Lean Production Using Modular Construction
Study of The ABC Company's Projects

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Master of Science

The University of Kansas

Fall Semester, 2011

An EMGT Field Project report submitted to the Engineering Management Program and the Faculty of the Graduate School of The University of Kansas in partial fulfillment of the requirements for the degree of Master of Science.

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ACKNOWLEDGEMENTS

First, I would like to thank my country, which has given me the opportunity to pursue a postgraduate degree in the United States.

Thanks to my parents who have been supporting me in completing my education. Also, I would like to thank my wife, Zainab Alshayeb, and my son, Nawaf, for allowing me the time to pursue the completion of this work towards a master's degree from the University of Kansas.

I would like to thank the EMGT faculty and staff. Also, thanks to my committee chair, Herbert Tuttle, and my committee members, Linda Miller and Tim Wilcoxon for their feedback and comments.

Last, but certainly not least, thanks to the faculty and staff of the University of Dammam (King Faisal University) where my engineering knowledge and basic understanding was formed. Special thanks to Professor Yousef Alohali for his guidance and support during my undergraduate education as well as during the completion of this work.

EXECUTIVE SUMMARY

Implementation of lean production theory into the construction industry represents a tremendous opportunity to improve productivity in construction and reduce waste. Lean production, first applied in Toyota's manufacturing process, is based on the idea of making each machine produce small volumes of many part numbers, which leads to a wide variety of low-cost and high-quality products. Toyota produces different car models from the same platform by having many common parts that fit several models. The aim of this paper is to implement the lean principles used in the automotive industry into the construction industry by using modular construction. The idea of producing a small volume of many parts can be simulated in the construction industry. A case in which lean principles are implemented is the ABC Company's projects.

CHAPTER 1: INTRODUCTION

New technologies have changed the way people work in many industries. Historically, goods have been designed and produced by the power of human endeavor. Industries have always needed people who have the skills and talent to manufacture and design products. After the Industrial Revolution, however, the role of machines became more important than that of the workers themselves. A machine could produce much more than what dozens of workers could produce. The amount of work that the machines were able to accomplish was unbelievable for that time, and the process known as Mass Production took hold.

Mass Production is based on a principle of quantity in which more is better. It requires the use of the same tools over and over again by human workers adequately trained in specialized tasks. Mass Production emphasizes cost reduction within processes through economies of scale (Liker and Morgan 2011). The problem with the Mass Production system was the inability to provide variety (Lean Enterprise Institute 2011). Some companies were able to produce whatever the market demand was but in only one model, shape, color, and specification; however, a mass number of the same product was not what the customers needed.

Ford Motor Company’s production system was considered an example of Mass Production. Ford’s problem was the inability to provide variety. The Model T was not just limited to one color, but it was also limited to one specification so that all Model T chassis were essentially identical up through the end of production in 1926 (Womack n.d.). Later on, Ford tried to provide customers with a choice of four or five body styles by implementing features from outside suppliers that were added at the very end of the production line. However, it appears that this was still not enough because every machine that the Ford Motor Company worked on had a single part number, and there were essentially no changeovers. Ford seemed to lose its way when the world wanted variety and demanded model cycles that were shorter than the 19 years for the Model T (Lean Enterprise Institute 2011).

After World War II, Kiichiro Toyoda, Taiichi Ohno, and others at Toyota looked closely at Ford’s situation and believed that a series of innovations might be made to provide both continuity in process flow and a wide variety of product offerings (Nasiri 2009). Therefore, they revisited the Ford System and invented the Toyota Production System, which was later known as the Lean Production System. Their system was based on the belief that by right-sizing machines for the actual volume needed, each machine could make small volumes of many part numbers. By having each process step notify the previous step of its current needs for materials, it would be possible to obtain low-cost, high-variety, high-quality, and rapid throughput times to respond to evolving customer desires (Lean Enterprise Institute 2011).

As the Lean Production System has shown huge success in the automotive industry, it has been introduced in many other industries such as the construction industry. Lean Construction is a production management-based approach to project delivery as well as a new way to design and build capital facilities. According to the Lean Construction Institute:

> Lean construction extends beyond the objectives of lean production system – maximizing value and minimizing waste – to specific techniques, which are: concentrating on supporting the customer purpose, designing process to maximize value and to reduce waste at the project delivery level, improving the total project performance is more important than reducing the cost or increasing the speed of any activity, and making sure that the performance of the planning and control systems can be measured and are improved. (Lean Construction Institute, 2011)

The construction industry is still struggling to move from the crafting production level – where every process is designed, specified, and executed individually – to Lean Production, especially for the construction of huge numbers of buildings. Mass Production has failed in construction projects because the customer needs variety. Architects believe that it is unacceptable to produce huge numbers of the same building and then distribute them over many sites. Customers have different needs in architecture and design. Thus, the solution has been to go back to the crafting level and improve that system by applying different quality approaches such as Total Quality, Six-Sigma, and Process Re-Engineering.

Some others have tried to take some of the construction tasks off-site in order to save time and control waste. This approach has revealed itself to be a great way of standardizing off-site work, especially when the mission is producing huge numbers of buildings that are used for the same purpose, but on different sites and with different sizes. Standardization does not mean having the same building size, color, shape, etc. Rather, standardizing means having the same building parts, pieces, or modules that will be used for constructing several different types of buildings.

CHAPTER 2: LITERATURE REVIEW

2.1 Lean Production in the Automotive Industry

As lean principles were first introduced in the automotive industry, it is important to study how that industry implemented them. Toyota has come up with thirteen principles of Lean Production, sorted under three main categories: (1) skilled people, (2) tools and technology, and (3) process (Liker and Morgan 2006). The thirteen principles are considered the guide for a Lean Production Development system effort, and most automotive companies have been using them.

2.1.1 Ford's Lean Product Development System

A study of Ford's Lean Production Development was made. In 2006, Ford Motor Company implemented a new Lean Product Development system in order to improve its performance. Ford realized that Toyota had gotten significantly ahead in the number of different car models that were derived from the same platform and had many more common parts (Liker and Morgan 2011). Ford made big investments and efforts in new products development, and they started by hiring skilled people and naming Alan Mulally as the company's new CEO.

Ford is different from many other companies when it comes to production. Ford has several production plants all over the world, and every plant has its own production line. Some other companies have standard production for all of their plants. For instance, most of Toyota's factories are located in Japan, which makes Toyota's production more controllable. Also, in the Japanese auto companies, a chief engineer has an overall vision for the product and helps integrate it across departments to enable simultaneous engineering. Both of these factors were not implemented in the Ford system.

Ford management formed teams to study each process individually and then identified the problems and solutions. The teams closely observed what the Japanese companies were doing by visiting Mazda factories and then comparing Mazda's process with what Ford had. This process was led using the *obay* (Japanese word for big room), a concept developed within Toyota. Each team had a team leader who had a section of the visual display wall. Teams had to develop reports that had detailed development timelines and identified gaps in productivity, lead-time, and quality. Each report was on A3 size paper and provided detailed information about the problem using pictures, drawings, and graphs.

One of the areas that Ford concentrated on was body and stamping engineering. Ford engineers recognized that real development could be made in body and stamping. The method used was to identify the value added processes and non-value added processes from the customer's point of view. Non-value added processes are those in which standard work can be applied. Even though body and stamping is what is mostly noticed by customers and is an area in which it is hard to apply standard work, Ford figured out some specific areas where standard work could be applied.

Ford engineers identified several tasks that could be considered non-value processes to the customer. Ford engineers developed standard platforms for some of its models and standard exterior door handles. They figured out that it was possible to produce two different models from the same platform. Although the journey to implementing the process was not easy, the engineers believed it to be a real development for reducing time and cost. As a result, Ford has two completely different vehicles that are produced from the same platform. The new Ford Explorer and Ford Taurus are both produced from the same platform.

Furthermore, the door handles were standardized for most of the Ford models. Making a different door handle for every Ford model was considered wasteful. Differentiating the door handle was identified as a non-adding value to the customer, so Ford's engineers decided to have one single design for all of Ford's models.

In summary, Ford focused on the three main aspects of the Lean Development system. They hired skilled people, implemented the right technology, and improved processes. The major improvement was in process by identifying value adding and non-value adding activities from the point view of the customers. That then led to standardizing work to come up with more varieties of vehicle models from the same platform and many parts that can fit into several models.

2.2 Waste in Construction

The construction industry produces more waste than any other industry in the entire world (Meadows 2011). Waste in construction is defined by Pheng and Tan in the *Construction Management and Economics* as “the difference between the value of those materials delivered and accepted on site and those used properly as specified and accurately measured in the work” (Ballard and Polat 2004). Bossink and Brouwers (1996) identified six sources for the main waste causes in construction: design, procurement, material, handling, operation, and residual. In another study, construction waste was sorted into two main areas: (1) time waste including waiting periods, stoppages, clarifications, variation in information, rework, ineffective work, interaction between various specialists, delays in plan activities, and abnormal wear of equipment, and (2) material wastes comprising over ordering, overproduction, wrong storage, wrong handling, manufacturing defects, and theft or vandalism (Garas, Anis, and El Gammal 2001).

2.2.1 Waste of Materials

Material waste is a huge area of waste in construction. Bossink and Brouwers (1996) indicated that 9% of total purchased materials end up as waste and from 1% to 10% of every purchased construction material leaves the site as solid waste in the Dutch construction industry. The same study also showed that in the Brazilian construction industry, 20-30% of the purchased materials are not used and end up as waste.

The impact of construction and demolition debris on the environment is staggering. A report by the Environmental Protection Agency (EPA) estimated that more than 135 million tons of debris from construction sites are brought to landfills in the United States every year, making the construction industry the single largest source in the waste stream (Meadows 2011). Moreover, according to Waste & Resources Action Programme (WRAP), in the United Kingdom, more than 120 million tons of demolition and excavation waste are generated every year, which amounts to around one third of all waste arising in the UK. Furthermore, over 25 million tons of this waste is sent to the landfill without any form of recovery or reuse (WRAP n.d.).

In the Gulf Cooperation Council (GCC) countries where most of their major cities are currently witnessing massive construction activities, huge amounts of debris are brought to landfills every year. Kuwait alone produces 2,000 to 2,500 tons of construction waste per day, according to figures from the country (Nazar 2009). There is no such data is available for Saudi Arabia, but Sultan Faden, a Saudi environmental activist and head of the Founding Group of the Saudi Green Building Council, claimed that since Saudi Arabia is the biggest country in the Gulf, it is also the largest contributor of solid waste in the Gulf (Nazar 2009).

2.2.2 Waste of Time

The second major type of waste in construction is waste of time. Construction tasks consist of process time, inspection time, move time, and wait time (Ballard and Polat 2004). The process time activities are the only value adding activities, while the remaining are non-value adding activities (Ballard and Polat 2004). Even though all the value added activities are only sorted under the process time, not all the process time activities are value added. The process time activities are also subject to waste resulting from overproduction, incorrect construction method, defects, and poor optimization in performing tasks (Ballard and Polat 2004).

The main causes of time waste have been identified. A study made to identify the main causes of time waste in the Turkish construction industry showed that 72% of the study participants reported delays in material supply

(Ballard and Polat 2004). This problem may be caused by the contractor's purchasing department, from a delay in sending the purchase request to the supplier, or it may be caused by the supplier, from a delay of delivery. The results of this study were consistent with two previous studies. The report also stated that 52% of the study sample responded that waste of time is caused by waiting for replacements due to receiving materials that do not fulfill project requirements.

2.3 Modular Construction

Modular buildings are built using an engineered approach to produce different types of buildings in the most efficient way. Instead of the old construction approach, most of the work is completed in a factory-controlled environment. When each section is completed and inspected in the factory, it is transported to the construction site and assembled to come up with a new building.

Modular building is not a recent innovation in the construction industry. Modular buildings are essentially pre-fabricated buildings taken to a new and large scale. The use of pre-fabricated buildings goes back to the beginning of the 20th century. In the United States, the end of World War II caused modular construction to explode when the returning soldiers began looking to buy homes and start a family. The huge demand for homes was greater than what the market was able to handle by using the traditional construction process. This led people to think about solutions that could meet the marketplace demand, increase efficiency, and lower total costs. The modular construction process was the answer to all of these challenges (Modular Today 2011).

The earlier modular buildings were much simpler than what can be accomplished today. The earlier designs were basic and mostly had a rectangular shape, which explains why when phrases such as modular buildings, pre-fabricated buildings, or pre-engineered buildings are mentioned, trailers or portable buildings are the first thing that come to mind. The simplicity of the building design was the result of several factors such as the capacity of cranes and transportation difficulties. In the last two decades, modular buildings have become much more sophisticated. The capacity of cranes has been increased to lift over 100 tons, making the ability to construct larger modules a non-issue. The only limitation is the size of each individual module due to the width of the road from the factory to the building site.

Historically, modular buildings have been viewed as temporary shelters (Vazquez 2008). A prototype image has been formulated in which modular buildings are mobile buildings and for temporary use. Inexpensive and poorly built structures such as trailer homes are the images conjured up by the word prefab (Kaysen 2011). Modular construction is used to construct permanent buildings as well as relocated buildings. The permanent modular construction buildings are manufactured in a safe controlled setting, and can be constructed of wood, steel, or concrete. Furthermore, modular construction is no longer limited to single story buildings. It can be used for multi-story buildings as well as singular (Modular Building Institute (MBI), 2011b).

2.3.1 Modular Is Resource Efficiency

Modular construction is the most efficient way to eliminate waste. Reducing the amount of waste that is generated by any project is an important part of sustainable building. The focus of Green Building programs for site-built construction is to reuse, recycle, or divert waste that is generated on the site. With off-site construction, however, the material can be managed prior to leaving the factory, offering a much more efficient process to reduce the amount of waste sent to landfills (MBI 2011b). The effort of managing and diverting the waste after it is generated can be avoided by choosing alternative methods of construction such as pre-fabrication, modularization, and off-site construction techniques, which are effective ways to design out waste (MBI 2011b).

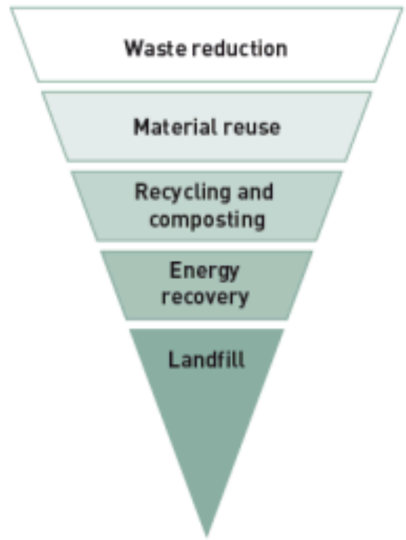

Figure 1: Waste Hierarchy
Source: WRAP- Designing out Waste: a design team guide for buildings

The waste hierarchy (Figure 1) shows that the effort of reducing waste must be done in the initial stages – the design stage – when potentially larger impacts can be made. A reduction strategy must be implemented to address and measure waste in construction. After an effective waste reduction strategy is developed, it is then more appropriate to focus on the next tier, which is recycling, reusing, and recovering any remaining material (WRAP n.d.).

The WRAP report mentions off-site construction as one of five key principles to reduce waste. By increasing the use of modular construction, up to 90% reduction can be achieved by reducing wastes such as wood pallets, shrink wrap, cardboard, plasterboard, timber, concrete, bricks, and cement

(Meadows 2011). The following figure estimates the levels of site waste that can be reduced by using modular construction (WRAP 2007).

Table 7: MMC & Estimates of Waste Reduction though Substitution for Traditional Building Methods		
MMC	Est. % reduction	Level of confidence
Volumetric building systems	70 - 90	Reasonable
Timber frame systems	20 - 40	Broad estimate – depends upon the level of pre-fabrication
Concrete panel systems	20 - 30	Broad estimate
Steel frame housing systems	40 - 50	Broad estimate
OSB SIPS	50 - 60	Reasonable – depends on the level of prefabrication
Composite panels	20 - 30	Broad estimate
Pre-cast cladding	40 - 50	Broad estimate
LSF systems	40 - 70	Reasonable – depends on the level of prefabrication
Bathroom/shower & kitchen pods	40 - 50	Broad estimate
Pre-cast flooring	30 - 40	Broad estimate
Thin joint masonry	30 - 40	Broad estimate
Insulating concrete formwork	40 - 50	Broad estimate
Tunnel form construction	50 - 60	Broad estimate
Source: AMA Research/trade estimates		

Figure 2: Estimates of Waste Reduction through Substitution of Traditional Building Methods
Source: WRAP report, 2007

According to the Environmental Protection Agency (EPA), the industry average for construction and demolition (C&D) waste for a non-residential project is approximately 4.34 Ib/sq. ft. (Meadows 2011). Xstrata, LEED Gold certified, is a modular project by NRN Inc. that generated only 2.86 Ib/sq. ft. of waste material, which is much less than the average industry C&D waste (MBI 2011b).

Modular construction is material and resource efficient because most of its processes are done in a factory-controlled environment. Having the ability to assemble repetitive units in a controlled condition is one of the greatest advantages of off-site construction. Since the modular units are largely finished prior to arrival to the site, the material waste due to the weather or construction site theft can be avoided (MBI 2011b). Most modules leave the factory 60-90% complete, with wiring, plumbing, structural, and mechanical system inspected and approved before arriving to the site (MBI 2011b). Furthermore, since modular buildings are constructed in a factory-controlled environment, many projects can be handled at the same time, and the material that may have been allocated to one project can be used for another one (MBI 2011b).

2.3.2 Modular Is Reusable

Modular construction supports the demands of reusing and deconstructing. The whole building can be reused. The process of constructing the modular building can be done in reverse by disassembling the building into pieces, which can be used for another project. The concept of reusing the whole building is more sustainable then demolishing the building and then recycling some materials.

Marriot Grande Lakes Sales Center, Orlando, FL, is a recent example of a relocated modular building. The center was initially manufactured in 2003 as a 10-unit custom office, and then after 6 years of use, it was disassembled and sent to storage. In 2009, when a new development in

Florida required a sales center, it was determined that 6 of the original 10 units could be used to construct the building and 4 new units would be added to the center (MBI 2011b).

Modular construction cuts the building time in more than half and is not limited to any size. In most cases, construction of modular buildings is 50% faster than conventional construction (MBI 2011a). The Modular Building Institute (MBI) annual report, 2011, states that MBI members design and build schools of all types using traditional construction materials such as wood, steel, and concrete, and almost any size permanent school can be built, installed, and ready to be occupied in as little as 90 days (MBI 2011a).

2.3.3 Modular Can Be Used for Different Types of Buildings

Modular construction can be used to construct various types of buildings in any size. Even though modular construction projects typically range in size from 5,000 sq. ft. to 10,000 sq. ft., many new projects are beyond that range.

The Fort Sam Houston project, Medical Education Training Center in San Antonio, TX, for instance, is one of the largest permanent modular buildings in the world and the largest in North America, with a total of over one million square feet of construction built off-site (MBI 2010). The project used a combination of three off-site construction methods. With a total of

520,000 sq. ft. of modular building, the project was completed within 134 days (MBI 2010). The project consists of four buildings, with each building containing 220,000 square feet of modular construction (Kanaby 2010).

High-rise buildings also can be built using modular construction. In 2009, a 24-story, $34 million high-rise tower was completed in Wolverhampton, England, which was considered the tallest modular building in Europe (Kalette 2009). Although the full project required a year to complete, the tallest structure was completed within 27 weeks only. The construction could have taken two years if it had been built using on site methods (Kalette 2009).

2.3.4 Modular Is Time Reduction

Another distinctive feature of modular construction is that multiple tasks can be done simultaneously. During site-built construction, walls cannot be done before floors, and the ceiling cannot be done before the walls; however, modular allows the ability to construct walls, floors, and ceiling at the same time. Furthermore, the site work can be begun simultaneously as the units are constructed in the factory, which greatly accelerates the schedule (Kanaby 2010). Figure 3 shows the modular construction schedule compared with the site built construction schedule.

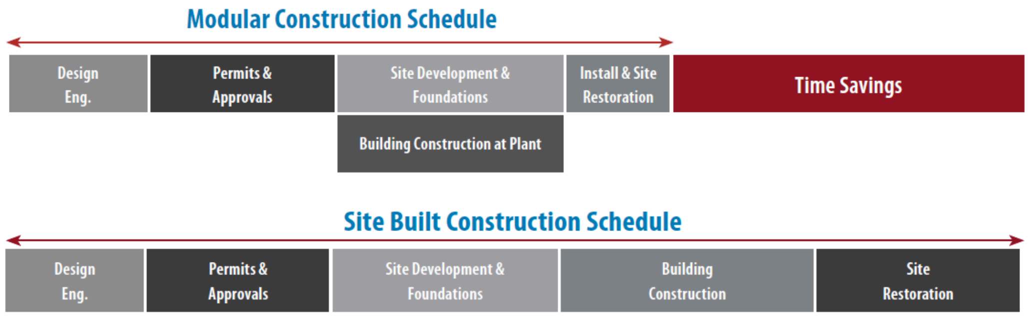

Figure 3: Modular Construction Schedule
Source: MBI, Permanent Modular Construction, 2011 Annual Report

The United Kingdom has recently started to construct public schools using prefab. The report shows that the government will be able to cut school construction time from 18 months to 13 weeks (Hopkirk 2011).

In conclusion, modular construction has become much more sophisticated. The prototypical image that modular is temporary buildings or trailers has changed due to the improvement in the modular construction industry. With the modular construction approach, any type of building can be constructed. Modular construction has the ability to enable lean construction and Green Building Trends in order to improve productivity in construction.

CHAPTER 3: THE ABC COMPANY'S PROJECTS

3.1 Background

3.2 The Company's Current Practices

The company's projects process can be divided into two main stages: the design stage and the construction stage.

3.2.1 Design Stage

In the design stage, the company engineers have found that prototype design templates are the best way of designing massive number of buildings. The company will not build several buildings when each building can be designed individually, so the idea of designing prototype templates was the answer. The company engineers studied school needs and requirements and designed templates that met the requirements. There are about 17 design templates that are used for large communities, and several design templates for small villages. Those designs are made to be used for the three educational levels (primary, intermediate, and high school) and in schools for both genders.

The company's engineers do not have to design a new architectural design for every new school. One of the templates will be pulled out when the need to construct a new school arises. There is no major modification that can be applied to those templates. The only effort that the company engineers expend in the design stage is to make sure that the selected design template fits into the new site. Some other minor modifications can be made such as closing unneeded doors or removing walls to join two classrooms together. Basically, the company has avoided spending time and money in the design stage by using the prototype design templates.

3.2.2 Construction Stage

In the construction stage, the company's projects are constructed using the traditional method, which is on-site construction. Most of the projects in XYZ are built using pre-cast concrete or on-site construction methods. After contractors are selected (law bid approach), the company's engineers play supervisory roles. Contractors have the right to manage all aspects of the construction process without the company engineers' influence. The average time of the construction process is 2 years.

School buildings are constructed by different contractors but under the company engineers' supervision. The company engineers have to get the contractor's approval before the contractors move to the next stage. Since every project might have a different contractor, the materials for each project are purchased by the contractor; however, the material must match the specified materials. Thus, the main responsibility of the company's engineers is to make sure that contractors are following the material specification and delivering work on schedule.

3.3 Evaluation of the Current Practices (problem)

Evaluation of the company's current practices in both stages – design and construction – has to be done, and the disadvantages of each stage need to be identified.

3.3.1 Evaluation of the Design Stage

The main problem in the design stage is that the company uses several prototype design templates that are applied to schools for all ages and in numerous locations. Although the prototype design templates idea seems to be a perfect solution because it saves time and money, many technical problems exist.

The prototype design template is a design limitation approach. Regardless of the number of templates that the company has developed, these designs are still limited compared with the number of school buildings that will be constructed. The same design templates are used for primary schools, intermediate schools, and high schools without any modification. The design templates have the same colors, materials, and look identical.

In addition, the same prototype design templates are used for construction in different locations. One of the templates has to be used no matter where the new school location is. The templates are used for sites that face north as well as the sites that face south, east, or west. The building orientation is an important factor for reducing energy consumption. Leadership in Energy and Environmental Design (LEED) considers where the building is located and how efficiently it manages resources while measuring the sustainability of building design.

The Oak Ridge Associated Universities Center for Science Education building, for instance, needs 23% less energy as compared with typical buildings. Several aspects enhance the building's energy efficiency and building orientation is the most important. The building is oriented on an east-west axis to take advantage of solar orientation by maximizing solar heat gain in the winter on the south side and minimizing solar heat gain in the summer (ORAU 2011). Furthermore, the building orientation allows natural lighting to eliminate the need for electric lighting during daylight hours.

Furthermore, the design templates do not consider the schools' future expansion. Schools in most cases need to have more classrooms in the future. The design templates do not have the flexibility to add any extra classrooms. Any future extension must be made by building a new building.

3.3.2 Evaluation of the Construction Stage

The problem with the construction stage is that every building is constructed individually by using traditional construction. Even though the company is constructing thousands of buildings every year, the construction process does not get affected. Contractors build school buildings with no regard for the number. Constructing one school or one thousand schools has the same impact on the construction process. Any improvement efforts are applied by the contractors into each project regardless of the other projects.

The construction materials are supplied individually for every project. Because every contractor is responsible for the whole project, the company management is not responsible for supplying the construction materials. This approach will increase the resources waste. As mentioned earlier, many previous studies have shown the construction industry is producing more waste than any other industry. These studies state that an average of more than 10% of the purchase materials end up as waste (details in Waste of Materials). That waste would be avoided if the extra materials could be allocated to another project.

The current construction approach, the traditional method, takes longer than the modern construction approaches. The problem with the traditional construction approach is that most of the work must be completed in a chronological order. For example, floors cannot be constructed before footings, and roofs cannot be constructed before walls. That approach eliminates the opportunity of speeding up the construction process especially for a project that consists of thousands of buildings.

In short, the problem with the ABC Company's projects begins in the design stage and extends to the construction stage. The company engineers can provide as much design as needed without expending much effort. However, the design templates have the same design, size, color, specification, etc. and are implemented into different locations. The design templates do not create design verities from the user's point of view. The design stage problem is similar to the problem with Mass Production. In contrast to the design stage practices, the construction stage is not affected by the massive number of buildings. The fact that the company is building thousands of schools every year has no impact on construction methods. Every building is constructed individually.

CHAPTER 4: IMPLEMENTING LEAN USING MODULAR CONSTRUCTION

Implementing lean principles into construction projects by using modular construction is the most appropriate method that will improve the quality of the ABC Company projects. The lean production system is an integrated system of people, process, and tools. In order to have successful results in implementing the lean production system, these three aspects must be considered. Implementing new technology without having skilled people, for instance, might not lead to expected results. The ABC Company has to implement lean production as a system that integrates the three aspects in order to achieve successful results.

4.1 Implementation Guideline

People Development: Implementing a new development plan will not achieve the expected result if the changes do not get to the people, culture, and organizational structure. As shown previously, the company's current practice is divided into two stages: design and construction. It is clear that the design stage is completely separated from the construction stage. The prototype design templates are made and prepared without the contractors and the suppliers' involvement. One of the lean principles is to integrate suppliers into the production development system (Liker and Morgan 2006). Contractors and suppliers have to be involved in the earlier design stage.

The contractors and the suppliers get involved after the bidding stage. Involving contractors and suppliers from the start will help to improve the design especially in the construction stage. They can propose alternative types of construction or different materials that might affect the design stage.

The organizational structure is an important area of development that affects people development. The designer engineers must have connections through several departments inside and outside the company. One of the thirteen principles is organizing to balance functional expertise and cross-functional integration. Several departments inside the company have to be involved such as the educational improvement specialists department. The educational experts' concerns have to be taken into consideration because their needs are important for the projects. Also, the finance department's involvement is important to figure out from the early stages what the allocated budget is.

Building a culture to support excellence is one of the lean thirteen principles. The focus of delivered value to the customer has to be a major cultural practice in the organization. Since students and teachers are the project users, the focus has to be delivering value to them. People who are involved in the project have to consider that the end users are their customers.

Tools Development: Adopting the right tools that fit the people and the process is one of the lean principles. The new tools and technology must be applicable to the people's skills. Introducing new tools to people who are not familiar with them or who have not been trained to use them might lead to failure. If new construction methods are used for the company projects, the technology has to be the appropriate one.

The development of tools has to extend beyond software or new construction materials to the standardization of skills. Toyota standardized its expert engineers' skills (Meadows 2011). The organization has to develop a tool that helps to standardize work on one hand, and on the other hand has enough flexibility to allow for creativity. The ABC Company has hundreds of engineers, and having no standard will increase variation; however, too much standardization can prevent creativity. The fine line between standardizing work and micromanagement has to be identified clearly.

Process Development: One of the lean principles is identifying the customer-defined value. The value added activities have to be separated from waste. The process overview maps have to be created to identify the value added and non-value activities. The foundation size, for instance, is a non-added activity to the customer. The end user does not care about the size of the footings or whether the footings are constructed on-site or off-site.

Process standardization to reduce variation and at the same time create flexibility is a major principle of lean production. Standardizing process is different from standardizing skills. Standardizing process is basically identifying the non-added value activities and then standardizing them over multiple products, whereas standardizing skills is about the activities of people. In school buildings, for example, differentiating the classroom door sizes is a non-added value process to customer. The possible standardized process can be identified by analyzing the process maps.

4.2 Implementation Plan

Implementing lean construction by using modular construction for the ABC Company's projects has to be made by following the previously discussed guidelines. Since the three aspects, people, process, and tools, are integrated with each other, the implementation plan would not be separate. Modular construction is the most efficient construction method that will fulfill the ABC Company's project needs. In addition, modular buildings can bring lean construction and green building together to improve productivity in construction. Implementing lean construction into the ABC Company can be started by using modular construction.

The school buildings can be constructed from standard modular cells, but the result would be a different design. Standardization must not eliminate variety. The current approach that the company uses reduces the school buildings' variety, but modular construction will not. Instead of standardizing the whole building, modular construction breaks buildings into small parts and then standardizes those parts. The engineers have to figure out how many modules are needed to create a school building. These modules can be integrated with each other to come up with a new school building.

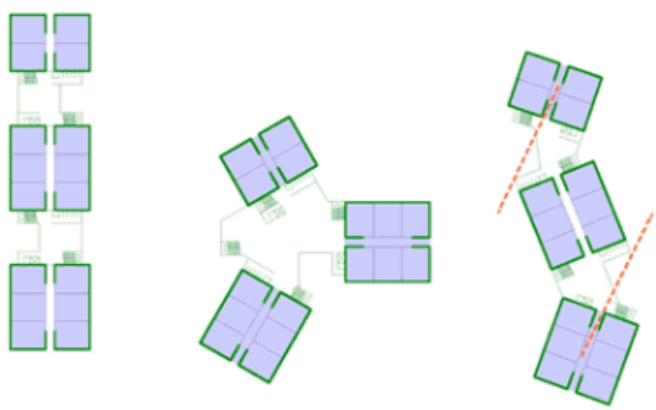

Figure 4: The Same Modules Are Integrated Differentially
Source: Unknown

As shown in Figure 6, three similar modules are integrated with each other differentially to create a different building. The cost of the three buildings will be almost the same because the modular cells are made off-site for the three buildings and then transported to the sites. Modular construction is also perfect for standardizing skills. Designers do not need to start their designs from nothing, but they have to design with the modular cells in mind. The modular cells, which will be the basis of any new school, will be used by different engineers; however, the outcomes result from every engineer will be within the company standard.

In order to select the appropriate number of the base modular cells that can generate as much variety as possible, the school building spaces program has to be studied. Contractors, suppliers, and educational specialists need to be involved. Contractors and suppliers can propose the possible construction materials as well as the appropriate size for transportation. During the design stage of the modular cells, engineers and contractors can decide on the number of different modules. For instance, a laboratory can be made from multiple different modules, or two classrooms modules can create a laboratory.

The educational experts must voice their concerns about the design if it will affect the educational environment. For example, the designers and contractors might feel that triangle classrooms are easiest to transport. However, the educational specialists might believe that triangle classrooms are not appropriate.

There are numerous opportunities to reduce waste during the design process. Preventing waste in the first place (during design) is more efficient than adopting any other programs that focus on recycling and reusing.

WRAP has recently published Design out Waste report. The report states five principles that the design team can use during the design process to reduce waste. The five principles are: design for reuse and recovery, design for off-site construction, design for materials optimization, design for waste efficient procurement, and design for deconstruction and flexibility (WRAP n.d).

After the modules sizes are finalized, the construction process can begin. Since the modules are made to be used for multiple locations, the off-site construction process can be started. When a new school is needed, the company engineers have to design a new layout for the new site, but they have to use the standard modules. After the design is completed, the contractor can start preparing the land while the cells are constructed in the factory.

Constructing modular cells in the factory will lead to reduced variation. Since the modular cells are constructed in the factory, the production assembly would be much more controllable. Furthermore, a continuous learning process model has to be developed. The construction process has to improve over time until the least materials and times accrue.

CHAPTER 5: RESULTS

Implementing lean into the ABC Company's projects will improve their quality. The improvement will be significantly observed in the ABC Company school buildings by having more varieties of buildings, increasing resource efficiency, reducing time schedule, increasing flexibility, and implementing a sustainable plan.

5.1 Increasing Variety

Using modular construction will increase the school building varieties. The company will no longer need to use prototype design templates that eliminate variety. Due to modular construction's flexibility, the variety of the schools' building design could be increased dramatically. The new schools will be constructed by integrating the off-site constructed cells together to create new designs.

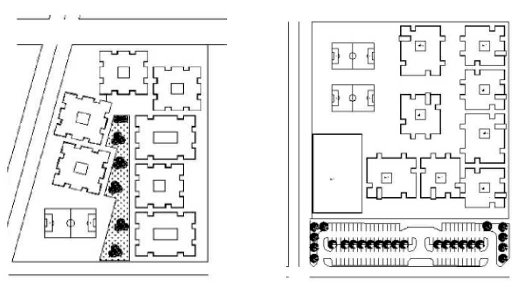

Figure 5: Modular Integrated into Different Sites
Source: Architectural Proposal Developed by the Author

As shown in the figure, the same modular cells are used to design two different school buildings that have different classroom numbers and different site size. With the new proposal, school buildings will be designed and constructed with the same modular cells regardless of the building sizes.

5.2 Increasing Flexibility

The flexibility of the new school buildings will be greater than in any other approach. The buildings will consist of modular cells that can be easier to orient in a direction that increases the advantage of the wind as well as natural light. With the prototype designs, the optimal building orientation is difficult to achieve.

In addition, the flexibility of the new proposal allows the ability to meet the need for any future expansion. The need for a future extension will be not difficult to achieve because modular can be attached to any existing school building. Also, buildings will be able to decrease their sizes or be relocated to another location by reversing the construction process.

5.3 Reducing Schedule Time

Off-site work helps to shrink the project time schedule. Many previous projects (see modular for more detail) show that prefabricated buildings are constructed within half the time of the traditional method. As shown in Figure 3, many tasks can be completed simultaneously. For instance, while the site is being prepared, the modular cells can be constructed in the factory. Time is important from the company point of view. Company officials believe that the existing rental schools are not the best environment for students to learn in. Also, the rental buildings are costly to the company. In 2010 when 494 rental buildings were replaced with new buildings, the company saved about $26 million (Al-Riyadh 2011).

5.4 Increasing Resource Efficiency

Modular construction is the most efficient method of designing out waste. Off-site construction generates much less waste than the traditional construction approach. The resources can be managed in a factory-controlled environment. Any extra materials that are allocated to project A, for example, can be used for project B because more than one school will be constructed at the same factory.

5.5 Decreasing Cost

Using modular construction will lead to cost saving. A survey was conducted by McGraw-Hill Construction of over 800 architecture, engineering, and contracting professionals to figure out how much can be saved by using modular. Sixty-five percent of them reported that the project budgets are decreased and 41% of them stated that the budget decreased by 6% or more (MBI 2011a). The United Kingdom slashed the cost of building schools by 30% by starting to use pre-fabricated buildings.

5.6 Sustainable Plan

The new proposal is implemented to be a sustainable solution. The company projects will not end when the current projects are completed. The growth rate in XYZ is exploding and more schools are needed every year.

CHAPTER 6: CONCLUSION

The construction industry is still far ahead of other industries, especially the automotive industry, when it comes to controlling waste of materials, reducing waste of time, and producing more variety. As the history of the construction industry shows, the fundamental principles of completing the work have not changed. The power of labor is still most important in the crafting process of construction projects. Most improvement efforts have been applied to improve current practices. The construction industry has to be moved into another stage where the whole process is revised to improve construction project quality.

The automotive industry had moved from crafting production to mass production, and then to lean production. The construction industry can be improved following the same principles that the automotive industry has applied. In addition, the stage of mass production, which was not completely successful in automotive industry, can be skipped. Many concerns have been raised about moving construction projects toward a mass production process. Construction projects are not like other projects that can be produced with the same color, size, specification, etc. Buildings have many other issues that need to be considered including location, users' need and age, environmental impact, and many other factors. Therefore, mass production will definitely not improve the construction process as needed.

Modular construction is an opportunity to improve the construction process. On first glance, modular construction seems like the construction of the same building over and over by moving the process off-site. It is true that modular uses the same design for cells (not for the whole building) repeatedly to construct different buildings. Automotive companies have tried to produce as many as possible of the common parts between several different car models. The same idea can be used in construction by constructing different buildings from the same modules.

A case study for the implementation of lean principles by using modular construction is the ABC Company's projects in XYZ. The majority of the ABC Company's projects are public schools for different levels and genders. Therefore, the idea of common parts can be implemented easier than finding common parts between buildings that have different uses. Schools have the same classroom sizes, the same laboratories, and many other common spaces; however, the number of the classrooms and laboratories can be different. Thus, it would be a great idea to design modules that are then integrated together to construct different buildings. The modules have to be designed and constructed to allow for the creation of different building sizes and the implementation into different sites.

Lean production is an integration process of people, tools and process. In order to have a successful outcome of such projects, these three main legs of lean production have to be implemented. Although modular construction is a lean process, applying modular by itself will be not enough. An organization must implement lean production as a package for improvement to reach the entire organization.

CHAPTER 7: SUGGESTIONS FOR FUTURE RESEARCH

There are several areas suggested for future research. Although implementing lean by using modular construction is the focus of this report, more study is needed to evaluate the ability of the modular construction industry in XYZ to construct the massive number of schools in the country. In XYZ, the majority of construction works are made with the traditional method. Off-site construction is limited to two types: mobile buildings and pre-cast concrete. The mobile buildings are mostly constructed with wood or steel and are used for commercial purposes. The pre-cast concrete buildings are a good choice, but pre-cast costs more than the traditional approach because a special form must be made for most of the parts. The question is: Can these off-site factory builders produce modular buildings?

Studying the modular construction in other regions is another possible area of study. If the XYZ's market is not capable of managing such a project, it would be important to know how the project will be completed with foreign companies' support. Some modular companies have shipped their modular cells overseas. The modules are constructed in the company factory and then shipped to another country. If the ABC Company decided to contract with overseas companies, that would impact the project time schedule as well as the economy and the construction industry.

Furthermore, future research can be undertaken to estimate how much a modular building costs compared with another building that is constructed on-site. The estimate could then be applied to determine the cost of construction for a massive number of buildings. Most studies have proven that modular buildings cost less than conventional construction, but the amount of savings has yet to be determined. The ABC Company project is unique because of the massive number of buildings involved. The saving in this project will be more than any other project because the same modules will be constructed multiple times.

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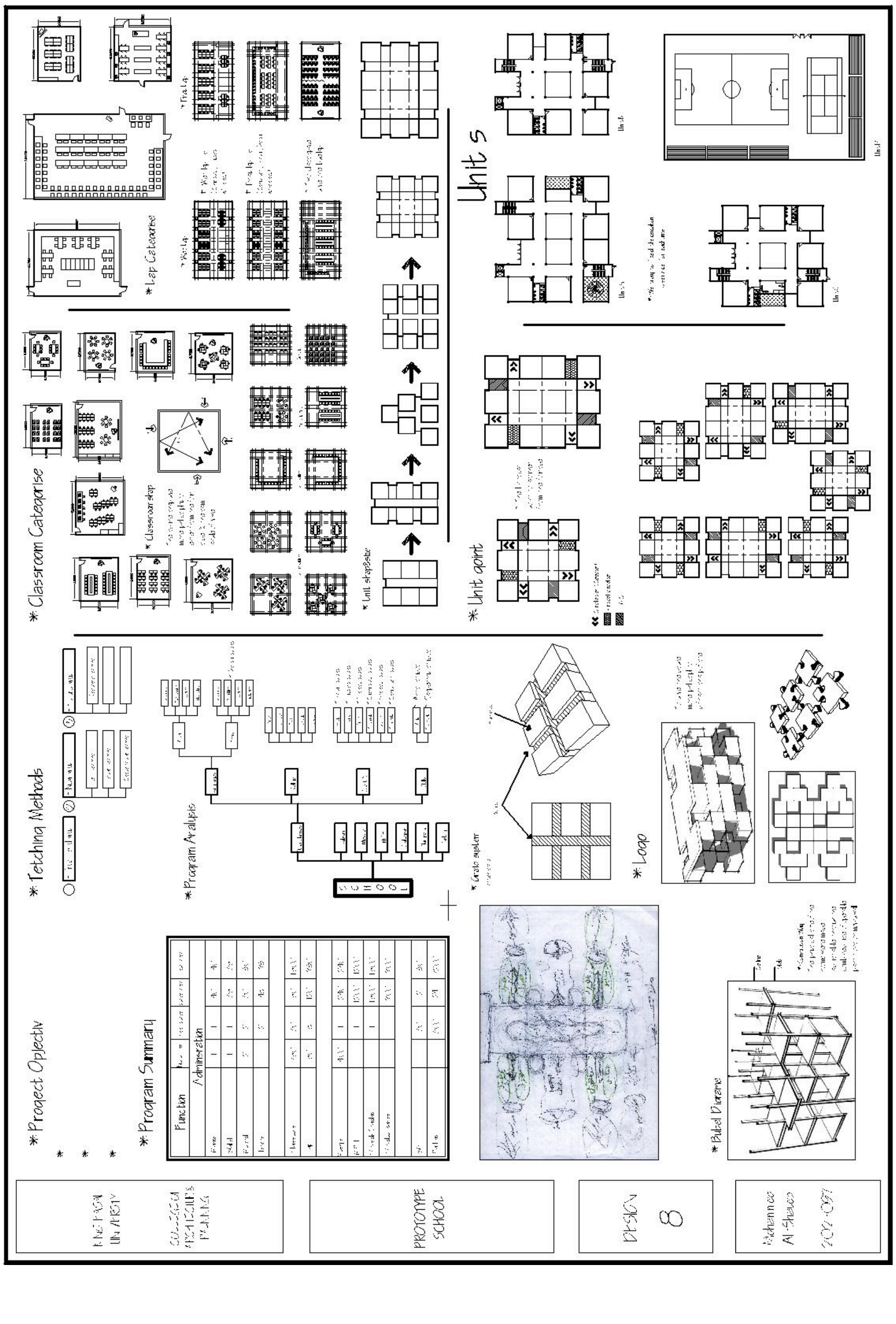
APPENDIX A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Program Analysis
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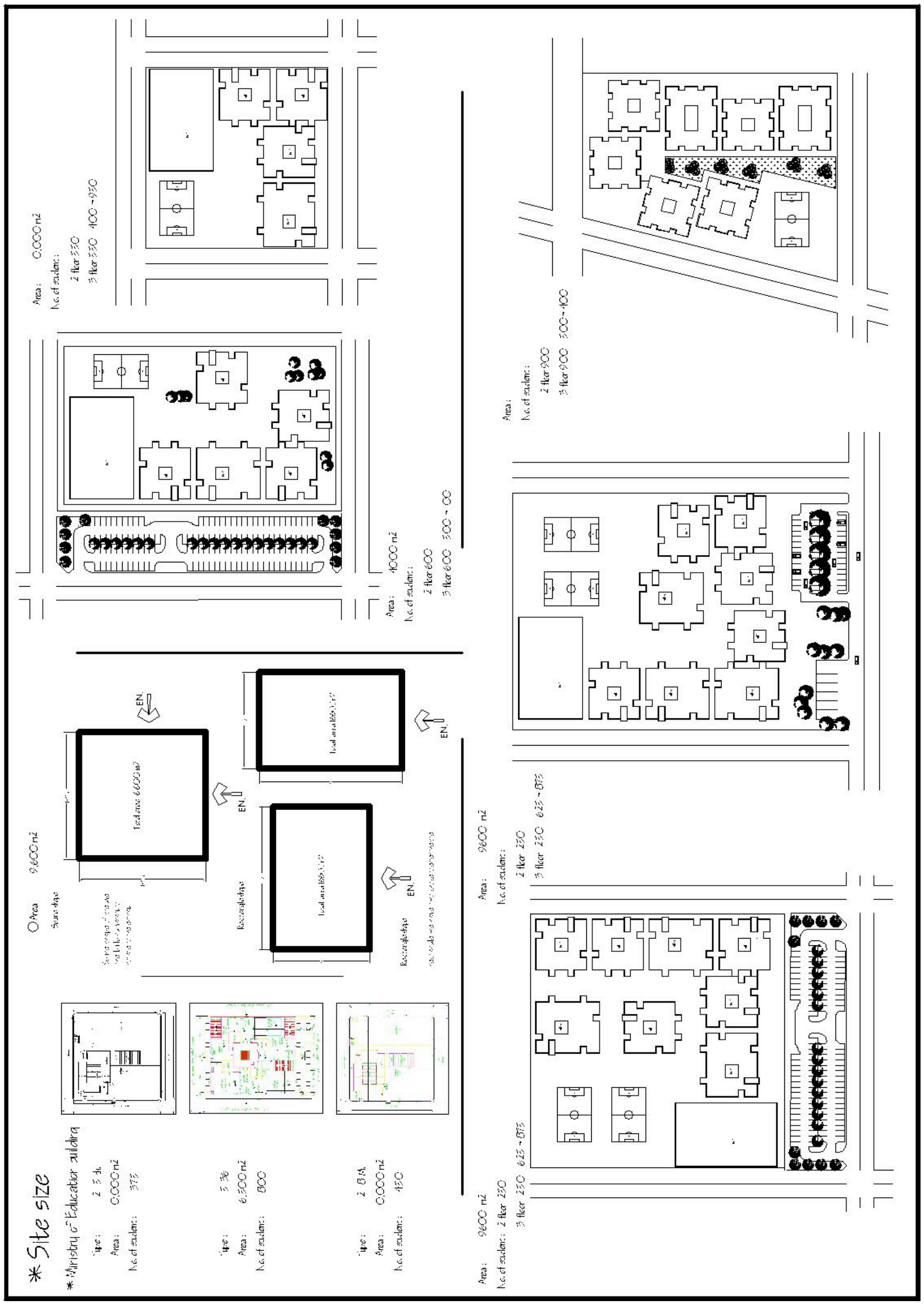
Unit s
Logo
PROTOTYPE SCHOOL
DESIGN 8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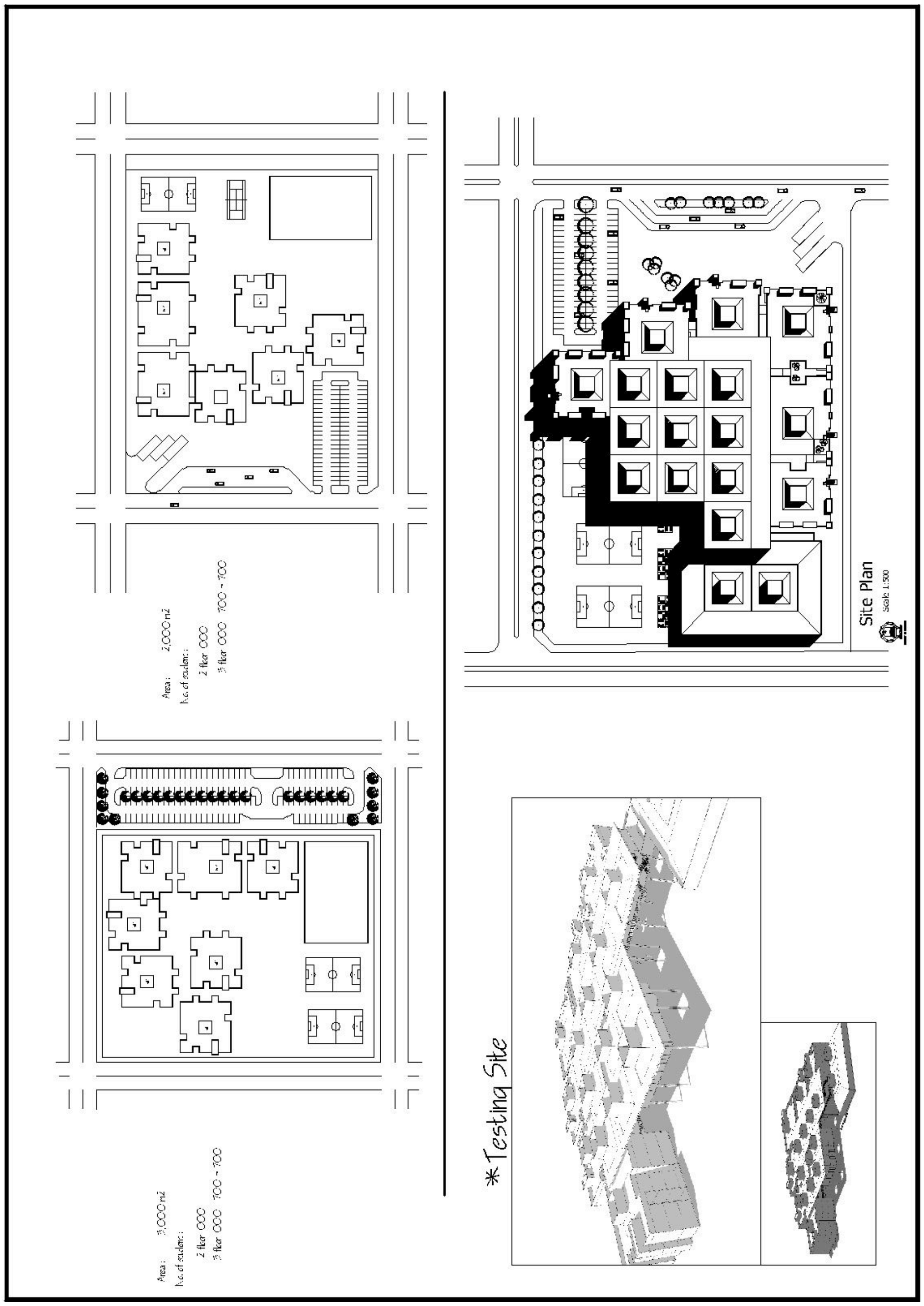
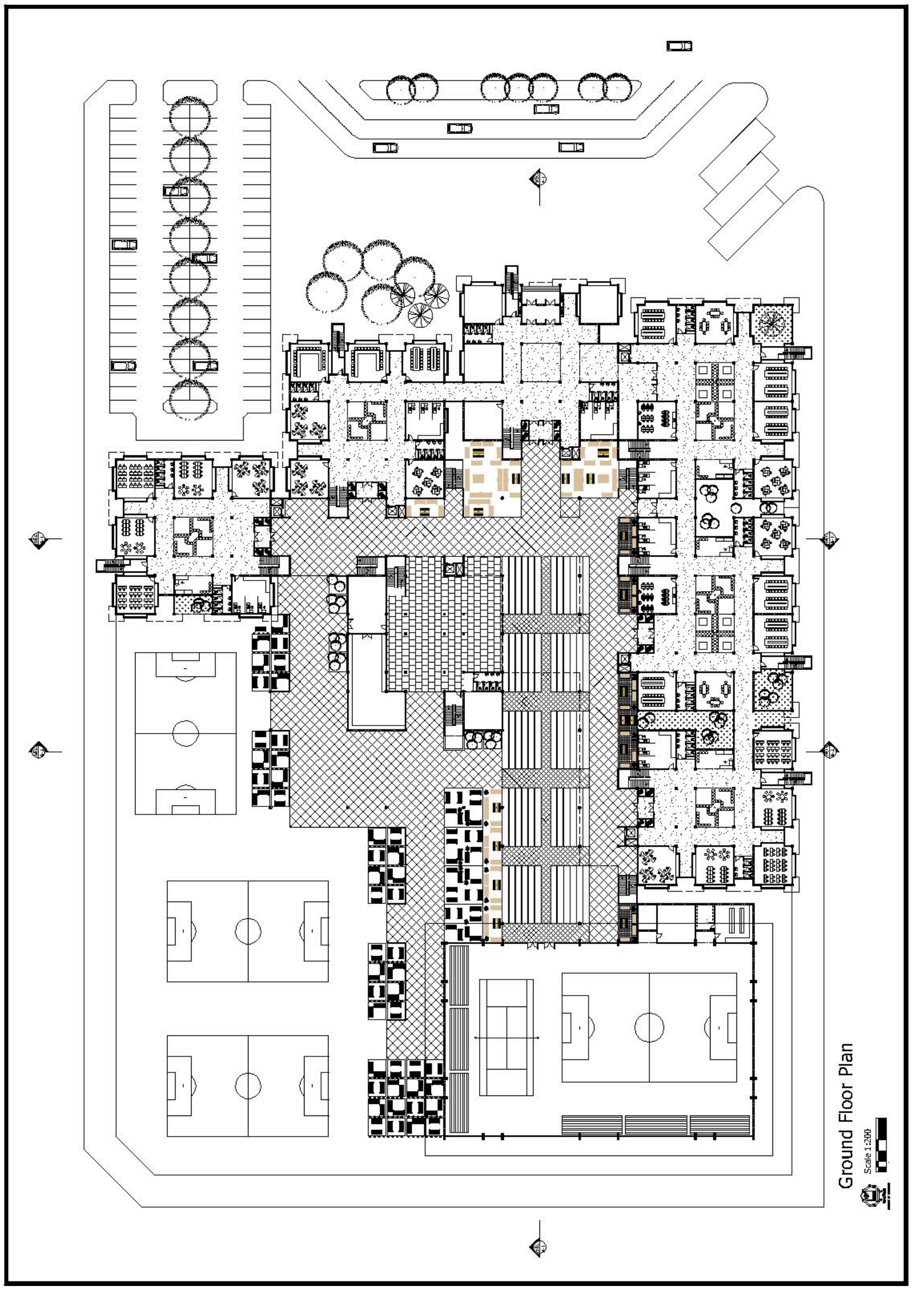

*Testing Site
Site Plan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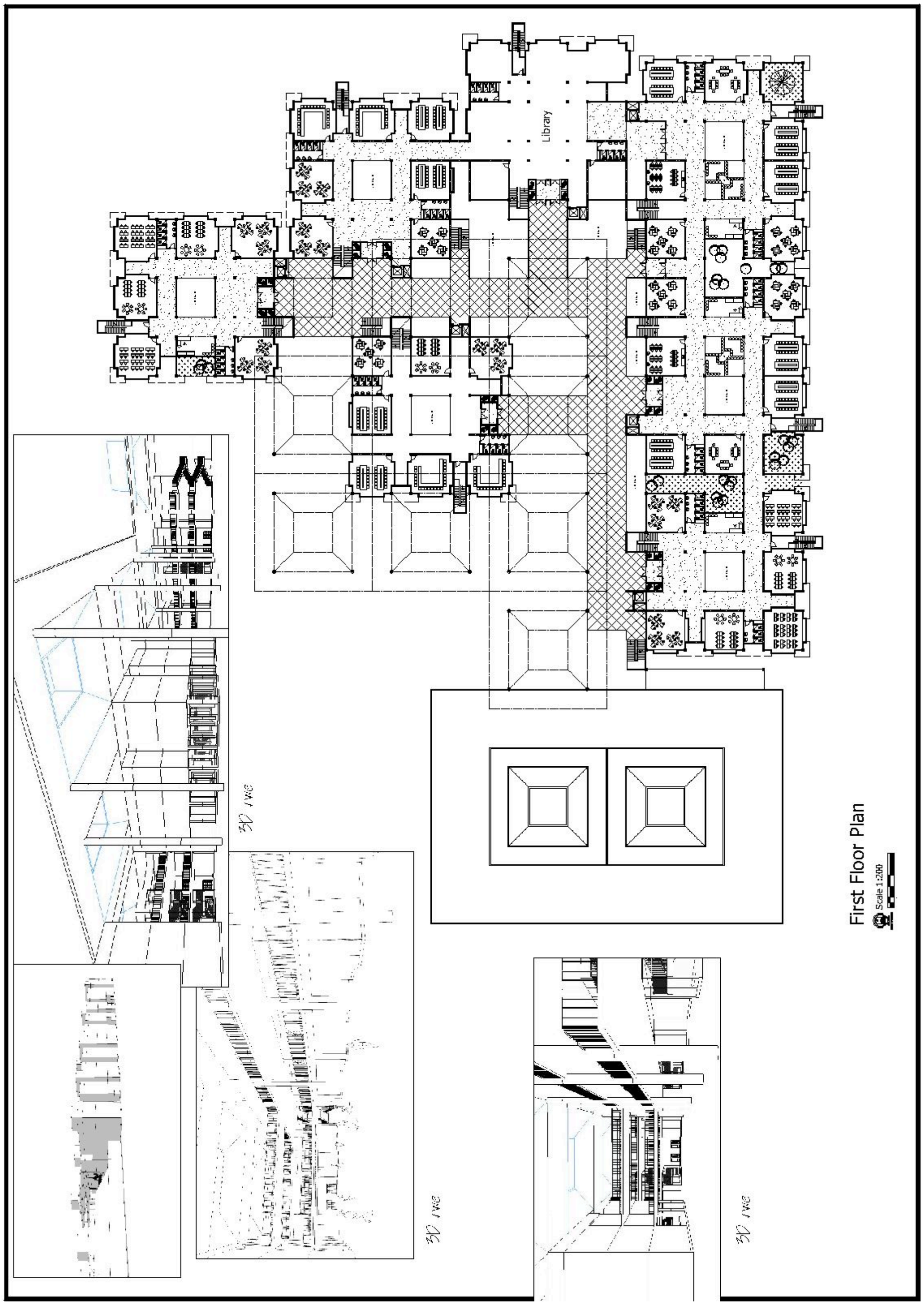
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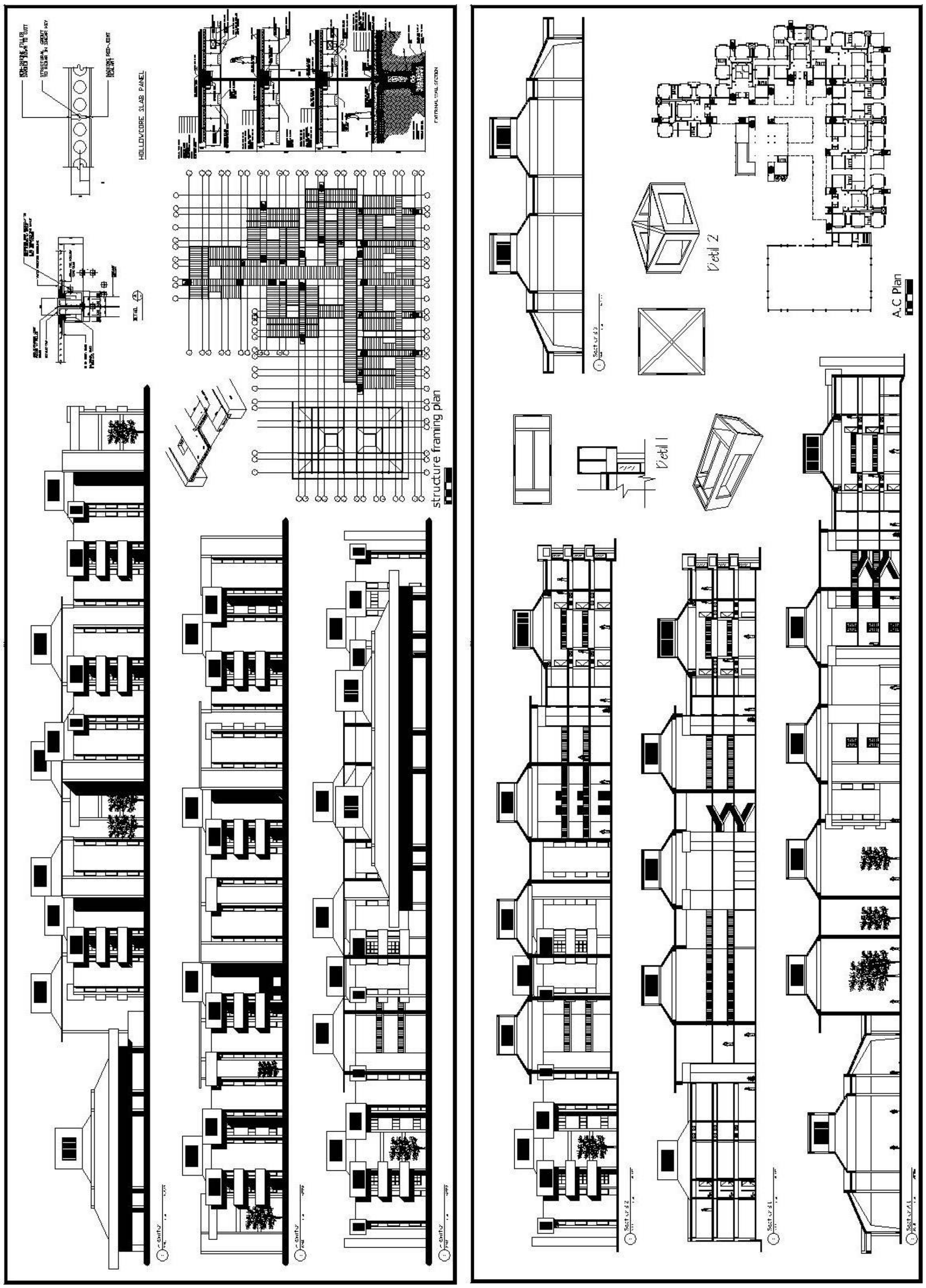
HOLLOWCORE SLAB PANEL
structure framing plan
Detl 2
A.C Plan