601	FF	ST	m2	Ceiling Finish
Ceiling Finish	ARC-101_02_LAS	1	Fail ceiling structural system	FF	ST*5/2	m	Ceiling Finish
Ceiling Finish	ARC-101_03_LAS	2	Fail ceiling thermal insulation 50mm thick	FF	(SL+SR)/2	m2	Ceiling Finish
Wall Finish	ARC-103_01_LAS-BOQ	1	Cement Plaster 14mm thick, soft finish	LF	(SL+SR)/2	m2	Plaster
Wall Finish	ARC-103_02_LAS-BOQ	1	Cement Plaster 6mm thick, hard finish	LF	(SL+SR)/2	m2	Plaster
Wall Finish	ARC-103_03_LAS-BOQ	2	Paint type PT104 on fair face	LF	(SL+SR)/2	m2	Painting
Wall Finish	ARC-103_04_LAS	1	Wall lining structural system	LF	(SL+SR)*4/2	m	Wall Lining
Wall Finish	ARC-103_05_LAS-BOQ	2	Ceramic wall lining type LIN302, 8mm, fixed by glue on hard surface plaster	LF	(SL+SR)/2	m2	Wall Lining
Wall Finish	ARC-103_06_LAS-BOQ	2	Marble cladding type LIN808, 20mm thick	LF	(SL+SR)/2	m2	Wall Tiling
Wall Finish	ARC-103_07_LAS-BOQ	3	Paint type PT305 direct to polished gypsum board	LF	(SL+SR)/2	m2	Painting
Wall Finish	ARC-103_08_LAS	2	Polishing work gypsum surface	FF	(SL+SR)*5/2	m	Painting
Wall Finish	ARC-103_09_LAS	2	Polishing work cement surface	FF	(SL+SR)/2	m2	Painting
Wall Finish	ARC-103_10_LAS-BOQ	2	Wooden sheet cladding type LIN809, 20mm thick	LF	(SL+SR)/2	m2	Wall Tiling
Wall Finish	ARC-103_11_LAS-BOQ	3	Paint type PT104 on cement plaster	LF	(SL+SR)/2	m2	Painting
Wall Finish	ARC-103_12_LAS	1	Filling surface	LF	(SL+SR)/2	m2	Painting

Figure 3.7 Sample Data from ***Task-Component*** Database

3.1.3 BIM-BOQ

BIM-BOQ contains quantities for each required task for each BIM entity. It is automatically generated from design BIM using formulas and entity geometry. Materials take-off report that is generated by BIM software includes thousands of raw items of quantities according to design BIM library WBS, and sometimes it includes unnecessary data. The ***Task-Component*** database (activities, tasks and their sequence) and BIM materials take-off report data is linked with ***Task-Component*** Database to automatically get the ***BIM-BOQ*** which is specifically customized for the simulation process.

Figure 3.8 shows sample data from **BIM-BOQ** as it represents joint information from BIM WBS and ***Task-Component*** breakdown. As shown, 'TaskCode' field is the combination of ***ObjectCode*** and ***Task-Component*** code for each individual entity. GSimX obtains quantities by matching with ***ObjectCode*** from design BIM and uses these quantities at locations corresponding to BIM entities during simulation.

ID	Sequence	TaskCode	TaskCategory	Component	Description	Unit	Total
20777	2	OZU_BE_FON_STR-CON_FOUN_12042/STR-100_01_LAS-BOQ	Formwork	STR-100_01_LAS-BOQ	Foundation foot edges formwork	m2	6
20777	1	OZU_BE_FON_STR-CON_FOUN_12042/STR-101_01_LAS-BOQ	Rebar	STR-101_01_LAS-BOQ	Foundation foot steel (estimated, depends on design)	kg	562.5
20777	3	OZU_BE_FON_STR-CON_FOUN_12042/STR-102_01_LAS-BOQ	Concrete	STR-102_01_LAS-BOQ	Concrete B300 for foundation foot	m3	2.25
20789	2	OZU_BE_FON_STR-CON_FOUN_12054/STR-100_01_LAS-BOQ	Formwork	STR-100_01_LAS-BOQ	Foundation foot edges formwork	m2	6
20789	1	OZU_BE_FON_STR-CON_FOUN_12054/STR-101_01_LAS-BOQ	Rebar	STR-101_01_LAS-BOQ	Foundation foot steel (estimated, depends on design)	kg	562.5
20789	3	OZU_BE_FON_STR-CON_FOUN_12054/STR-102_01_LAS-BOQ	Concrete	STR-102_01_LAS-BOQ	Concrete B300 for foundation foot	m3	2.25
20801	2	OZU_BE_FON_STR-CON_FOUN_12078/STR-100_01_LAS-BOQ	Formwork	STR-100_01_LAS-BOQ	Foundation foot edges formwork	m2	6
20801	1	OZU_BE_FON_STR-CON_FOUN_12078/STR-101_01_LAS-BOQ	Rebar	STR-101_01_LAS-BOQ	Foundation foot steel (estimated, depends on design)	kg	562.5
20801	3	OZU_BE_FON_STR-CON_FOUN_12078/STR-102_01_LAS-BOQ	Concrete	STR-102_01_LAS-BOQ	Concrete B300 for foundation foot	m3	2.25
20813	1	OZU_BE_FON_STR-CON_FBED_14303/STR-100_03_LAS-BOQ	Formwork	STR-100_03_LAS-BOQ	Slab edges formwork	m2	7.2
20813	2	OZU_BE_FON_STR-CON_FBED_14303/STR-102_02_LAS-BOQ	Concrete	STR-102_02_LAS-BOQ	Concrete B200 for foot bed	m3	0.324
20825	1	OZU_BE_FON_STR-CON_FBED_14519/STR-100_03_LAS-BOQ	Formwork	STR-100_03_LAS-BOQ	Slab edges formwork	m2	7.2
20825	2	OZU_BE_FON_STR-CON_FBED_14519/STR-102_02_LAS-BOQ	Concrete	STR-102_02_LAS-BOQ	Concrete B200 for foot bed	m3	0.324
20837	1	OZU_BE_FON_STR-CON_FBED_14531/STR-100_03_LAS-BOQ	Formwork	STR-100_03_LAS-BOQ	Slab edges formwork	m2	7.2
20837	2	OZU_BE_FON_STR-CON_FBED_14531/STR-102_02_LAS-BOQ	Concrete	STR-102_02_LAS-BOQ	Concrete B200 for foot bed	m3	0.324
20849	2	OZU_BE_FON_STR-CON_FOUN_12150/STR-100_01_LAS-BOQ	Formwork	STR-100_01_LAS-BOQ	Foundation foot edges formwork	m2	6.4
20849	1	OZU_BE_FON_STR-CON_FOUN_12150/STR-101_01_LAS-BOQ	Rebar	STR-101_01_LAS-BOQ	Foundation foot steel (estimated, depends on design)	kg	640
20849	3	OZU_BE_FON_STR-CON_FOUN_12150/STR-102_01_LAS-BOQ	Concrete	STR-102_01_LAS-BOQ	Concrete B300 for foundation foot	m3	2.56
20861	2	OZU_BE_FON_STR-CON_FOUN_12174/STR-100_01_LAS-BOQ	Formwork	STR-100_01_LAS-BOQ	Foundation foot edges formwork	m2	6
20861	1	OZU_BE_FON_STR-CON_FOUN_12174/STR-101_01_LAS-BOQ	Rebar	STR-101_01_LAS-BOQ	Foundation foot steel (estimated, depends on design)	kg	562.5
20861	3	OZU_BE_FON_STR-CON_FOUN_12174/STR-102_01_LAS-BOQ	Concrete	STR-102_01_LAS-BOQ	Concrete B300 for foundation foot	m3	2.25
20873	1	OZU_BE_FON_STR-CON_FBED_14315/STR-100_03_LAS-BOQ	Formwork	STR-100_03_LAS-BOQ	Slab edges formwork	m2	7.2
20873	2	OZU_BE_FON_STR-CON_FBED_14315/STR-102_02_LAS-BOQ	Concrete	STR-102_02_LAS-BOQ	Concrete B200 for foot bed	m3	0.324
20885	1	OZU_BE_FON_STR-CON_FBED_14942/STR-100_03_LAS-BOQ	Formwork	STR-100_03_LAS-BOQ	Slab edges formwork	m2	7.6
20885	2	OZU_BE_FON_STR-CON_FBED_14942/STR-102_02_LAS-BOQ	Concrete	STR-102_02_LAS-BOQ	Concrete B200 for foot bed	m3	0.361
20897	2	OZU_BE_FON_STR-CON_FOUN_12162/STR-100_01_LAS-BOQ	Formwork	STR-100_01_LAS-BOQ	Foundation foot edges formwork	m2	16.448
20897	1	OZU_BE_FON_STR-CON_FOUN_12162/STR-101_01_LAS-BOQ	Rebar	STR-101_01_LAS-BOQ	Foundation foot steel (estimated, depends on design)	kg	2634

Figure 3.8 Sample of Extracted ***BIM-BOQ*** by Design BIM

3.1.4 Site Progress

On-site progress monitoring is essential for keeping track of the on-going work for performing look-ahead scheduling. Missing or inaccurate site progress information will cause errors throughout the LAS process, as a result, project may delay or project costs would increase. BIM provides a good underlying structure for performing progress monitoring. BIM entities are associated with site progress over time, and actual status at any given point in time during the project can be compared with the planned state. This is a more detailed approach than relating activities from master schedules to building elements as in 4D CAD and comparing progress with the construction schedule. Any process deviation can be detected by identifying missing or additional building components, which directly affects LAS and master schedule.

Figure 3.9 shows the site progress information workflow. Using ***Task-Component*** database, tasks series' codes are automatically added in proper sequence for each individual BIM entity. This is added as an attribute on the BIM model with ***SiteProgress*** tag. For example, a BIM entity with ***SiteProgress*** tag <STR-101_09(100%)/STR-100_07(100%)/STR-102_07> means STR-101_09 and STR-100_07 tasks for the BIM entity has been completed and task STR-102_07 is ready to proceed if there are no other constraints. The sequence of tasks should be respected, for example, the second task for a BIM entity can only start after the first task is 100% complete. This ***SiteProgress*** tag for BIM entities can be attached design BIM automatically through developed macros and using existing detailed schedules, reports from site team or automatically collected using sensors. GSimX parses this updated progress data to update current status for locations and perform simulation with current progress as the start point.

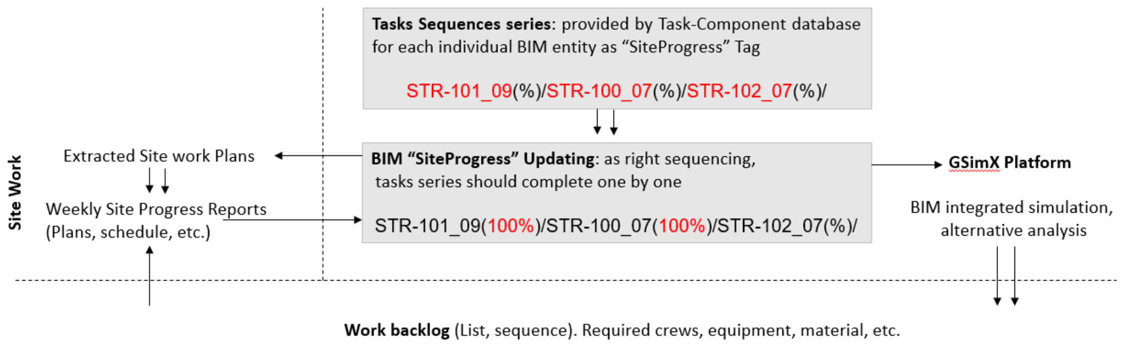

Figure 3.9 Design BIM ***SiteProgress*** Information Integration Workflow

3.1.5 Constraints-Model Database

A basic function of LAS is to establish when and how each task should proceed without violating any constraints (Dong, Fischer et al. 2013). All critical construction constraints have to be integrated into look-ahead planning process. Planners should be able to analyse and remove constraints in order to make sure that all prerequisites and activity resources (crews, equipment and materials) would be available on-site-on-time, thus, planners can be able to assign these tasks into look-ahead schedules.

There are many types and sources of construction constraints that are integrated in this presented approach. Some of these constraints are by default part of GSimX process model: preceding work, crews and equipment capacity. For example, GSimX simulation checks whether all preceding work is complete before an activity can proceed at a particular work location.

In order to achieve better and realistic look-ahead scheduling process, other types of constraints are linked to LAS simulation process using a ***Constraints-Model*** database. ***Constraints-Model*** database includes identified construction constraints by design team, cost engineers, procurement, planners, on-site engineers, safety and risk control team and other project design and construction participants. These types of constraints could be design changes, any expected changes of on-site resources (crews, construction components and materials, equipment and machinery), space availability. In addition, safety requirements, risk, and financing can be supported as well. These constraints have been integrated throughout ***Constraints-Model*** database.

Within ***Constraints-Model*** database, the identified constraints are linked with ***Task-Component*** database activities and classified into three main types, which are:

(1) Constraints per activity; such as missing safety approval for façades cladding activity, therefore, all façades cladding activities in the project will be blocked,

(2) Constraints per activity per zone; such as specific room has space constraints, therefore, ceiling activity will be blocked for this room, and

(3) Constraints per BIM entity (construction component; wall or column); such as pending RFI for specific column in the project, therefore, all related activities for this item will be blocked.

For each tagged constraint, there is 'Constraint Time-Period', which reflects the dates of active time-period for the assigned constraint. Some constraints can be active until one week after current date in ***Constraints-Model*** database; such as pending RFI; other constraints can be active for as long as six months, such as required material type will not arrive on site before six months of tagging date; while some others can be active for one specific day during LAS period, such as urgent safety checking for all work site.

Not all identified and tagged (assigned) constraints within ***Constraints-Model*** database are critical for upcoming selected LAS period, some constraints become critical after that period. Therefore, ***Constraints-Model*** database can work as an archiving system for construction constraints over time for a project. Thus, it helps to ensure that all identified constraints will be not missed and they will be integrated into upcoming LAS simulation process.

3.2 Look-ahead Scheduling Simulation Process

In this thesis, the required information for GSimX simulation comes from various sources. Design BIM tool provides the tagged and updated BIM model. In addition, ***BIM-BOQ*** and ***Task-Component*** database is transferred to GSimX. Master schedule and ***Constraints-Model*** database are other inputs to GSimX. As look-ahead tasks in GSimX are in sync with the master schedule activities, they can be used to update the master schedule.

Once all required inputs are received, detailed location flows are automatically generated in GSimX. Through BIM integrated simulation and alternative analysis, GSimX determines detailed tasks as workable backlog and matches them with appropriate resources. GSimX generates output for possible alternatives for LAS, and required resources for look-ahead activities. Based on BIM model breakdown structure, and after the simulation and analysis is complete in GSimX, look-ahead scheduling tasks, their relationships, and required resources are generated. These can be exported for planning and construction improvements, and various project control tasks such as cost controls, schedule updates and value engineering. Figure 3.10 summarizes the proposed look-ahead scheduling simulation steps:

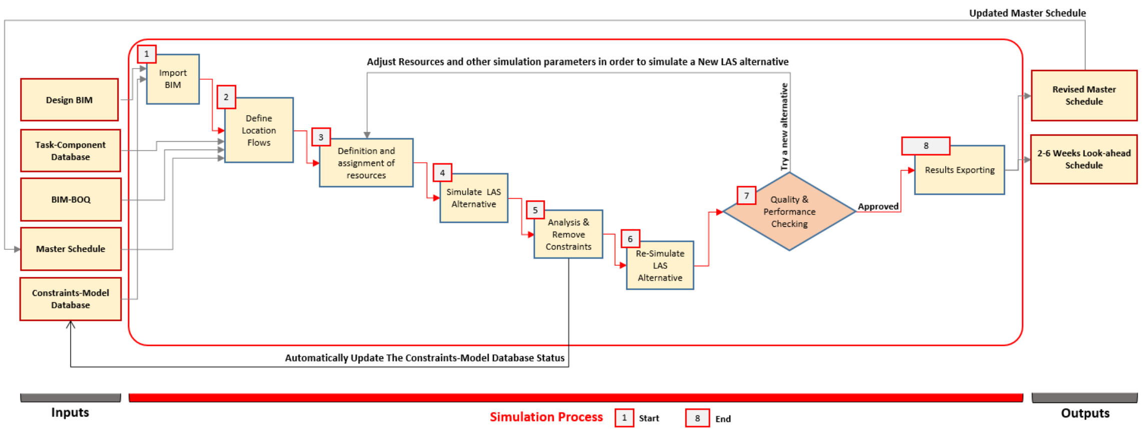

Figure 3.10 Look-ahead Scheduling Simulation Process

(1) Import BIM model; this includes importing design BIM model and ***Constraints-Model*** database, in addition to all other LAS simulation process inputs such as ***Task-Component*** database, ***BIM-BOQ*** and master schedule to GSimX platform. At this point, GSimX prepares linking of ***Design-BIM*** model and ***Constraints-Model*** database, the result of linking process is identification of BIM entities with their related predefined constraints.

(2) Define location flows in GSimX; GSimX generates simulation structures from related work on BIM called 'location flows' using BIM entities, defined activities and their sequences from ***Task-Component*** database. ***BIM-BOQ*** defines the correct quantities for each BIM entity for a particular task.

(3) Definition and assignment of resources; In this presented approach, master schedule provides GSimX with available crews, equipment, and materials for the project and resource needs for each activity. These resources can also be defined within GSimX, but here they are imported from Microsoft Project schedule. All primary resources; crews, equipment and materials, are individually tagged and become part of the simulation process.

(4) Performing simulation in GSimX to generate look-ahead schedule alternative; Based on (a) defined location flows, (b) assigned resources parameters by planning participants according to current project requirements, such as crew and equipment capacity and production rate, number of crews per activity, (c) defined target LAS period, and (d) BIM information such as ***SiteProgress*** information and ***ObjectCode*** information, and (e) identified constraints, GSimX generates a look-ahead schedule alternative.

(5) Analysis, evaluation and removing of constraints for simulated alternative of look-ahead schedule; Planning participants work on analyzing and removing selected

constraints during ***Constraints-Model*** database mapping in step (1). Planning participants can check and decide that some constraints can currently be removed, others can be removed earlier than assigned 'Constraint Time Period' in the ***Constraints-Model*** database, and others cannot be removed. Analysis process allows the planners to check and ensure that assigned activities can be ready when assigning them into look-ahead schedules. Later on, planners work to make sure that there are no remaining on-site constraints to assign activities into weekly planning process. As a result of this step, ***Constraints-Model*** database becomes automatically updated after constraints analysing process by planners.

(6) Updated simulation for the look-ahead schedule alternative; using the updated ***Constraints-Model*** status after planners' actions in step (5), GSimX generates the updated LAS alternative based on analysed and removed constraints status.

(7) Evaluate quality and performance of look-ahead schedule alternatives; based on previous LAS simulation process, planners can obtain many look-ahead schedules alternatives, some of them feasible within project cost and time requirements, and others are not feasible. For those feasible LAS alternatives, planners need to evaluate and choose one as the look-ahead schedule. During this evaluation, all scheduled activities have to be allowed to keep in the look-ahead schedule only if planning participants are sure that assigned activities can be ready when scheduled. Once the planners have feasible look-ahead schedule, the process moves to step (8). But, if planners decide that they need to generate a new LAS alternative by adjusting simulation parameters such as defining a new resources capacity, assigning new resources to activities, or update work sequence for target look-ahead schedule, then move to step (2).

(8) Look-ahead schedule exporting; this includes:

a. 2-6 weeks (or more) look-ahead schedule and work backlog; which will be used to prepare weekly planning later on, and
b. revised master schedule if necessary.

3.3 Chapter Summary

This chapter defines the required information of LAS simulation process such as design BIM model with all required tagged information (***SiteProgress*** and ***ObjectCode***), ***Task-Component*** database, ***BIM-BOQ***, master schedule, ***Constraints-Model*** database and existing simulation tool called GSimX. The presented methodology describes the relations between this information in order to generate alternatives of look-ahead schedules. This Chapter also describe the enabling of GSimX into presented LAS simulation approach.

Next chapter includes an experimental test case; technical description for design BIM information management and GSimX implementation for LAS simulation procedure.

CHAPTER IV

TEST CASE

In order to validate the presented approach in the previous chapter, a test case has been implemented on a hypothetical 10 floor building, which consists of structural (STR) and architectural (ARC) components. A CPM master schedule is created for the construction activities. Afterwards, design BIM and other LAS simulation process requirements such as master schedule, construction constraints, and other generated databases have been imported into the simulation platform for LAS simulation process. The implementation has been evaluated to improve the presented approach.

This chapter discusses the technical process of the implementation using the test case. This includes the design BIM modeling process, ***Task-Component*** database development, tagging process, extracting ***BIM-BOQ***, converting BIM files, CPM master scheduling, LAS simulation via GSimX and results discussion.

4.1 Design BIM Development

In this test case, BIM model for 10 floor building has been created. The created building is a sample residential reinforced concrete building of medium project scale. Scope of work has been identified as main structural components and various architectural finishing works. The structural discipline includes super-structure: column, foot, wall, landing, slabs and others; and sub-structural elements, which includes foot bed, raft slab and others. The architecture discipline includes partitions: block work and gypsum, false ceiling, floor finish, wall finish, doors, façade cladding, accessories and others. Each item category may have different types. For example, column structural category may have column type 1, column type 2, etc. for each individual category type there is a unique part name into BIM library.

The design BIM model for the test case building; concrete structural and architectural components, has been built using AECOsim Building Designer V8i (series 6) BIM application. In this test case, the scope of BIM model Level of Detail (LOD) has been defined as LOD 350; where the BIM entities are graphically represented within the model as a design-specified system, object, or assembly having accurate quantity, size, shape, location and orientation (Couto Cerqueiro 2014).

Classification standards such as Uni-Format (1999) and materials design specifications have been integrated into ***Task-Components*** database development and design BIM phase to extract the ***BIM-BOQ*** of each single task at ***Task-Components*** database. Some existing macros have been used to integrate and tag all required data to design BIM such as ***SiteProgress*** and ***ObjectCode***. Other macros have been used to generate required database from design BIM such as ***BIM-BOQ*** and all tagged information.

4.1.1 Task-Component Database Development

Based on defined work scope, the ***Task-Component*** database have been created. ***Task-Component*** database includes main construction activities and their tasks sequence for construction process for each entity category. It also contains the production rate of a standard crew performing the particular task. In addition, it includes the formulas and equations for material take-off process from design BIM. Figure 3.7 shows a sample set of items from ***Task-Component*** database for the test case. Also, Figure 4.1 shows the required information to create ***Task-Component*** database.

4.1.2 Design BIM Library Development

Task-Component database has been used to automatically create design BIM library (xml file format), which has been used within AECOsim to automatically generate ***BIM-BOQ***. Figure 4.1 shows the relations between ***Task-Component*** database, BIM xml library, BIM modeling process, materials take-off process and ***BIM-BOQ*** customization process.

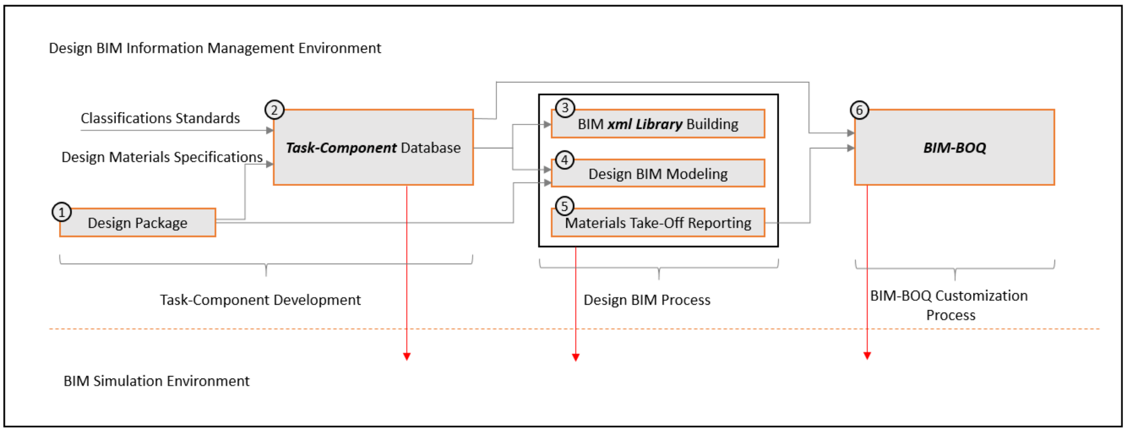

Figure 4.1 Information Flow throughout BIM to Create ***BIM-BOQ***

BIM xml Library is the link between ***Task-Component*** database, design package and ***BIM-BOQ***. Design BIM library includes the formulas and equations required for ***BIM-BOQ*** extraction. As Figure 4.2 shows, each part (BIM entity) in design BIM library has one or more formulas to calculate materials and LAS tasks quantities according to ***Task-Component*** database. For example, these formulas may include area, volume, length, thickness, arithmetic operations, and other types of equations in order to calculate the required material quantities that are mentioned into ***Task-Component*** database.

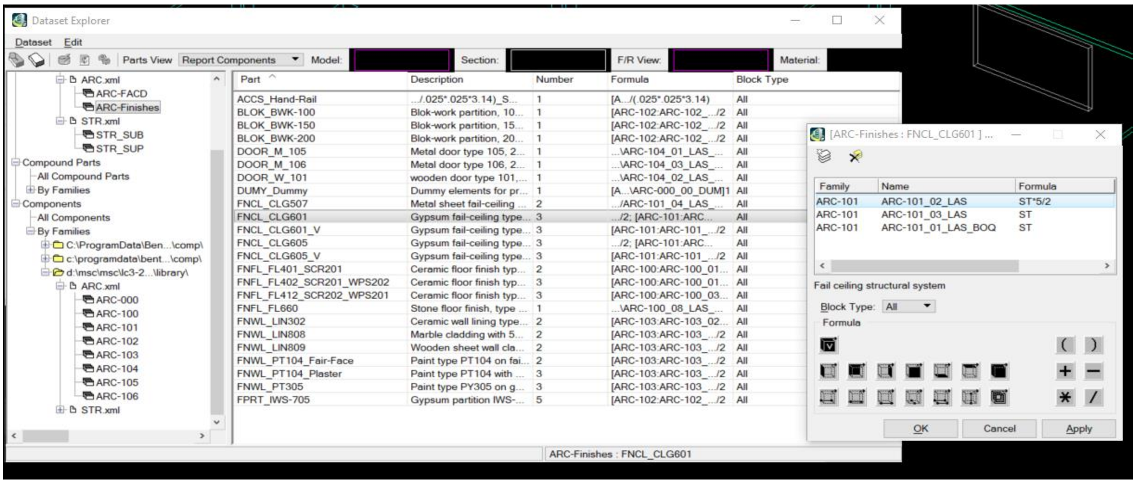

Figure 4.2 Sample of Library Formulas and Equation for BOQ Extraction

4.1.3 Tag Sets (Tagging Process)

Tag sets are a set of additional user defined attributes assigned to BIM entities. Each BIM entity can be assigned as many tags as needed. Throughout design BIM process, a set of macros have been used in order to automate attributes tagging process. In this presented test case, the following tags (Figure 4.3) are attached into 'Object LAS Code' tag set to add information to the BIM entities:

- ***ObjectCode***; WBS information for each BIM entity in the project. Figure 3.4 describes the coding WBS of ***ObjectCode,*** and Figure 3.5 shows a sample ***ObjectCode***.
- ***SiteProgress***; site progress information based on ***Task-Component*** database activity sequencing. Figure 3.9 shows the design BIM ***SiteProgress*** information flow, and
- ***Zone:*** location data for each BIM entity according to construction zones, which is used link BIM entities and ***Constraints-Model*** database.

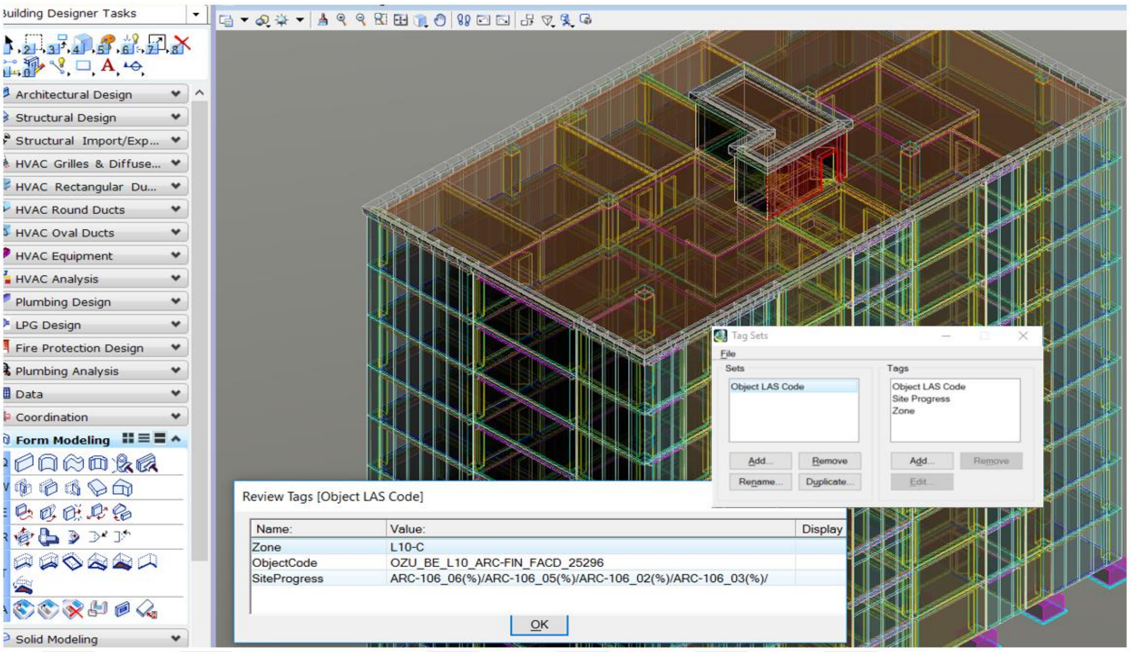

Figure 4.3 Defined Tag Set for Test Case

4.1.4 Extracting BIM-BOQ

Once the design BIM was completed and all required information and attributes were tagged within BIM model, BIM materials take-off report has been extracted in MS Excel format. BIM materials take-off report includes thousands of raw items of quantities according to design BIM library WBS. Then, ***Task-Component*** database (activities, tasks and their sequence) and generated BIM materials take-off report data have been automatically linked in order to get the customized ***BIM-BOQ***. Figure 3.8 shows an extract of BIM-BOQ for this test case.

4.1.5 Converting BIM Files

A universal BIM data exchange is needed to facilitate the flow of information between different BIM platforms. AECOsim has native dgn format for its BIM files. Since GSimX currently supports Revit format and does not support AECOsim models, it requires file conversion.

AECOsim entities information do not transfer well between AECOsim and Revit. To achieve an open BIM project environment, original BIM model needs to be exported into a non-proprietary format such as IFC. Industry Foundation Classes (IFC) was developed by 'BuildingSMART' an international organization which aims to improve the exchange of information between software applications used in the construction industry. IFC is supported by about 150 software applications worldwide to enable better work flows for the AEC industry (Ruiz 2009). IFC is a neutral and open specification format, it is an object-based file format directed to address all building information over the whole project lifecycle. A macro has been used to exchange information across IFC BIM model from AECOsim BIM model and ensure Revit receives all tag data that all get into GSimX.

4.2 CPM Master Scheduling

In this test case, the master schedule represents an overall planning view that identifies major test case phases; structural and architectural, and milestones for these phases. As Figure 4.4 shows, the Microsoft Project scheduling tool has been used with the following steps to generate required master schedule:

(1) The test case building is subdivided into major work activities,

(2) The duration and work force requirements are determined for each major activity,

(3) The major activities are placed in a logical sequence to form the master schedule. For example, slab's formwork and rebar activates placed before a concrete activity,

(4) Typically, overall duration is reconciled with the contractual requirements of each project. In this test case, major activities' durations are adjusted in order

to match real conditions. For example, the time required for placing reinforcement can be estimated by normal crew production rate, and

(5) To achieve target LAS simulation approach, three attribute fields are added into prepared master schedule, these include required information for GSimX simulation process. These three attribute fields are used throughout LAS simulation process to link between ***ObjectCode*** into ***BIM-BOQ*** and Design BIM entities tags, tasks activities and their sequencing into ***Task-Component*** database and master activities. These additional columns are:

   a. Building Level; which includes activity location into design BIM model (foundation level, L01, L02, L03, etc.),

   b. Element Category; which includes element category code of assigned activity (wall, foundation, column, slab, floor finish, wall finish, etc.), and

   c. Discipline; which include activity discipline type (excavation, filling, formwork, concrete, rebar, partition, wall tiling, painting, etc.).

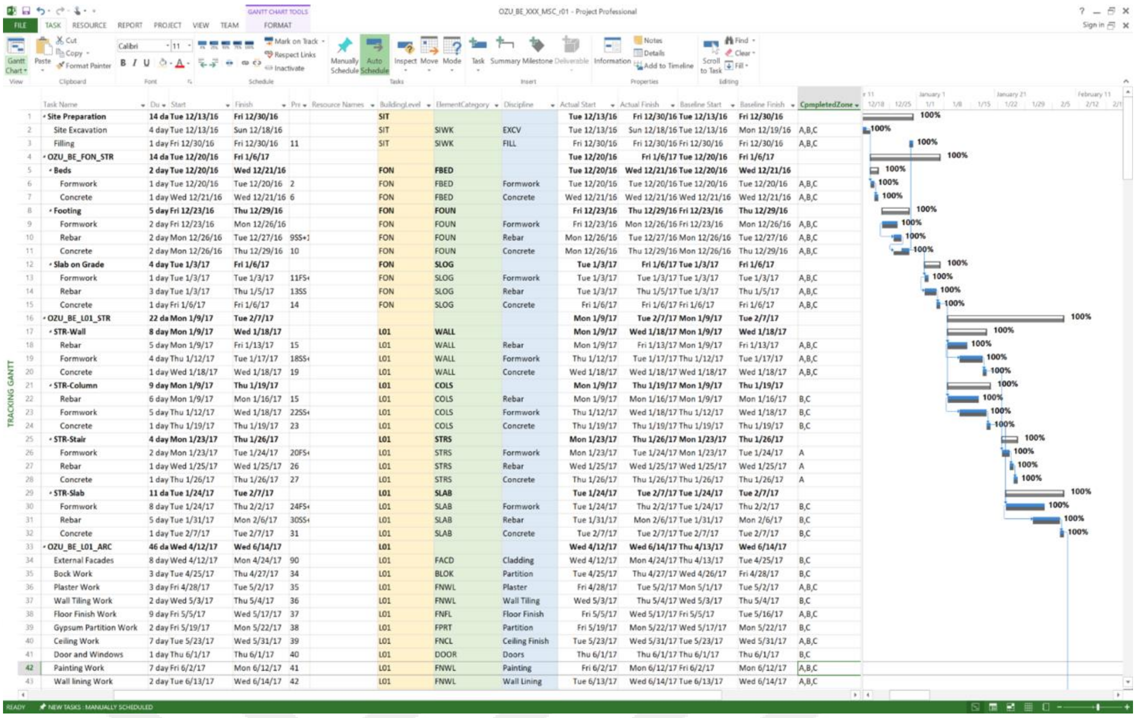

Figure 4.4 CPM Master Schedule for The Test Case

4.3 GSimX Simulation

Once all LAS inputs requirements are ready to proceed with LAS simulation process, all inputs are imported into GSimX platform (Figure 4.5). In GSimX, design BIM and constraints linking process defined constraints with relative BIM entities into BIM model. The design BIM, ***Task-Component*** database, and ***BIM-BOQ*** are used into GSimX and automatically build location flows. Master schedule activities are automatically matched with detailed tasks within location flows. ***Task-Component*** database helps define the sequence of tasks for each location. This task sequence is respected in GSimX simulation and the production rate is assigned to generated activities in GSimX. GSimX generates location flows with assigned activities, matches site resources with tasks, and identifies resource assignments to achieve the requirements of the master schedule.

Next, available crews and equipment were defined for the project and requirements for each activity were updated in GSimX. Although, these resources can be defined within GSimX, in this case they were imported from MS Project.

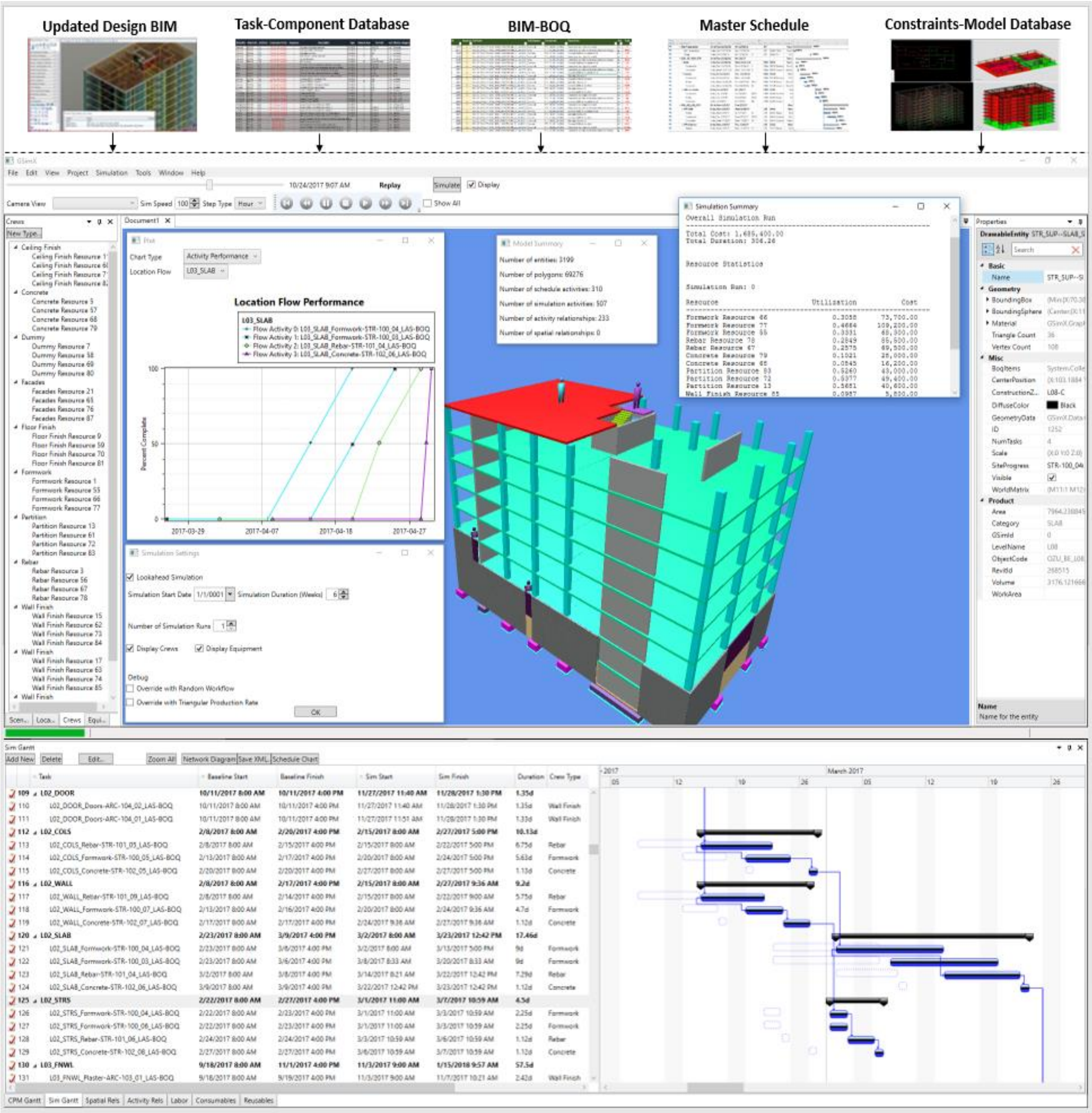

Figure 4.5 LAS simulation Process via GSimX Platform

Site progress information has been added to some BIM entities in design BIM using the ***SiteProgress*** tag to emulate construction progress at a certain point in the project. This information and updated schedule has been transferred to GSimX.

Next, simulation for a look-ahead period during the project has been tested. Simulation has been performed starting from the current date with the actual status for the duration of the look-ahead period. GSimX generated outputs for possible alternative for look-ahead schedule taking in consideration the defined constraints status. Then, the generated results and identified constraints are analyzed and evaluated by planning participants.

The simulation process has been repeated after changing some of simulation parameters such as resources capacity and LAS period time. Then, GSimX generated more look-ahead schedules alternatives that matched with target conditions such as target time and cost.

As results of the simulation (Figure 4.5), associated resources and costs are obtained. This helps revise the master schedule; if necessary, and compare actual vs baseline activities as Gantt charts. Results also show capability to extract work backlog (task list and sequence). Figure 4.6 shows a proposed LAS simulation output report, which can be exported for planning and construction control improvement purposes, in addition to various project control tasks such as; cost controls, schedule updates and planning drawings.

Project Number	104A/2017
Project Name	Ozyegin University
Main Contractor	TAV Construction
Drawing Name	6 Weeks LAS
Drawing Number	LAS-6W-0001
Period From	1/1/2017
Period To	11/2/2017
Prepared By	GSimX Team
Checked By	GSimX Team

Working Area	Zone	Object Category	Category	Component Code	Description	Unit	Total QTY	Referance Drawings [these drawings are automaticly extracted by GSimX <PDF plans includes target objects and excuted objects>]
OZU_BE_FON_STR-CON	FON-A	FOUN	Concrete	STR-102_01_LAS-BOQ	Concrete B300 for foundation foot	m3	47.218	OZU_BE_FON-A_FOUN_LAS-001_r00.pdf
OZU_BE_FON_STR-CON	FON-A	FOUN	Formwork	STR-100_01_LAS-BOQ	Foundation foot edges formwork	m2	29.052	OZU_BE_FON-A_FOUN_LAS-002_r00.pdf
OZU_BE_FON_STR-CON	FON-A	FOUN	Rebar	STR-101_01_LAS-BOQ	Foundation foot steel (estimated, depends on design)	kg	11804.5	OZU_BE_FON-A_FOUN_LAS-003_r00.pdf
OZU_BE_FON_STR-CON	FON-A	SLOG	Concrete	STR-102_04_LAS-BOQ	Concrete B250 for slab on grade	m3	5.337	OZU_BE_FON-A_SLOG_LAS-001_r00.pdf
OZU_BE_FON_STR-CON	FON-A	SLOG	Formwork	STR-100_03_LAS-BOQ	Slab edges formwork	m2	20.44	OZU_BE_FON-A_SLOG_LAS-002_r00.pdf
OZU_BE_FON_STR-CON	FON-A	SLOG	Rebar	STR-101_03_LAS-BOQ	Slab on grad steel (estimated, depends on design)	kg	426.95	OZU_BE_FON-A_SLOG_LAS-003_r00.pdf
OZU_BE_FON_STR-CON	FON-A	SUBC	Concrete	STR-102_02_LAS-BOQ	Concrete B200 for foot bed	m3	6.69	OZU_BE_FON-A_SUBC_LAS-001_r00.pdf
OZU_BE_FON_STR-CON	FON-A	SUBC	Formwork	STR-100_03_LAS-BOQ	Slab edges formwork	m2	35.64	OZU_BE_FON-A_SUBC_LAS-002_r00.pdf
OZU_BE_FON_STR-CON	FON-B	FOUN	Concrete	STR-102_01_LAS-BOQ	Concrete B300 for foundation foot	m3	44.234	OZU_BE_FON-B_FOUN_LAS-001_r00.pdf
OZU_BE_FON_STR-CON	FON-B	FOUN	Formwork	STR-100_01_LAS-BOQ	Foundation foot edges formwork	m2	96.752	OZU_BE_FON-B_FOUN_LAS-002_r00.pdf
OZU_BE_FON_STR-CON	FON-B	FOUN	Rebar	STR-101_01_LAS-BOQ	Foundation foot steel (estimated, depends on design)	kg	11058.5	OZU_BE_FON-B_FOUN_LAS-003_r00.pdf
OZU_BE_FON_STR-CON	FON-B	SLOG	Concrete	STR-102_04_LAS-BOQ	Concrete B250 for slab on grade	m3	52.314	OZU_BE_FON-B_SLOG_LAS-001_r00.pdf
OZU_BE_FON_STR-CON	FON-B	SLOG	Formwork	STR-100_03_LAS-BOQ	Slab edges formwork	m2	82.5	OZU_BE_FON-B_SLOG_LAS-002_r00.pdf
OZU_BE_FON_STR-CON	FON-B	SLOG	Rebar	STR-101_03_LAS-BOQ	Slab on grad steel (estimated, depends on design)	kg	6975.23	OZU_BE_FON-B_SLOG_LAS-003_r00.pdf
OZU_BE_FON_STR-CON	FON-B	SUBC	Concrete	STR-102_02_LAS-BOQ	Concrete B200 for foot bed	m3	6.576	OZU_BE_FON-B_SUBC_LAS-001_r00.pdf
OZU_BE_FON_STR-CON	FON-B	SUBC	Formwork	STR-100_03_LAS-BOQ	Slab edges formwork	m2	119.84	OZU_BE_FON-B_SUBC_LAS-002_r00.pdf
OZU_BE_FON_STR-CON	FON-C	FOUN	Concrete	STR-102_01_LAS-BOQ	Concrete B300 for foundation foot	m3	33.656	OZU_BE_FON-C_FOUN_LAS-001_r00.pdf
OZU_BE_FON_STR-CON	FON-C	FOUN	Formwork	STR-100_01_LAS-BOQ	Foundation foot edges formwork	m2	77.248	OZU_BE_FON-C_FOUN_LAS-002_r00.pdf
OZU_BE_FON_STR-CON	FON-C	FOUN	Rebar	STR-101_01_LAS-BOQ	Foundation foot steel (estimated, depends on design)	kg	8414	OZU_BE_FON-C_FOUN_LAS-003_r00.pdf
OZU_BE_FON_STR-CON	FON-C	SLOG	Concrete	STR-102_04_LAS-BOQ	Concrete B250 for slab on grade	m3	53.963	OZU_BE_FON-C_SLOG_LAS-001_r00.pdf
OZU_BE_FON_STR-CON	FON-C	SLOG	Formwork	STR-100_03_LAS-BOQ	Slab edges formwork	m2	81.6	OZU_BE_FON-C_SLOG_LAS-002_r00.pdf
OZU_BE_FON_STR-CON	FON-C	SLOG	Rebar	STR-101_03_LAS-BOQ	Slab on grad steel (estimated, depends on design)	kg	7195.02	OZU_BE_FON-C_SLOG_LAS-003_r00.pdf
OZU_BE_FON_STR-CON	FON-C	SUBC	Concrete	STR-102_02_LAS-BOQ	Concrete B200 for foot bed	m3	4.948	OZU_BE_FON-C_SUBC_LAS-001_r00.pdf
OZU_BE_FON_STR-CON	FON-C	SUBC	Formwork	STR-100_03_LAS-BOQ	Slab edges formwork	m2	94.56	OZU_BE_FON-C_SUBC_LAS-002_r00.pdf
OZU_BE_L01_STR-CON	L01-A	SLAB	Concrete	STR-102_06_LAS-BOQ	Concrete B300 for structural slab	m3	2.239	OZU_BE_L01-A_SLAB_LAS-001_r00.pdf
OZU_BE_L01_STR-CON	L01-A	SLAB	Formwork	STR-100_04_LAS-BOQ	Slab 250mm / Landing formwork	m2	11.942	OZU_BE_L01-A_SLAB_LAS-002_r00.pdf
OZU_BE_L01_STR-CON	L01-A	SLAB	Rebar	STR-101_04_LAS-BOQ	Structural slab steel (estimated, depends on design)	kg	89.568	OZU_BE_L01-A_SLAB_LAS-003_r00.pdf
OZU_BE_L01_STR-CON	L01-A	STRS	Concrete	STR-102_08_LAS-BOQ	Concrete B300 for stair	m3	1.773	OZU_BE_L01-A_STRS_LAS-001_r00.pdf
OZU_BE_L01_STR-CON	L01-A	STRS	Formwork	STR-100_06_LAS-BOQ	Stair formwork	m2	11.309	OZU_BE_L01-A_STRS_LAS-002_r00.pdf
OZU_BE_L01_STR-CON	L01-A	STRS	Rebar	STR-101_06_LAS-BOQ	Stair steel (estimated, depends on design)	kg	106.384	OZU_BE_L01-A_STRS_LAS-003_r00.pdf
OZU_BE_L01_STR-CON	L01-A	WALL	Concrete	STR-102_07_LAS-BOQ	Concrete B300 for shear wall	m3	19.9	OZU_BE_L01-A_WALL_LAS-001_r00.pdf
OZU_BE_L01_STR-CON	L01-A	WALL	Formwork	STR-100_07_LAS-BOQ	Shear wall formwork	m2	172.717	OZU_BE_L01-A_WALL_LAS-002_r00.pdf
OZU_BE_L01_STR-CON	L01-A	WALL	Rebar	STR-101_09_LAS-BOQ	Shear wall steel (estimated, depends on design)	kg	1392.945	OZU_BE_L01-A_WALL_LAS-003_r00.pdf
OZU_BE_L01_STR-CON	L01-B	COLS	Concrete	STR-102_05_LAS-BOQ	Concrete B300 for column	m3	13.714	OZU_BE_L01-B_COLS_LAS-001_r00.pdf
OZU_BE_L01_STR-CON	L01-B	COLS	Formwork	STR-100_05_LAS-BOQ	Column formwork	m2	88.4	OZU_BE_L01-B_COLS_LAS-002_r00.pdf
OZU_BE_L01_STR-CON	L01-B	COLS	Rebar	STR-101_05_LAS-BOQ	Structural column steel (estimated, depends on design)	kg	1371.5	OZU_BE_L01-B_COLS_LAS-003_r00.pdf
OZU_BE_L01_STR-CON	L01-B	SLAB	Concrete	STR-102_06_LAS-BOQ	Concrete B300 for structural slab	m3	87.19	OZU_BE_L01-B_SLAB_LAS-001_r00.pdf
OZU_BE_L01_STR-CON	L01-B	SLAB	Formwork	STR-100_03_LAS-BOQ	Slab edges formwork	m2	82.5	OZU_BE_L01-B_SLAB_LAS-002_r00.pdf
OZU_BE_L01_STR-CON	L01-B	SLAB	Formwork	STR-100_04_LAS-BOQ	Slab 250mm / Landing formwork	m2	348.761	OZU_BE_L01-B_SLAB_LAS-003_r00.pdf
OZU_BE_L01_STR-CON	L01-B	SLAB	Rebar	STR-101_04_LAS-BOQ	Structural slab steel (estimated, depends on design)	kg	3487.615	OZU_BE_L01-B_SLAB_LAS-004_r00.pdf
OZU_BE_L01_STR-CON	L01-B	WALL	Concrete	STR-102_07_LAS-BOQ	Concrete B300 for shear wall	m3	10.619	OZU_BE_L01-B_WALL_LAS-001_r00.pdf
OZU_BE_L01_STR-CON	L01-B	WALL	Formwork	STR-100_07_LAS-BOQ	Shear wall formwork	m2	88.205	OZU_BE_L01-B_WALL_LAS-002_r00.pdf
OZU_BE_L01_STR-CON	L01-B	WALL	Rebar	STR-101_09_LAS-BOQ	Shear wall steel (estimated, depends on design)	kg	743.356	OZU_BE_L01-B_WALL_LAS-003_r00.pdf
OZU_BE_L02_STR-CON	L02-A	SLAB	Concrete	STR-102_06_LAS-BOQ	Concrete B300 for structural slab	m3	2.239	OZU_BE_L02-A_SLAB_LAS-001_r00.pdf
OZU_BE_L02_STR-CON	L02-A	SLAB	Formwork	STR-100_04_LAS-BOQ	Slab 250mm / Landing formwork	m2	11.942	OZU_BE_L02-A_SLAB_LAS-002_r00.pdf
OZU_BE_L02_STR-CON	L02-A	SLAB	Rebar	STR-101_04_LAS-BOQ	Structural slab steel (estimated, depends on design)	kg	89.568	OZU_BE_L02-A_SLAB_LAS-003_r00.pdf
OZU_BE_L02_STR-CON	L02-A	STRS	Concrete	STR-102_08_LAS-BOQ	Concrete B300 for stair	m3	1.787	OZU_BE_L02-A_STRS_LAS-001_r00.pdf
OZU_BE_L02_STR-CON	L02-A	STRS	Formwork	STR-100_06_LAS-BOQ	Stair formwork	m2	11.39	OZU_BE_L02-A_STRS_LAS-002_r00.pdf
OZU_BE_L02_STR-CON	L02-A	STRS	Rebar	STR-101_06_LAS-BOQ	Stair steel (estimated, depends on design)	kg	107.239	OZU_BE_L02-A_STRS_LAS-003_r00.pdf
OZU_BE_L02_STR-CON	L02-A	WALL	Concrete	STR-102_07_LAS-BOQ	Concrete B300 for shear wall	m3	19.9	OZU_BE_L02-A_WALL_LAS-001_r00.pdf
OZU_BE_L02_STR-CON	L02-A	WALL	Formwork	STR-100_07_LAS-BOQ	Shear wall formwork	m2	172.717	OZU_BE_L02-A_WALL_LAS-002_r00.pdf
OZU_BE_L02_STR-CON	L02-A	WALL	Rebar	STR-101_09_LAS-BOQ	Shear wall steel (estimated, depends on design)	kg	1392.945	OZU_BE_L02-A_WALL_LAS-003_r00.pdf

Figure 4.6 Proposed LAS Simulation Output Report

4.4 Discussion

The presented approach has been evaluated through this test case. In this test case, evaluation and feedback from different perspectives (planning and control engineers, BIM experts, construction engineers and project management team) are discussed as follows:

(1) The presented approach is integrated with design BIM. It ensures that all project information, updates, design changes, site progress and others are involved into LAS simulation process. Therefore, the results should be more reliable compared to traditional planning approaches,

(2) The presented approach is integrated with construction constraints during simulation process. In case constraints cannot be removed for any reason, planners

update the simulation parameters and run the GSimX simulation process in order to get different LAS alternatives to keep workflow improvement, and

(3) The developed and integrated databases are applicable to other similar type projects. The developed databases can help achieve better design information management and improve design changes tracking process. Therefore, planning duration can be reduced and results can be trusted more.

CHAPTER V

CONCLUSION

Current look-ahead scheduling approaches have many practical problems and challenges. There is a gap in the link between master planning and detailed planning. Also, there is a gap between LAS process and on-going on-site works in terms of information; such as design changes, site progress, and resources availability. Poor information flow between weekly and master levels usually leads to poor resource distribution, poor planning, on-site work conflicts, missing site works and others. As a result, site management may face construction delivery delays and significant waste of project resources and cost.

In this thesis work, BIM is integrated into construction planning and control system for better and more effective look-ahead scheduling process. Also, it affords better design and construction information management system for look-ahead scheduling process.

Throughout effective BIM implementation, the presented approach ensures better participation and communication from different project participants and departments throughout design and construction processes for look-ahead scheduling. In this thesis work, BIM used to manage project data such as design details, specifications, materials procurement, site progress.

Although there are many research and studies discussing construction production planning, the practical use of simulation for look-ahead planning and scheduling are not very common. In this thesis, existing simulation approach of GSimX has been integrated into the presented LAS approach; it is a multi-modal simulation platform that implements discrete-event and agent-based at the same time, in order to afford an ability to test alternatives to get full value out of look-ahead scheduling process.

5.1 Contributions

In this thesis, through simulation scenarios, planning participants are able to effectively generate workable backlog as look-ahead tasks and match them with resources with accurate and up-to-date information all within a BIM environment. This provides an ability to test look-ahead schedules alternatives in order to get full value out of look-ahead scheduling process.

In this thesis, the suggested improvements on the BIM-resources integrated simulation approach will support planners to generate effective construction workflow plans and reliable LAS; given site progress, plans for crew, equipment, construction constraints, and material availability to satisfy master schedule requirements; all within a BIM and simulation environment, taking into consideration lean construction principles.

The presented approach supports lean construction principles by simulating tasks within the target look-ahead window; this could be 2-6 weeks or more, in relation to the master schedule in order to achieve workable weekly planning afterwards. In other words, the presented approach can help to finish project on-time by effective simulating of required resources and improving their workflow.

Using BIM and simulation, the presented look-ahead scheduling approach can ensure the availability of resources before start of activity, emphasize productivity through the full work chain vs. individual activities and improves constraints satisfying, analyzing and removing within BIM environment. Therefore, the presented approach improves the planning process and look-ahead schedules performance.

In this thesis, the gap between LAS process and required information sources and the gap in the link between master planning and detailed planning can be filled throughout structured BIM resources-integrated simulation approach. This includes an implementation of LC principles, LPS techniques, BIM and simulation advantages.

This thesis work describes a BIM and resources integrated LAS approach. The presented LAS approach adopts on developing a methodology for building look-ahead schedules using BIM-based simulation that satisfies project goals. The developed methodology:

(1) Identifies the information requirements for BIM and resource-based simulation to support look-ahead construction schedules. This includes design BIM model with required tags; ***ObjectCode*** which represent a deliverable oriented hierarchy that organize the project's team work into manageable sections, ***SiteProgress*** which represent the on-site progress status for each entity, and ***Zone*** which represent the construction zone for each BIM entity. The requirement list also includes ***Task-Component*** database which includes data from various sources including (i) design specifications, (ii) information from site personnel, (iii) material installation data, and (iv) planning schedule, ***BIM-BOQ*** which contains quantities for each required task for each BIM entity; it is automatically generated from design BIM using formulas and entity geometry, and ***Constraints-Model*** database which includes the identified construction constraints by design and construction participants,

(2) Describes the project information management process at design BIM and construction phases in order to support look-ahead scheduling process. The BIM information management process includes tagging process, ***BIM-BOQ*** extracting

process, master activities scheduling process, design BIM work breakdown structure (WBS) identification, and

(3) Discusses simulation process within the presented LAS process. Adopting on existing simulation approach and by describing design BIM work breakdown structure, this thesis discusses an integrated, general, and flexible approach to support more than one type of construction activities, and all types of construction physical components; structural, architectural, mechanical and electrical components.

5.2 Assumptions

In this presented approach, the BIM model is assumed to be developed to an adequate level-of-detail (LOD) that enables all required BIM uses and deliverables in the planning phase. The required scope of the BIM model LOD of the presented approach has been defined as:

(1) LOD 300 (Issued for Construction); the model entity is graphically represented within the model as a design specified system, object or assembly and associated components having accurate quantity, size, shape, location and orientation. Interfaces with other building elements and systems have been identified and coordinated; approximate allowances for spacing and clearances required for all specified supports and seismic control. Parameters required for procurement, including specification, materials and performance criteria are attached to the model entity. Model entities are uniquely tagged with defined required information for LAS process.

(2) LOD 350 (Shop Coordinated); in addition to the LOD 300 requirements, an element may not be declared as LOD 350 until the Shop Information associated

with it has been received, reviewed and approved. Non-graphic information compliant with the shop information will remain attached to the model entity as per LOD 300.

(3) LOD 400 (Fabrication and Installation 'Shop Drawings'); in addition to the LOD 300 requirements, the BIM entities should be suitable for fabrication and installation. Required nongraphic detailing, fabrication, assembly, and installation information is attached to the model entity.

In the presented approach, the ***Task-Component*** database is the database source of ***BIM-BOQ*** and tasks sequencing. The LOD of ***Task-Component*** database depends on level-of-detail of design and specifications. In LOD 300 BIM model, some entities might be missing due to incomplete or uncoordinated design, in which case ***Task-Component*** is supposed to cover those components. In LOD 400 BIM model, some detailed BIM entities can cause unnecessary ***BIM-BOQ*** items, therefore, ***Task-Component*** is supposed to include only required ***BIM-BOQ*** items for LAS process.

The presented approach supposed that all required information is available, accurate and coordinated. The missing or wrong information such as inaccurate site progress information, missing BIM-BOQ items, missing BIM entities, wrong tasks sequencing and resources status leads to poor LAS results. Also, the missing construction constraints and poor constraints analysis leads to poor LAS and poor construction workflow.

The presented approach supports construction workflow from contractor perspective. Once planning participants define the target LAS period, they have to take in consideration that master schedule is a contractual document that contains many contractual and commercial milestones, therefore, it must be respected as much as possible, deviation from the master schedule can be accepted within certain tolerances and guidelines.

5.3 Limitations

The presented approach has not yet been evaluated on a real construction project. However, the developed test case is on a realistic building, and it contains common structural and architectural components. The mechanical and electrical components have not been integrated in the test case in order to simplify the LAS simulation process. However, the mechanical and electrical components can be integrated into this approach.

The presented approach has been developed to match with the workflow of reinforced concrete and steel structure buildings (residential and commercial). Heavy and civil construction projects (highways, dams, etc.), and specialized industrial construction projects require modification on ***Task-Component*** databases and BIM support in order to become workable for LAS process for those types of construction projects.

This thesis work did not aim to generate the best look-ahead schedule; the presented approach supports generating alternatives of look-ahead schedules that are feasible within project cost and time requirements. Planning participants and project management need to evaluate these alternatives and choose good feasible look-ahead schedule that best match with current construction process conditions.

5.4 Recommendations

The following are some recommendations during LAS simulation process in order to achieve good LAS alternative:

(1) The planning participants should generate and evaluate multiple alternatives of LAS that match with project cost and time requirements. The project management

and decision makers should work to choose the best look-ahead schedule among alternatives,

(2) Once planning participants simulate the process and calculate resources needed to achieve the target schedule, the project management team need to work to avail these resources on-site in time,

(3) In the event that providing required resources is impossible due to any reason, a new forecast schedule need to be developed based on the capacity of resources that can be achieved; this capacity needs to be entered in the simulation process for defining the new look-ahead target work and revised schedule, and

(4) This planning process should be iterative until planning participants arrive at the most acceptable schedule from the different perspectives and for all the involved stakeholders.

5.5 Future Work

The presented approach can support more required information in order to achieve better LAS process during construction process; such as providing the ***Materials-Delivery*** database and providing the look-ahead drawings extraction. Also, as the presented approach can be developed to proving a detailed weekly planning.

5.5.1 Materials-Delivery Database

GSimX platform supports construction resources; crews and equipment, identification before and throughout simulation process (Akbas 2016). The presented approach supports material availability and their constraints throughout ***Constraints-Model*** database and through GSimX platform. However, the presented approach could be supported by another database for material delivery, which includes the information of required materials during upcoming 3 months (or more). This information can include required and delivered materials quantities, and delivery dates. Project procurement department and decision makers will work to afford required materials on-site in time, thus, constraints of missing materials can be avoided throughout upcoming look-ahead scheduling process.

By effective analysis of whole master schedule one time, the presented approach has a capability to provide 3 months (or more) resources look-ahead. This helps planners and project management to improve construction workflow by working on resources securing on-site-on-time.

During simulation process, and based on design BIM, ***Task-Component*** database and ***BIM-BOQ,*** GSimX identifies the required materials for each individual work item during simulation. Material status; such as delivery date and delivered quantity, can be added into database throughout continuous updating process. Later on, GSimX can use this database to identify any missing material and simulate LAS alternatives based on on-site available resources.

5.5.2 Weekly Planning Approach

Although this research focuses on look-ahead planning, the presented approach and ***Constraint-Model*** database can be effectively developed and integrated to support weekly planning process. Since removing constraints and making sure that all prerequisites and activity resources (crews, equipment and materials) are available makes activities and tasks ready assignment when scheduled into weekly work plan.

In weekly planning, no task can start on site without assurance that all related constraints have been removed. Using ***Constraint-Model*** database, the presented approach can directly start working on weekly planning by breaking down the generated look-ahead schedule.

APPENDIX A

AECOsim Building Designer BIM Tool

AECOsim Building Designer is "a shared, multiple-discipline building information modeling application. AECOsim is specifically developed for architecture, structure and mechanical[1] design and construction works" (Ruiz 2009).

AECOsim affords a unified workspace for all project disciplines, this helps designers, planners, construction, and BIM coordinators to share project data into design BIM entities.

In this test case, AECOsim tool enables researcher to employ a strategy that addresses various essential requirements for presented approach checking, including:

(1) Construction oriented activities throughout modeling process such as creating a floor, wall, column and doors,

(2) Data scheduling and reporting during modeling process,

(3) By unified workspace, AECOsim improves BIM friendly operability, and

(4) Effective clash detection approach throughout design and BIM phases.

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[1] According to UniFormat 1999, mechanical discipline includes mechanical, electrical and plumbing works Charette, R. P. and H. E. Marshall (1999). UNIFORMAT II elemental classification for building specifications, cost estimating, and cost analysis, US Department of Commerce, Technology Administration, National Institute of Standards and Technology.

APPENDIX B

Task-Component Database Sample

The following table shows part of the implemented ***Task-Component*** database in presented test case.

Discipline	Component Code	SQ.	Description	Formula	P.R./ D.	Master category
Formwork	STR-100_01_LAS-BOQ	2	Foundation foot edges formwork	SA-ST-SB	50	Formwork
Formwork	STR-100_02_LAS-BOQ	2	Underground beam formwork	SL+SR	50	Formwork
Formwork	STR-100_03_LAS-BOQ	2	Slab edges formwork	PER	80	Formwork
Formwork	STR-100_04_LAS-BOQ	1	Slab 250mm / Landing formwork	SB	15	Formwork
Formwork	STR-100_05_LAS-BOQ	2	Column formwork	SA-ST-SB	17	Formwork
Formwork	STR-100_06_LAS-BOQ	1	Stair formwork	(SA-SB-ST)*0.43	15	Formwork
Formwork	STR-100_07_LAS-BOQ	2	Shear wall formwork	SL+SR+SS+SE	17	Formwork
Formwork	STR-100_08_LAS-BOQ	1	Drop beam formwork	SL+SR+SB	15	Formwork
Formwork	STR-100_09_LAS-BOQ	2	Upstand beam formwork	SL+SR	30	Formwork
Rebar	STR-101_01_LAS-BOQ	1	Foundation foot steel (estimated, depends on design)	VOL*250	550	Rebar
Rebar	STR-101_02_LAS-BOQ	1	Underground beam steel (estimated, depends on design)	VOL*200	450	Rebar
Rebar	STR-101_03_LAS-BOQ	1	Slab on grad steel (estimated, depends on design)	ST*20	650	Rebar
Rebar	STR-101_04_LAS-BOQ	3	Structural slab steel (estimated, depends on design)	ST*40	450	Rebar
Rebar	STR-101_05_LAS-BOQ	1	Structural column steel (estimated, depends on design)	VOL*100	450	Rebar
Rebar	STR-101_06_LAS-BOQ	2	Stair steel (estimated, depends on design)	VOL*50	450	Rebar
Rebar	STR-101_07_LAS-BOQ	2	Drop beam steel (estimated, depends on design)	VOL*100	450	Rebar
Rebar	STR-101_08_LAS-BOQ	1	Upstand beam steel (estimated, depends on design)	VOL*50	450	Rebar
Rebar	STR-101_09_LAS-BOQ	1	Shear wall steel (estimated, depends on design)	VOL*70	450	Rebar
Concrete	STR-102_01_LAS-BOQ	3	Concrete B300 for foundation foot	VOL	120	Concrete
Concrete	STR-102_02_LAS-BOQ	2	Concrete B200 for foot bed	VOL	120	Concrete
Concrete	STR-102_03_LAS-BOQ	3	Concrete B300 for underground beam	VOL	120	Concrete
Concrete	STR-102_04_LAS-BOQ	3	Concrete B250 for slab on grade	VOL	120	Concrete
Concrete	STR-102_05_LAS-BOQ	3	Concrete B300 for column	VOL	90	Concrete

Concrete	STR-102_06_LAS-BOQ	4	Concrete B300 for structural slab	VOL	120	Concrete
Concrete	STR-102_07_LAS-BOQ	3	Concrete B300 for shear wall	VOL	90	Concrete
Concrete	STR-102_08_LAS-BOQ	3	Concrete B300 for stair	VOL	105	Concrete
Concrete	STR-102_09_LAS-BOQ	3	Concrete B300 for upstand beam	VOL	120	Concrete
Dummy	ARC-000_00_DUM	0	Dummy elements for presentation purposes	1	NA	Dummy
Floor Finish	ARC-100_01_LAS-BOQ	1	Screed type SCR201	ST	35	Floor Finish
Floor Finish	ARC-100_02_LAS-BOQ	1	Screed type SCR202	ST	35	Floor Finish
Floor Finish	ARC-100_03_LAS-BOQ	2	Water prof type WPS201	ST	20	Floor Finish
Floor Finish	ARC-100_04_LAS-BOQ	2	Water prof type WPS202	ST	20	Floor Finish
Floor Finish	ARC-100_05_LAS-BOQ	2	Ceramic type FL401	ST	15	Floor Finish
Floor Finish	ARC-100_06_LAS-BOQ.A	3	Ceramic type FL402	ST	15	Floor Finish
Floor Finish	ARC-100_07_LAS-BOQ	3	Ceramic type FL412	ST	15	Floor Finish
Floor Finish	ARC-100_08_LAS-BOQ	1	Stone tile type FL660	ST	15	Floor Finish
Ceiling Finish	ARC-101_01_LAS-BOQ	3	Gypsum board 12mm thick type CLG601	ST	75	Ceiling Finish
Ceiling Finish	ARC-101_02_LAS	1	Fail ceiling structural system	ST*5/2	50	Ceiling Finish
Ceiling Finish	ARC-101_03_LAS	2	Fail ceiling thermal insulation 50mm thick	(SL+SR)/2	80	Ceiling Finish
Ceiling Finish	ARC-101_04_LAS-BOQ.A	2	Metal board 15mm thick type CLG507	ST	60	Ceiling Finish
Ceiling Finish	ARC-101_05_LAS-BOQ	3	Gypsum board 12mm thick type CLG605	ST	75	Ceiling Finish
Ceiling Finish	ARC-101_06_LAS-BOQ	3	Gypsum board 12mm thick type CLG601_V	(SL+SR)/2	60	Ceiling Finish
Ceiling Finish	ARC-101_07_LAS-BOQ	3	Gypsum board 12mm thick type CLG605_V	(SL+SR)/2	60	Ceiling Finish
Partition	ARC-102_01_LAS-BOQ	1	Blok-work partition, 200mm thick, 2H fire resistance	(SL+SR)/2	24	Partition
Partition	ARC-102_02_LAS-BOQ	1	Blok-work partition, 100mm thick, 2H fire resistance	(SL+SR)/2	21	Partition
Partition	ARC-102_03-BOQ	0	Gypsum partition IWS-705, 144mm thick, 1H fire resistance, with insulation, LF	(SL+SR)/2	NA	Partition
Partition	ARC-102_04_LAS	1	Partition structural system	(SL+SR)*4/2	70	Partition
Partition	ARC-102_05_LAS	3	Vertical partition thermal insulation 50mm thick	(SL+SR)/2	90	Partition
Partition	ARC-102_06_LAS	2	Gypsum partition, 1st side sheet fixation 12mm thick, LF	(SL+SR)/2	80	Partition
Partition	ARC-102_07_LAS	4	Gypsum partition, 2nd side sheet fixation 12mm thick, LF	(SL+SR)/2	80	Partition
Wall Finish	ARC-103_01_LAS-BOQ	1	Cement Plaster 14mm thick, soft finish	(SL+SR)/2	50	Plaster
Wall Finish	ARC-103_02_LAS-BOQ	1	Cement Plaster 6mm thick, hard finish	(SL+SR)/2	105	Plaster
Wall Finish	ARC-103_03_LAS-BOQ	2	Paint type PT104 on fair face	(SL+SR)/2	80	Painting
Wall Finish	ARC-103_04_LAS	1	Wall lining structural system	(SL+SR)*4/2	70	Wall Lining
Wall Finish	ARC-103_05_LAS-BOQ	2	Ceramic wall lining type LIN302, 8mm, fixed by glue on hard surface plaster	(SL+SR)/2	30	Wall Lining
Wall Finish	ARC-103_06_LAS-BOQ	2	Marble cladding type LIN808, 20mm thick	(SL+SR)/2	50	Wall Tiling
Wall Finish	ARC-103_07_LAS-BOQ	3	Paint type PT305 direct to polished gypsum board	(SL+SR)/2	40	Painting
Wall Finish	ARC-103_08_LAS	2	Polishing work gypsum surface	(SL+SR)*5/2	30	Painting

Wall Finish	ARC-103_09_LAS	2	Polishing work cement surface	(SL+SR)/2	20	Painting
Wall Finish	ARC-103_10_LAS-BOQ	2	Wooden sheet cladding type LIN809, 20mm thick	(SL+SR)/2	50	Wall Tiling
Wall Finish	ARC-103_11_LAS-BOQ	3	Paint type PT104 on cement plaster	(SL+SR)/2	60	Painting
Wall Finish	ARC-103_12_LAS	1	Filling surface	(SL+SR)/2	60	Painting
Doors	ARC-104_01_LAS-BOQ	1	Metal door type 105, 2H fire resistances	1	7	Doors
Doors	ARC-104_02_LAS-BOQ	1	wooden door type 101, 2H fire resistances	1	7	Doors
Doors	ARC-104_03_LAS-BOQ	1	Metal door type 106, 2H fire resistances	1	7	Doors
Accessori es	ARC-105_01_LAS-BOQ	1	Metal handrail 50mm radius	Vol/(.025*.025*3.1 4)	25	Accessori es
Facades	ARC-106_01_LAS-BOQ	1	Glass panel 1000x3500mm, 2H fire rating, 150mm thick	1	15	Cladding
Facades	ARC-106_02_LAS-BOQ	3	external thermal insulation, 2H fire rating, 50mm thick	(SL+SR)/2	40	Cladding
Facades	ARC-106_03_LAS-BOQ	4	Stone cladding type 08, 20mm thick	(SL+SR)/2	60	Cladding
Facades	ARC-106_04_LAS-BOQ	4	Stone roof stop, length as per location	LC	15	Cladding
Facades	ARC-106_05_LAS	2	Cladding structural system	(SL+SR)*4/2	50	Cladding
Facades	ARC-106_06_LAS-BOQ	1	External water proofing, painting type, 2mm thick	(SL+SR)/2	60	Cladding

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