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Adam Kozel

Poděkování

Děkuji za skvělou spolupráci a vedení této diplomové práce panu Ing. Radanu Tomkovi MSc. a také panu prof. Mohammad Arif z University of Salford, který mi ukázal nové možnosti ve stavebnictví.

Utilization of new off-site trends and manufacturing techniques in construction projects

Abstrakt

Stavebnictví v České republice je již po dlouhou dobu za rovnocennými ekonomikami z hlediska industrializace a zavedení manufakturních technik, jako je Lean a Off-site. Po celém světě došlo k nárůstu využití manufakturních technik ve stavebnictví. Nedávné zvýšení zájmu po výstavbě Lean a Off-site je zčásti zapříčiněno zvýšenou poptávkou po stavebních projektech a větší poptávkou klienta po certifikátech kvality, které zvyšují prestiž a hodnotu budovy. Toto vede zejména ke zvýšení efektivity, kvality a bezpečnosti výstavby. Poptávka velkých developerů po zlepšení kvality výstavby, řízení životního cyklu budovy a prefabrikovaných konstrukcích bude v budoucnu jistě narůstat.

Tato práce představuje výzkum manufakturních nástrojů a technik a jejich využití ve stavebnictví v závislosti na kritériích úspěšnosti. Výzkum hledá odpovědi na vhodnost zavedení těchto postupů a jejich dopad na náklady, čas a kvalitu výstavbového procesu. Toto také ukazuje současný trend, který nahrazuje nebo doplňuje klasické stavební postupy manufakturními stavebními metodami.

Klíčová slova

Manufakturní metody, kritéria úspěšnosti, modulové stavby, metoda Off-site, metoda Lean, systém pásové výroby, řízení kvality.

Abstract

Construction industry in the Czech Republic has been for a long time behind equivalent economies in term of industrialization and implementation of manufacturing techniques such as Lean and off-site construction. All over the world there has been an increase in utilization of manufacturing techniques in construction industry. Recent increase in interest for Lean and off-site construction is partly attributed to the raised demand for construction projects and the client's pressure for building certificates which increase their prestige and value. It improves the performance particularly in efficiency, quality, value and safety of its construction. Major developers' demand for improved quality, life cycle management and more prefabrication surely increase in the future.

This paper presents a research on the topic of manufacturing tools and techniques and their utilization in construction industry based on the success criteria evaluation. My research seeks for answers on convenience of implementation of these techniques and the impact on time, cost and quality of the construction process. It also depicts the current trend of replacement and/or complement of traditional construction with manufactured construction methods.

Key words

Manufacturing techniques, project success criteria, modular buildings, off-site construction, lean approach, conveyor belt system, quality management.

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1. Introduction

This paper investigates the possibilities of new methodologies and philosophies utilized in the construction industry. It provides a scale of options for the different sectors in construction industry. Because of the fragmented nature of current construction industry, it is not practical to assess every part of the industry. This study aims to provide a survey of current construction and its possibility to implement Lean and off-site construction within the construction process.

Although plenty new inventions and innovations constantly emerge in technical industries all over the world, this paper focuses on connections among these branches and utilizes authenticated methods from manufacturing industry into a construction industry. Even though manufacturing has developed many of these new procedures years ago, construction did not tend to implement these authenticated methods until now. The interest of the construction industry in modern methods such as Lean and off-site construction has been recently increasing.

Manufacturing industry differs a lot against construction industry, but it is definitely very beneficial to apply some of its techniques, approaches and methodologies into construction. Some of manufacturing techniques have been already utilized in modern construction, however current clients are still strongly influenced by negative perceptions of post-war ‘pre-fab’ and they mostly resist such innovations in building construction. However, our paper aims to prove that these modern manufacturing techniques and methodologies significantly improve the efficiency of traditional construction. Manufacturing techniques and approaches bring higher certainty into a project regarding to its risk management, shortening the total time, cost and quality resulting with the overall client’s satisfaction.

The increase of recent interest for lean and off-site construction is partly attributed to the increased client’s demand for both, residential and non-residential construction and for building certificates that raise project’s prestige. These techniques improve the performance particularly in efficiency, quality, value and safety.

2. Hypotheses

Hypothesis No. 1

Off-site techniques and lean approach can replace traditional construction procedures. With these approaches a project will be built in a shorter time with smaller budget than traditional building procedures.

Hypothesis No. 2

It is convenient to use off-site technique by residential buildings, where a benefit is in utilizing repeated type of units. However, off-site techniques can be utilized also in non-residential buildings.

Hypothesis No. 3

The idea behind off-site technique and lean approach is to collaborate with contractor during the pre-construction and construction phase. This collaboration results in higher productivity and quality of the project.

3. Actual situation of building projects

The construction industry is plagued with a number of different definitions for describing what is arguably the development of a product such as a new building or the refurbishment of an existing one (Ferry & Brandon, 1999). Traditionally, design and construction process is one presented in terms of its main participants. Indeed, many descriptions of the process rely more upon presenting the roles and responsibilities of the parties involved, rather than the stages through which the process must pass (see RIBA Plan of Work). For example in the past the project process was described in terms of the procurement system or approach employed (i.e. design and build, Design-built-own-operate, design and construction, etc.), the contractual arrangements or in many cases the process was and in some cases is confused with project management activities (Gantt charts rather than project process). As a result the process of the project was firmly 'fixed' from the beginning of a project with 'fixed' rules (Ferry & Brandon, 1999). The construction process is nowadays firmly fixed in boarders with technological improvements however no philosophical improvements. Although in manufacturing processes have been changed the whole philosophy, construction industry is old fashion with boredom and lack of developing enthusiasm.

The construction industry as a whole is dominated by small and medium-sized enterprises (SMEs), with small and micro businesses accounting for approximately 90 per cent of the sector. Large construction companies are typically major contractors on large-scale building and infrastructure projects, with a lot of smaller companies working as a sub-contractors. Larger companies, although constituting a very small proportion of enterprises operating in the sector, conduct a disproportionate share of the work by value. (UK commision for employment and skills, 2013). Construction is a tough environment with a lot of fights about cost and responsibilities. This kind of environment cannot bring an added value into a project. The stronger will win, the weaker will lose and no one brings an effort into a better project. It is the proportion of construction environment which makes the fights. From the basic nature construction must be tough environment, however the fight should be in a strict boarders which must not be inviolable.

Typically, the construction process is described as one, in which a client says to an architect/engineer to facilitate the project process. The architect/engineer obtains a set of requirements, where are set out the main performance attributes of the construction facility. Following this, other consultants (specialist designers, engineers and cost consultants) work with the architect/engineer as a design team to develop a design, which will meet the client's requirements. The design is developed through several stages, including concept, feasibility, drawings and detailed design. Documents relating to the technical specification of the design are cost and construction duration. These documents are produced in each stage of the design process.

The Royal Institute of British Architects Plan of Work was originally published in 1964 as a standard method of operation for design team work and has become widely accepted as an operational model throughout the building industry. The Plan of Work offers a procedure suitable for traditional procurement methods, the stages and sequences of which are defined in table 1.

Stage A	Inception	Stage G	Bills of Quantities
Stage B	Feasibility	Stage H	Tender Action
Stage C	Outline proposal	Stage I	Project Planning
Stage D	Scheme design	Stage J	Operations on site
Stage E	Detail Design Stage	Stage K	Completion
Stage F	Product Information	Stage L	Feedback

Table 1 - RIBA Plan of Work

Source: (University of Salford, 2013)

As it is seen on the table 1, construction preparation phase is very important part of the whole process. 9 out of 12 stages take place in pre-construction phase. This is basic reality that shows, how important a planning in construction is. These 9 stages in pre-construction phase cover all the risk management, implemented techniques and procedures. Even though pre-construction

phase has 9 stages and there is a lot of communication between client and designer, the contractor comes when the whole project is on the papers in stage J and he cannot put his ideas and experiences to the certain project. It means that the contractor is not a benefit for the project, only a worker and this attitude miss the added value in the project. RIBA plan of work simply shows, how important the pre-construction phase is. In this phase is established the whole project with all details. It shows the design and cost, on the other hand in this phase is established the profitability of the project. Asset managers will determine the final client, the price for square meter for either selling or renting. This is the most important part where is created the whole project.

During the pre-construction and construction phase there usually occur some problems which are specific for construction:

1. Procedures according building-permissions
2. Construction time, cost and quality

Although procedures according building-permissions can be very long and can slow down or even stop the project, it is more legal problem than construction. However construction success criteria time, cost and quality are very easily streamlined. In this area are shortage of ideas and new approaches which should utilized. There are many ideas among the universities and professional groups all over the world, however it is much more difficult to utilize these ideas into construction procedures.

Technical engineering such as mechanical and electric engineering are going forward in an enormous speed. For instance, car industry, air-space industry, ships and submarine, electrical engineering or computer engineering. Companies put huge amount of money into a new researches and new procedures, however construction stays in its own way. Have a look at car industry and see how quickly they make cars with machines and process flow. And compare this attitude and put it into construction industry. Where are the changes between before and now? Even with a new technologies and material, 100 years ago they were able to build a house in 2 years and nowadays I am convinced, that they would build the same house in the same time. How is this possible?

3.1 The quality of current collaborative work

A typical construction project is a collaborative venture that involves a number of different organizations brought together to form ‘‘the construction project team’’. This team is responsible for the design and construction of the project (Baiden, et al., 2006). Consequently, the construction industry is organized around specific trades and functions, with the project team members being selected on the basis of the technical and financial soundness of design and the competitiveness of the tender sum (Baiden, et al., 2006). Selection processes have focused on individual professional capability rather than their collective ability to integrate and work together effectively to accomplish certain project.

Construction firms are operating in dynamic environment and there are evolving process in both external competition and internal environment. The companies has to repeatedly adapt and remain profitability in changing condition. Customers require organization’s change and have the demand for performance, growth and value for money. And construction industry should also improve its performance by modeling processes (Cooper, et al., 2005). There are significant advantages in IDEF0 and UML diagrams. An activity flowchart easily spot problems, where can be seen disconnections between individuals and departments and it can help to identify quality issues and calculate quality cost (Madison, 2005). IDEFO and UML diagrams help in providing service for client, however it has not been highly integrated, because this procedures require time and money and supervisors who welcome every change. Construction industry is a very unique industry because of the huge size of each project. It is an environment, where mistakes are very expansive and supervisors cannot make mistakes. They follow the previous procedures without any positive or negative change.

The construction team is often consideration as an architect/engineer or design team, client, and contractor. The design team is comprised of architects, engineers and consultants that produce the drawings and construction documents for the client. The client provides the project requirements and funding for design and construction. The general contractor typically builds a unique project in a very competitive environment. Other participants are sub-contractors, suppliers, governmental regulators etc. These team members share the common goals of a

project, however because of conflicting and competing interest, a project may suffer from a lack of teamwork. These conflicts of interest are due to the fragmented nature of the industry, having new team members for each project, and the different perspectives and priorities that manifest to some degree on all projects. The construction process is a very competitive environment for all parts of the team such as owner, design team, and contractor. The owner desires the best value and highest quality for their money. The design team strives to achieve this for the owner and is under the constraints to operate a successful business. Finally the contractor works in a very competitive environment where profit margins are low and risk is high. The competitive nature of these participants may cause a breakdown of the teamwork which is crucial to the project success.

The construction industry is so long described as a fragmented. Fragmentation happens when the number of small firms increases while their average size decreases. Also fragmentation has a negative impact on the construction industry. This fragmentation leads to unclear role of learning in construction organizations. This is because fragmentation reduces mutual knowledge of capturing and sharing, inhibits knowledge production, limits learning and innovative solutions. It occurs due to the industry's unique characteristics and due to other reasons, which are client dependency, location dependency and weather influenced activities (Alashwal, et al., 2011). As a critical barrier to change, fragmentation inhibits information and knowledge that lead to the low level of productivity. Fragmentation makes:

1. Eliminates learning and innovative solutions
2. Hampers the useful experience and know-how, which might be used sufficiently during the planning process
3. Lowers the intention to invest in innovation, inhibits the mutual sharing of information and knowledge
4. Causes numerous contracts and leads into unclear liability

This makes information more complex and more difficult to achieve (Alashwal, et al., 2011). During the preparing and planning phase, it is important to create a bespoke construction-process which reduce time and cost and increase quality.

3.2 Current problems in construction

It has been recognized, that construction is not always able to manage commercialization of the technologies and innovations developed by researchers in an effective way. In the Construction Industrial Strategy is apparently a 'low levels of innovation' and notes that "investment in intangible assets such as new processes (particularly in the contracting sub-sector) is low due to uncertain demand for new goods and limited collaboration" (UK commision for employment and skills, 2013). It notes other obstacles for realizing the sector's potential growth and modernization. According to UK commission for employment and skills (2013), there are 2 main general obstacles in construction industry:

- **Skills:** In construction there is a significant low training among self-employed and skills shortages among trade and professional occupations which might inhibit in technology deployment and low innovation.
- **High degree of fragmentation:** It is very common in construction that too much competitiveness leads into huge fragmentation. Other sectors grow on levels of collaboration, innovation and ability to access foreign markets.

In construction there is a very strong advance theory research on techniques and procedures, however relatively little direct connection between this research and practical industry. For instance, the Computer Aided Design (CAD) technology has improved the efficiency of drawing, it cannot reduce design errors and these can cause the need for rework. This construction reworks make the construction process difficult for construction managers. With these rework the construction manager cannot optimize the process so he cannot reduce the cost (Aziz & Hafez, 2013). This is a typical 2 side's problem where industry must see a business benefit to such collaboration and academia must be willing to share research and work in partnership on particular projects.

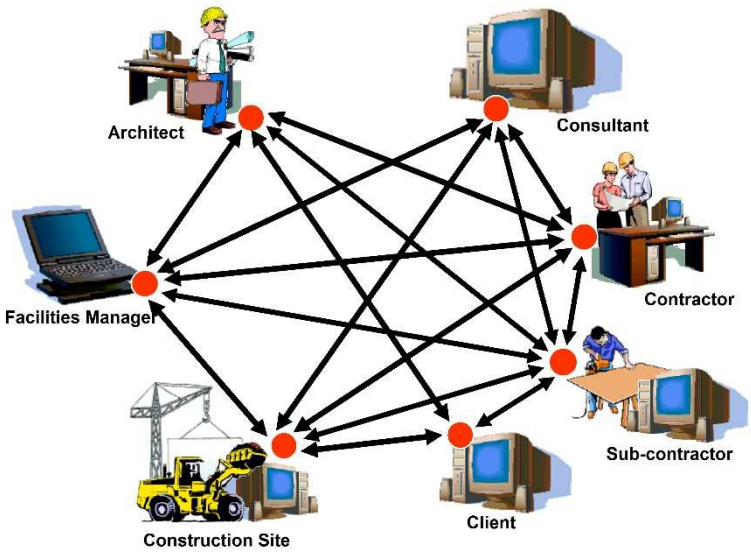

Figure 1 - fragmentation of construction

Source: (Arayici & Coates, 2012)

Government investment should also play a role in this collaboration. In the past, pre-fabrication has been a poor quality which resulted in some cases in building collapses. Quality of current projects has improved dramatically and is now considered to be following guaranteed norms of critical Government policies. The Construction Law is now supervising the entire construction system. Charges of higher prices in construction result in a better management and leading to fewer issues which are related to quality (Chartered Institute of Building, 2013). It is important to know what is a 'situational awareness', such as a clearer understanding of other job roles in a process and the overall project. It also includes the awareness of behaviors such as risk register, communication and inter-disciplinary education. These are identified as priority needs for the site supervisor/project manager.

4. Success criteria

Construction projects are frequently complicated with circumstances in which decision-makers need to choose the possible alternatives and decide an optimal solution, which represents a compromise among various objectives that are often conflicting (Monghasemi, et al., 2015). The idea of project success is to get a best value for money. The aims for successful project criteria are to fulfil key objectives and client's requirements (Office of Government Commerce, 2007), any constraints identified such as budget, funding mechanism or performance, client's experience and qualification, the length of operational service required from the facility (British Standars Institution, 2011) and risk allocations (British Standards, 2006). Project success is not just "iron triangle" which describes connections among time, cost and quality. There are also many other criteria which became more important such as environmental impact, work environment or innovation (Masterman, 2006). This all together is a project success which is reflected in an iron triangle. However it is very difficult to evaluate any criterion on certain percentage. In a bidding phase of a construction project, it is quite late to choose certain contractor. The contractor should be called in pre-construction phase based on criteria such as previous success, collaboration, references from other projects and others, so he should collaborate with the project manager on a design and evaluate certain procedures based on value for money.

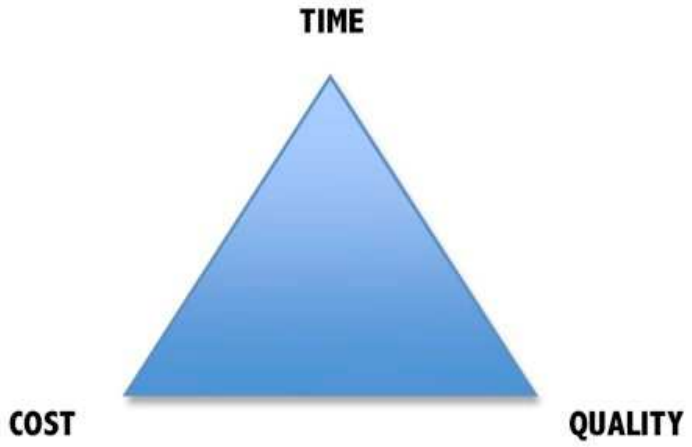

Figure 2 - Time, cost, quality triangle

Source: http://www.the-self-build-guide.co.uk/time-cost-quality-triangle.html

Client plays the crucial role in a success of certain project. Client will set out an initial team responsible for his interest, which is taken into account during the whole project from inception of design, during the construction process until the project end. It includes people who understand relevant business issues and construction implications (Carmichael, 2002). The success criteria can be achieved only if there are met numbers of success factors. From the inception, a project brief must be agreed with client, it must be well defined with good planning and scheduling methods. Also time controls and feedback system is crucial for the time certainty of the project. In the inception of a project there must be settled rigorous variation controls, tight financial control and comprehensive quality control. Finally, there must be competent design, project management and motivated and well integrated team.

Project success can be described by many factors, however the most certain description of project success are in basic three values. These three variables are time, cost and quality. Clients has to answer three basic question: “How long will the project take? How much do I have to pay for the project? Will be the customer satisfied with the quality of the project?”

4.1 Time

In every construction projects, one of the primary challenge is scheduling its execution. Project scheduling problems are therefore a critical part of a project’s overall success, especially in terms of managing organizational resources (Monghasemi, et al., 2015). In today's highly competitive society, time with its connected cost have become a precious values. It is permeating every facet of the businesses, from research and development through marketing to distribution. Time is a more useful and universal item than cost or quality. For example, it can be used to drive improvements. Moreover, time cannot be stored, borrowed, purchased, traded, or changed (Shingo, 1988). Time is vitally important for both a building and each participant in the construction process, including lender, owner, architect / engineer, contractor and subcontractor, as well as those, who provide bonding and insurance coverage.

Construction management suffers many problems and the majority are practical, which need to be solved or better understood. As a result, the construction industry is overwhelmed by delay and often has suffered cost and time overrun (Aziz & Hafez, 2013). Avoidance and mitigation of extended time and cost overruns are based on an effective management. It is necessary for participant in construction to have a basic understanding of:

- Critical path scheduling techniques, the associated specification and the software involved
- Delay and how it occurs
- The pros and cons of various schedule and delay methodologies which are used by project participants and experts
  (Driscoll, 2013)

These four bullet-points show where might be the biggest lacks in time management and time usage. It is very important to schedule the project properly with possible risks and do not make delays. Delays bring pour quality or it cost a lot of money.

4.2 Cost

In situations where the formula 'cost + profit = price' attention usually moves away from improvements (Shingo, 1988). However, this formula is no longer applicable in today's competitive environment. Price has become market controlled and profit is affected by the final cost determined with production. It is important for design professionals and construction managers to realize, that while the construction cost may be the single largest component of the capital cost, other cost components are not insignificant. For example, land acquisition cost are a major expenditure for building construction in high-density urban areas, and construction financing costs can reach the same order of magnitude as the construction cost in large projects, such as the construction of nuclear power plants.

The cost for the client include both the initial cost and the subsequent operational cost with maintenance cost. All these groups consist of many items such as land acquisition, studies,

planning and construction. On the other hand cost also include operating staff, labor and material for maintenance, periodic renovations, financing cost and many others (Project Management Institute, 2013). Therefore the initial and subsequent cost are very important. For a client, cost make either profit or loss. The first calculation of cost decide, if the project will start or not. The cost will decide the profitability of the project and that is why client builds projects, he wants to make a profit. If the cost are too high compared to the price, the client will stop the project in inception.

4.3 Quality

Quality as a competitive variable has many different interpretations. From an internal point of view, the most practical and straightforward visible way of testing quality in production systems is the low variability of processes. In this line, the achievement of quality in production systems could be obtained through a continuous effort for process improvements. The manufacturing process aims at the reduction of variability (Shingo, 1988). Quality then becomes the fitness for purpose or the capacity to consistently meet or exceed the customer needs and expectations. Quality is not standard. Standard is a rule which has to be achieved. Quality is a customer's satisfaction. Why people say that something is a high quality. There are two answers: 1) It looks expansive, 2) People like it, because they cannot see any imperfections.

One of the shortcomings of internally oriented definitions of quality is the assumption that production is working on specifications that match what the customer wants. However, this assumption may not be correct. Therefore, quality has to begin with an external process that identifies the customer's needs and expectations (Shingo, 1988). In any project, the quality is a moving target. The standards of outcome will vary in accordance to many factors.

The dissatisfaction become apparent where a gap between the understanding of what the client expects to get and what the contractor delivers. When the gap between these two appearances

is large enough, it might lead into claims and disputes and eventual litigation. Once this path is entered, no one involved will benefit, regardless of the conclusion.

5. Analysis of manufacturing techniques

In construction become apparent a new technologies and approaches how to improve construction processes. People still talk about moving construction industry from craft-based to manufacturing industry. According to Lanigan (1992), the manufacturing is the application of technology to wealth creation by providing cost-effective solutions to human needs and problems. Manufacturing is becoming a great solution for some project and it can improve the time, cost and quality of a project. However in construction there is a huge variety of projects with different kind of need.

Figure 3 - Off-site manufacturing process

Source: https://sturgischarterschool.wordpress.com/category/off-site-construction/feed/

There are 2 approaches to evolution of craft-based industry to manufacturing industry. The first one is standardization of building. The second approach is to make the production process as flexible as possible. It allows a large variety of building with a small number of components (Crowley, 1998). Within the project structure, customer satisfaction is achieved by ensuring that drawings and specifications are communicated to the rest of the parties. The parties are

affected by the changes and then they can promptly adjust their information and help to reduce the amount of time wasted (Pheng & Teo, 2004). The pre-cast and pre-fabricated components increased the construction speed. It is much faster and it does not require too many labors for construction. It also provides flexibility in the design. This is the branch where construction will move on in the future. It is higher flexibility with less time spend on site and higher quality based on repetitive work.

Some suppliers believe that in construction is a lack of understanding for the full benefits which off-site construction might bring. Problem is that a general understanding of off-site just means volumetric modular boxes, usually grey, like from communistic ages. Many customers in the industry routinely use products and methods such as precast concrete without appreciating that this is a form of offsite (Goodier & Gibb, 2005). Many construction companies have already been using off-site techniques, or parts of it. It is common because utilization of off-site technique in construction is very beneficial and with design and build procurement contractors usually use part of off-site techniques such as prefabricated elements in construction.

In general terms, the earlier a decision is taken in the business process the higher its potential impact on competitive variables, such as cost and time. This is illustrated in Figure 1. The client's satisfaction has to be review at the briefing stage to determine the exact efforts during the project production completion. It reinforces the need that the impacts of the decisions in the production is in relation to the whole business process. It also relates to the competitiveness of the organizations. The earlier decision is made, the cheaper the consequences are.

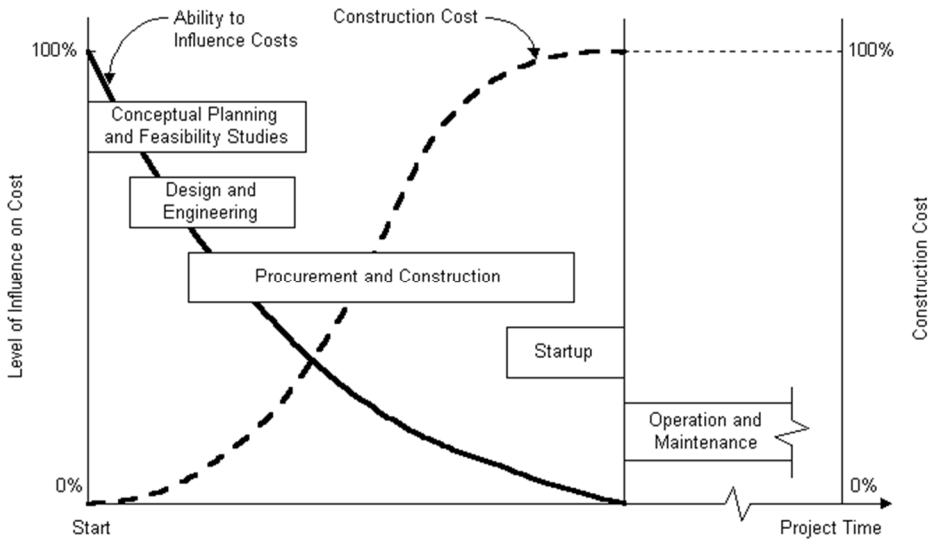

Figure 4 - Cost/time reduction potential vs. cost/time of making changes

Source: (Akinci, et al., 1998)

Processes have not always been recognized because they are covered by the traditional departmental organizational structure. The construction process should be driven as a perspective manufactured industry. It benefits from reorganizing the main value-adding processes, increasing the focus of decisions and promoting positive interactions among the various organizational functions which become more evident. The functions of project production has an important role in construction context. The production philosophy says, that the product is repeatedly created. In a manufacturing processes is a focus on value of many. Profit is a small with a single item, however is a quite huge with many of the same items. That is the idea of implementing manufacturing procedures in construction. The cost and time saving should be based on repetitive work and collaboration with suppliers.

The Construction Industry Board's (CIB) "Code of Practice for Clients of the Construction Industry" is one such manifestation driving such change (Construction Industry Board, 2015). The CIB's model presents the process as a sequence of activities with identified milestone targets. These include:

• Get started

• Define the project

• Assemble team

• Design & Construction

• Complete & Evaluate

The interesting development within this model is the presentation of the process participants as teams. The model still maintains boarders between the roles of the designers and contractors. The presentation of the model as a process 'map' and process flow begins to open up the process to debate. This offers a flexibility of traditional system by limited range of procurement options which are available for clients. It creates opportunity for collaboration and a new philosophy of construction. It is not a single man act, it is a collaboration of teams which have the same aim, to finish the project in certain time, cost and quality. The project is a big collaboration which leads into client's satisfaction and the client will evaluate the contractor's and subcontractor's effort.

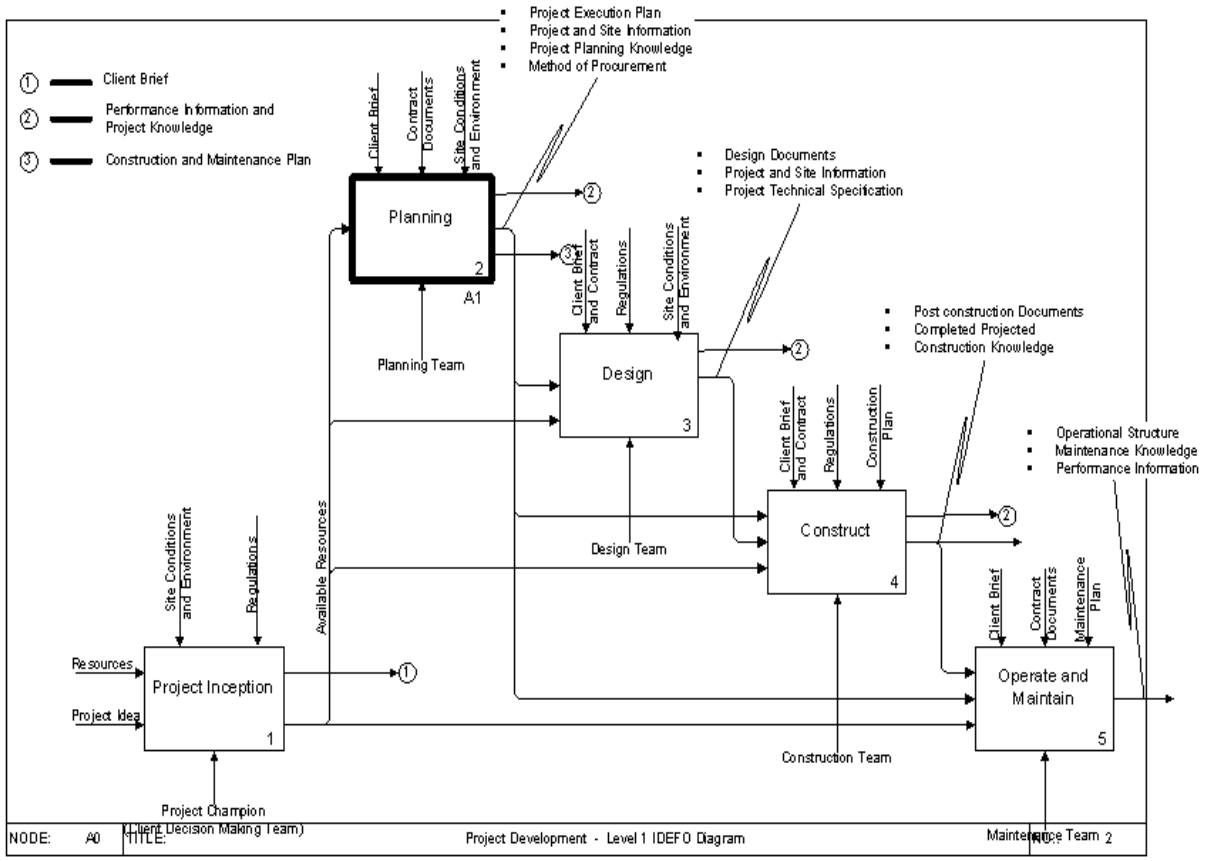

Figure 5 - Process planning

Source: (University of Salford, 2013)

The CIB model also presents whole-life view of the construction process. Most common definitions of the process end with completion of the construction process. This is followed only by the operational and maintenance procedures. A fundamental development within the CIB model is the “evaluate and feedback” activity. Both end-project and in-project evaluations are promoted by the CIB Code of Practice. And both are very important for operational phase of the project and also for other projects as a studying material from previous mistakes.

According to general knowledge about manufacturing techniques, there is a significant increase of these techniques in the word. Modular technologies grow in popularity.

5.1 Challenges

In this chapter are shown the main claims about utilizing manufacturing tools and techniques in construction industry and arguments against them. It is important to see the dependencies of these two industries.

Claims	Argument against the claim
The construction industry produces one off products	True, but there always is the first car or the first plane (car)
Manufacturing deals with mass production	Yes, but not all the time. In fact the trend moves towards small scale customized production
In construction temporary organizations are set up to undertake project and then the teams are dismantled	That is true in terms of supply chain involved in the manufacturing industry, which in fact involves a large number of products and suppliers
Because teams are dismantled after the end of a project it is very hard to have any cross project learning	The main problem is that the industry is based on adversarial practices that restrict passing of information freely
Because the construction industry’s products are one-offs, manufacturing methods cannot be applied	Although the product are different, the processes and philosophies are applicable

Manufacturing production processes are different and therefore not applicable	Yes they are different but they are usually designed under improved production philosophies which are applicable to construction
The construction industry is identical to the manufacturing industry	No it is not: - The products produced are different and the technology used in terms of production equipment is quite different - The final, constructed product in construction cannot be tested and rectified as easily as in manufacturing - Production work in construction is under additional constraints than manufacturing, e.g. weather, space, land, special fixity, access routes, on-site production etc.

Table 2 – Traditional construction vs. Manufacturing

Source: (University of Salford, 2013)

5.2 Off-site

Off-site construction methods have been traced back as far as the practices of Roman military engineers. Off-site has a very strong potential to facilitate the mainstream of a modern construction, especially the advantages connected with low carbon and energy efficient buildings. It integrates timber or light steel frames and thin joint blocks into the build process. Realizing these types of structure is of course heavily dependent on appropriate skills and knowledge of workforce at all levels in the construction process, off-site and also on-site (UK commision for employment and skills, 2013). Off-site philosophy is a typical PUSH system. Push system offers customer several options what the customer wants. Then the customer has a feeling that he decided what he wanted. On the other hand with this variability, the main building procedures and techniques are similar. With repetitive work and design the contractor can lower the cost based on a collaboration among the suppliers.

The biggest advantage of offsite against traditional construction is the decrease of construction time on site. This factor is of particular benefit to contractors and also for client. There is also significant increase of quality with an indoor assembling. A more consistent product and reduction of defects are also huge advantages (Goodier & Gibb, 2005). However, current clients are so strongly influenced by negative perceptions of post-war 'pre-fab' that they resist any innovations in house construction. It affect what a 'traditional' house looks like (Goodier & Gibb, 2005). With off-site technique can be build different types of building, where it is impossible to the differences between traditional and off-site construction. It is a typical approach for the centers of build-up towns and cities, where there is not sufficient space for annexation or where the annexation cost a lot of money. Off-site can be divided into several types or sections which are shown in figure 3.

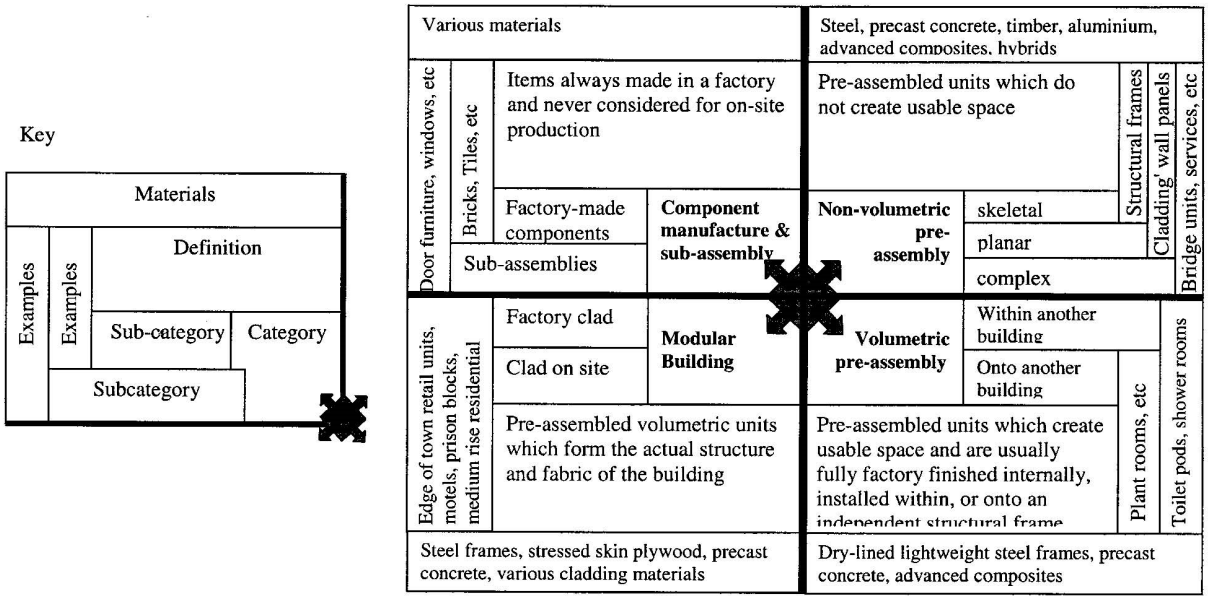

Figure 6 - Types of Off-site Construction, Gibb and Isack (2003)

Source: (University of Salford, 2013)

Off-site construction can be divided into 4 sections. These sections are component manufacture and sub-assembly, modular building, non-volumetric pre-assembly and volumetric pre-assembly. All these 4 sections vary only in the size of the building and the percentage of usage off-site construction which is seen in the end of off-site phase before the sections move on site.

The belief that using off-site is more expensive than traditional construction is the main barrier to the increased use of off-site construction all over the word. Even though a large amount of people think, that advantages of off-site construction are both a reduction of initial cost and a reduction of whole life cost. However, suppliers often argue, that off-site is not more expensive as costs are not comparable in the right manner. Advantages such as reduction of time on site and economies of scale are very important. This issue is also addressed on the IMMPREST (Interactive Method for Measuring PRE-assembly and STandardisation benefit in construction) tool developed by Loughborough University. This tool seeks to provide a framework for comparing solutions in a complex manner. Other advantages such as enhancement of quality and reduction of breaks are rarely included in costings and many projects are still judged purely on first or initial cost (Goodier & Gibb, 2005). Off-site has the biggest connection with manufacturing processes, especially with production theories. However off-site has a huge barrier that people think, that they cannot choose the design and that the houses will be identical and also low-cost. It is the same with cars, everyone can choose their type with specifications and the price.

Off-site construction can be used on different types of buildings which vary based on their purpose such as residential, educational, health care or commercial. The amount of modular units depends on the size and architecture of the building and can vary from a few units to several hundreds of units.

5.2.1 Conveyor belt system

It is a metaphor that links the construction to a conveyor belt. Each unit in factory is in a flow and all the procedures are made inside of the factory. It is a flow where is a repeated work and the work is much faster because of the stable conditions such as temperature, wind, no snow, no rain, humidity, no sunshine, no very low degrees, no very high degrees. The process is being made during the whole year without breaks. These conditions are very helpful also for a longer life of the material. Conveyor belt process also helps in health and safety, where the threats are known and the labors work in the same environment all the time.

Another problem is solved with resources. With conveyor belt process it is possible to make a supplies on a one place in advance and then move it on site. Construction do not have to wait for a material, however material is ready to use and a project flow is much faster. But there are huge requirement for a storage of the prepared units.

A conveyor belt type production of off-site construction is seen in figure 4. It is a Servaccomm company's factory in a city Hull on the west site of north England. There are only two factories for this type of social housing in northern hemisphere.

Figure 7 - Servaccomm off-site construction factory in a city Hull, UK

5.2.2 Details required

Actual production and construction can be undertaken when there is established the proper supply chain interfaces and the key responsibilities for executing the detailed design. The prefabricated components must be introduced as a bespoke rather than repeated. As a bespoke

design, it may be necessary to develop prototype or trial constructions in the initial phases of construction phase to ensure “fit” on site. This developmental stage needs sufficient time programmed to allow modifications to the design and any tooling (Stirling, 2003). The systematic approach optimizes the combination of a predefined and engineered building system and the appropriate use of factory-made off-site solutions. This approach can be applied to whole buildings or to elements within a building. This method has sometimes been accused of producing boring, pedestrian architecture, but excellent design can produce excellent results (Loughborough University, 2014). Off-site construction requires detailed and appropriate design, thinking and programming of logistics to site to ensure correct timetabling and sequences on site. Off-site has its own disadvantages which have to be planned into details to ensure smooth flow of all construction processes and procedures.

In particular, there is a need for detailed plan of the route to site. The framed panels and volumetric components has to be planned into details where they will be required and transported. There is a need for sufficient width and turning circle along the route to allow the access of proposed vehicular. Particular attention should be paid to location and site access to ensure that it is possible to enter the site and that there is sufficient space to off-load and transfer components to the point of use. Where components are to be stored on site, there is a need for sufficient space to provide and allow both storage and subsequent maneuvering (Stirling, 2003). The process of off-site manufacture has been described as an automotive manufacturing process. The comparison is that the finished product in off-site is most often signed off before a manufacture begins and that the manufacture itself is a repetitive ‘conveyor belt’ type process. Within traditional construction it is not common to commit to the solution so early in the process. There is usually some flexibility and this is valued by architects, builders and end users/purchasers alike (UK commision for employment and skills, 2013). With off-site construction there is a need for change-order of certain practices to ensure, that the result will be perfect. Pre-construction procedures are currently very fast. Current construction is not open for a good pre-construction planning, most of the plans are made during the process. In off-site construction there is a massive increase of pre-construction time required, however the total time of construction work is decreasing. Even though this decrease of total time is confirmed by several researches, it would be very difficult to implement this thinking into the client’s mind that he will be for this option. The client puts a lot of money into something, which is tested only in a number of years, not decades or hundred s of years.

5.2.3 Level of sills required

In current construction there is a perception that there is a requirement for lower level of skilled laborers on sites in off-site construction techniques. In some respects, this may be true. However, although there may be a reduction of requirements for large numbers of tradesmen (joiners, bricklayers, plumbers, painters and others), there is a need for skilled assembly and finishing trades. Prefabricated components need to be handled and fitted carefully on site; joints and connections between components need particular attention to ensure accurate fit on site (Stirling, 2003). There is a need for absolutely exact measurements that will fit on site and do not require another works on site.

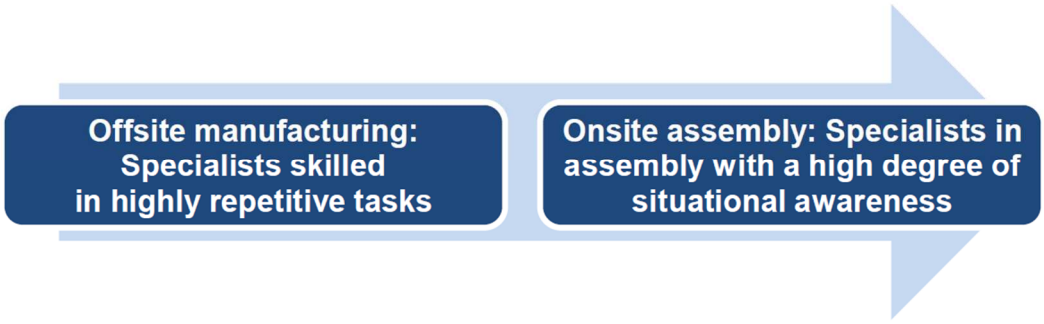

Figure 8 - Core skills differences between off-site manufacturing and on-site assembly

Source: (Vokes & Brennan, 2013)

The Steel Construction Institute carried out in-depth studies of several construction projects involving various degrees of pre-fabricated steel construction in urban locations. The study identified the pros of modern methods of construction with particular regard to the disruption caused to local residents from dust, noise and commercial vehicle movements and the environmental impact of site-generated waste (Taylor, 2014).

With off-site there are many favorable attributes such as:

- Reduction in waste material
- Shorter building times
- Controlled building environment
- Made to order
- Less noise, dust and local disruption

- Fewer workman on site
- Creation of employment in areas away from building site
- Cost
- Reduction of accidents and ill health

(Taylor, 2014)

For all these attributes, which are shown in the bullet point above, are necessary the skills of all the team involved. It is necessary that each laborer has to know into detail what he has to do and why he has to do it and he has to study his field and its subsequences of his work. It is reasonable that the faster workflow is replaced by the higher knowledge.

Figure 9 - Detailed assembling of the off-site units

Source: http://www.shiftmodular.com/

Off-site makes it more important to consider how work is planned, designed and scheduled. If managers have been qualified with high level of technical qualifications but their expertise is traditionally onsite then it could be very difficult to move to offsite. It is not necessary to have the technical skills that are different, but it is more important to have the soft skills including planning, sequencing and link between design and build. With the increasing complexity of modern building services, there are clear benefits in removing the processes of running cables and pipes, and connecting controls and interfaces from site to the controlled environment of a factory or workshop. However, the complicated nature of the routing of many building services

can make compact pre-assemblies and subsequent installations difficult. Pre-fabricated modules are generally broken down into a series of modules, transported to site and assembled into one building. As with any other element of the construction process the integration of modular services needs careful attention during the early stages of the design process (Stirling, 2003). It is the change of thinking and proper planning which make the off-site technique adaptable and effective.

5.3 Lean

A process of lean approach aims at increasing market shares while minimizing the used resources. This approach was generally accepted and pioneered in Japan. Lean Construction is using the same principles as lean production to reduce waste and increase the productivity and effectiveness in construction work. The direction for implementation of lean construction are continuous improvement, pull production control, and continuous flow (Aziz & Hafez, 2013). Lean construction is primary a philosophy and then comes the rules and procedures. Lean approach is a typical PULL system, where the client must say first what he wants and the he bring the architect/engineers to design it and general contractor to build it. The idea is that client is the first and want something special which is not on the market.

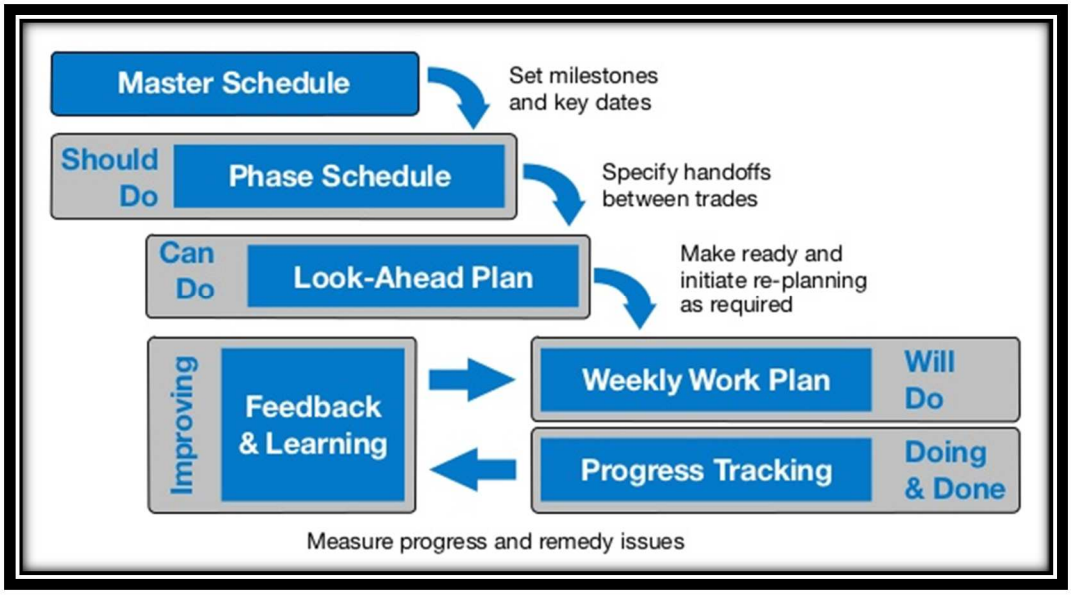

Figure 10 - Agile and lean for construction

Source: http://envisionapp.com/lean

Companies should apply the most reasonable and cost effective method to achieve optimum benefit and client satisfaction. The construction industry is rife with examples of additional work, pure education of workmanship, cost overruns and project delays. Construction quality requires a total change of mindset or philosophy among all participants of construction project so that everybody should achieve excellence as a win-win solution rather than to merely meet the minimum acceptable standards (Tam & Le, 2006). Construction has some specific factors against manufacturing procedures. The life-cycle of a project is much longer than a life-cycle of most manufacturing projects. There are also no uniform standards in evaluating overall construction quality. Construction projects are usually a single-order design project, where the owner directly influences the building or structure as a result. The participants in the construction projects such as owner, architect/engineer, general contractor or material supplier are different for each project (Arditi & Gunaydin, 1997). Construction is a very complicated process which requires distribution into right sub-processes. The contractors are evaluated mostly on their reputation and previous contracts. There is a high focus on pre-construction, construction and operational procedures. Lean thinking brings a tool, how to easily identify problems in pre-construction phase and with certain moves avoid some issues, which may occur.

Figure 11 - Example of Lean last planner approach

Source: http://www.blach.com/blog/november-25-2013/lean-construction-15th-annual-congress

There may also be a need for a change of procurement and project management practices. Full volumetric approaches should ideally be decided before the design process begins. The usual procurement process designs first and then seeks tenders for construction. This is classical

design, bid, build procurement approach. There is also a usual ‘critical path’ based on the project management approach assumes a largely sequential approach to construction (UK commision for employment and skills, 2013). IDEF0 diagrams show and describe the exact proces of the whole project. The process can be defined as a group of activities which lead to some results, or as a mechanism, that creates and delivers value to a customer (Madison, 2005). Construction project is a temporary endeavor witch challenges of uncertainty during its lifecycle. The project execution organization usually divides the project into project phases where can be utilized more effective management (Chen, et al., 2008).The construction project is usually divided into several smaller sections. This distribution has a huge affect on the project delivery and project success. The correct distribution with focus on lean implication might have a significant impact on project time,cost and quality.

5.3.1 Just-In-Time and Waste reduction

The Japanese industry has managed the largest share of the world markets for many products. The Japanese success has been attributed to their management philosophies that isolate problems rather than pieces of certain solutions. Just-in-time (JIT is a philosophy which aims to eliminate waste in all its possible forms, including unnecessary inventory, scrap in production and any sort of wasteful activities). JIT cuts the cost across business sectors and is firmly based on principles which should be applied in the whole organizations and across supply chains (Akinci, et al., 1998). JIT requires higher control on site and makes from site a more controllable environment.

Toyota motor company was the first which moved into fully implementing a JIT system. Toyota have developed this process so successfully, that the Japanese sometimes call it the “Toyota production system”. Characteristics of the drive that JIT can introduce in a company are the goals that are usually set out as part of a JIT implementation program, which include:

- Zero defects
- Zero set-up times
- Zero inventories
- Zero handling

❖ Zero breakdowns

This process is closely connected with waste reduction and the whole coordination during both the preparatory process and the construction process both on-site and off-site. A key principle of Lean and JIT is the identification and systematic elimination of process waste from every stage of the construction procedures. There are eight categories of waste, which help to identify the level and type of waste within a process:

- transportation
- inventory
- motion
- waiting
- over-production
- over-processing
- defects
- skills misuse

(O'Connor & Swain , 2013)

These 8 forms show the areas, where the biggest possibility and opportunity for waste reduction are. Proper planning and using suitable procedures can help with a problem of transportation which includes unnecessary movement of people, machines, goods or tools within the whole projector on the site. It seems to be a problem of supervisor, however this problem created mainly an architect/engineer, who did not think about issues connected within transportation. Waste reduction solve an inventory problem. Inventories have strict principles of planning and controlling which should prevent the possibility of shortages. Motion means unnecessary movement, which can produce labors during their working hours when they carry out their daily job. Unnecessary motion is the biggest difference between manufacturing and construction industry. Over-production is a process when contractor produce more than is required. This over-production has or might have significant subsequences which result in waste due to “out-of-sequence” works. Over-processing is similar to over-production. When contractor do more than is required to meet certain requirements, for example in quality. The contractor spends more time to get on better quality than is required, however he misses other factors from golden triangle which means time, cost and quality. Defects are quite usual in construction. Non-‘right

first time' quality require rework, which cost money and spend time. There is an only way, how to avoid defects, and that is repeated work. On a repetitive work the labors will avoid the same mistakes. The last issue connected with waste management are skills misused. The right people have to be on the right place and do the right things.

Based on the waste management, a comparison below shows the results, when there is the right utilization of skills and workforce for a waste reduction and a better productivity in a manufacturing and construction industry.

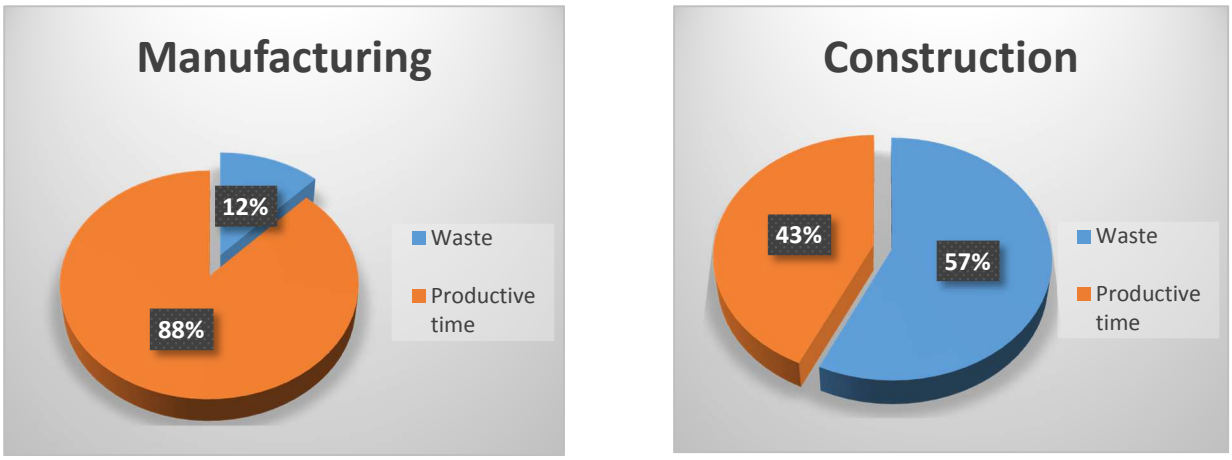

Table 3 - Waste percentage of time in manufacturing and construction

Source: (University of Salford, 2013)

5.3.2 Quality management

Construction industry has a lot of barriers and in other to overcome these barriers, there is a suggestion that construction should be viewed as a product development process. If the world were stable there would be no need to change business operations and methods (Cooper, et al., 2005). IDEF0 is focusing on modelling activities necessary to support system analysis, design, improvement or integration (Demirag, et al., 2004). IDEF0 diagrams can affect and help to understand the whole process and to improve the exact procedures into a better quality management. The fusion of quality management tools in the lean construction is based on the change from conformance based quality to the quality at the source. A point system is normally

employed to evaluate the execution of planned controls, which will help workers to follow planned controls instead of quality corrections

Quality management is organizational orientation to have process rather than function as a basic fundamental unit of analysis (Pheng & Teo, 2004). Over the last 60 years, many innovations has emerged to improve the manufacturing process, include statistical quality control, total quality control, material resources planning, manufacturing resources planning, optimized production technology or just in time (Crowley, 1998). According to D. J. Stockdale (1997), the basic characteristics for quality management are strong leadership, clearly defined and communicated objectives, focus on satisfaction of customers, applying innovation to products, services and operating processes to improve created value and having the ability to attract, develop and retain talent to create the skills, competencies, abilities and know-how. Quality management is a connection among a good quality control, optimized planning, sufficient management and leadership with added value.

The cost of quality is considered primarily as a tool how to measure quality. In the construction industry, contractors are selected by owners on a competitive basis. Especially when the owner is not a public sector, the owner also considers the contractor's safety record, technical support, equipment, capabilities and especially reputation (Arditi & Gunaydin, 1997). In the project must be a careful balance among owner's requirements of the project cost and schedule, desire operating characteristics, materials of construction, and the design professional's need for adequate time and budget to meet those requirements (Tam & Le, 2006). Contractor with a poor quality reputation is not likely to be awarded in competitive marketplace. The contractor wants to achieve high work quality in order to increase chances of winning contracts.

Quality management requires customer feedback system, continuous improvement, encourage teamwork, reduce number of suppliers, process management and improvement through productivity studies, effective communication system and top management to show commitment (Pheng & Teo, 2004). The environmental friendly ideas are in the pre-construction phase, from where are developed into detailed solutions. This quality management brings to a project great added value during the whole operational phase.

5.3.3 Collaboration A/E + client + contractor

In order to improve the implementation of lean construction, there is important the flow between main contractors and subcontractors and the variability to improve performance and labor flow for better productivity as lean construction principles (Aziz & Hafez, 2013). Lean principles has the basis in 4P Triangle. It is focusing on the principles of lean approach and the philosophy of the whole process from the most important foundation to the top as it is seen in Figure 7.

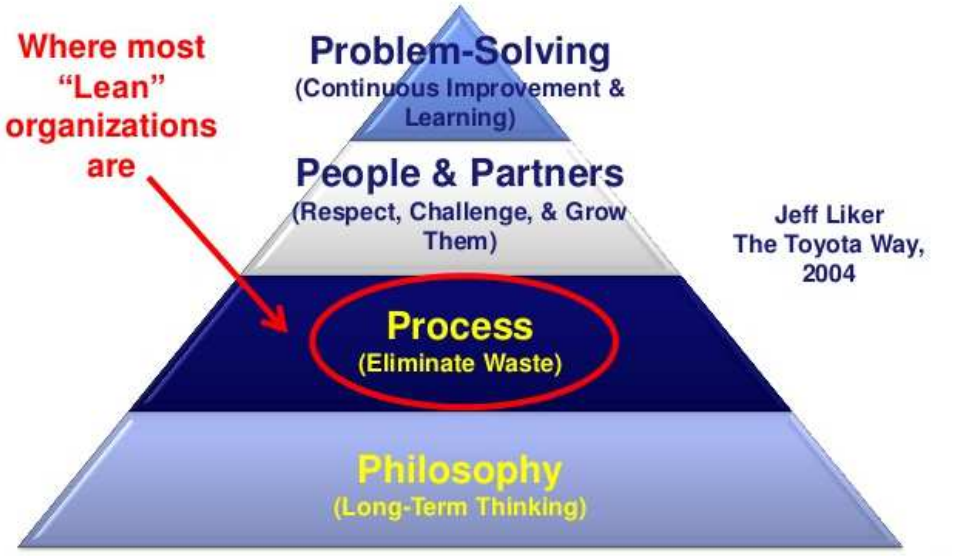

Figure 12 - Toyota's 4P Business Model

Source: http://missiontps.blogspot.cz/p/14-principles.html

Current engineering can be described as an execution of various tasks with the goal of obtaining most favorable products. These products are concerning a functionality, quality, and productivity. The enhancements of these three variabilities can be done by using collaborative work. It is focusing on the team efforts, such as communication and information flow. The utilization of these techniques will sufficiently enhance the productivity of the project (Aziz & Hafez, 2013). Partnering with suppliers is also a good chance for better productivity with lower cost, however the success of lean production is depending on the involvement of all participants in the early stages of the design.

The distributed information model and an evolving technology trends in the construction industry mean, that a range of BIM tools exist for each player to create their own models, which have to be periodically combined for collaborative work. This is the current practice in industry and has benefits as it allows a flexibility in business models, technology and business practices to emerge organically (University of Salford, 2013). Collaboration is among contractor, architect and client, however the collaboration within the company is also very important and non-removable. This process highlights the needs for specific data creation and exchange protocols which ensure information in appropriately managed place throughout the design process. Procedures for collaborative working are needed to support the whole project management leading procedures and also each smallest section of this project. In this project period designers/engineers concurrently work on the same project. In the context collaboration or collaborative work in construction, there should be address the following issues:

- how to ensure that everyone has up-to-date information
- how to make sure that several people are not editing the same objects at the same time
- how to notify about ongoing work and changes
- there is a need for flexible distribution of the work based on location, task, object type and attribute type.

(University of Salford, 2013)

In construction process there are also other issues, which have to be addressed during coordination of multi-discipline design, which includes:

- is there a need to see what the other designers are currently doing?
- what information is needed by other designers for critical decision making, and when is it needed?
- there are many temporary changes in trying to find solutions, so when is it adequate to exchange information?
- is there a need to ‘freeze’ design solutions so that other disciplines can start design?

“An extensive value process mapping exercise” can help to understand these issues including identifying critical design, the level of detail required from each discipline and general scheduling of the design process. In Lean and BIM design, there is an effective information management and a need for information modelling and process improvement (University of Salford, 2013). The collaboration in evaluating the processes during the construction process is very important. The collaboration makes better certainty of time, cost and quality with less risk and constraints, which make in a private sector a better assurance for the client and a greater value for money.

The need for involvement of major project stakeholders from the initial stages of a project is an issue of every single project. As an example of benefits from early involvement, contractors can contribute on design development by providing construction specific information early in the design process. This improves decision making and results in fewer design errors and less re-work. More professional opinions mean risk reduction. Also, the design models will be more usable for contractors in their processes, e.g. estimating, detailing for fabrication, site planning, production planning. As an example are BIM models (3D, 4D, 5D BIM models) which are connected with 3D design planning, timetables and cost of a project flow. The BIM process gives the project team the opportunity to virtually plan and build construction projects before there are made major commitments to time and money, i.e. enhancement of constructability analysis. Constructability reviews of BIM models through the design modelling highlighted more than 200 issues at each stage, which were not found by the simultaneously process carried out by traditional constructability process. BIM models resulted in reduction of errors in the execution stage of construction process (University of Salford, 2013). However BIM is not about design, time and cost modeling, it is mainly about collaboration among all parties in a construction process that every single member of a team can reach every information, which is for the whole team up to date.

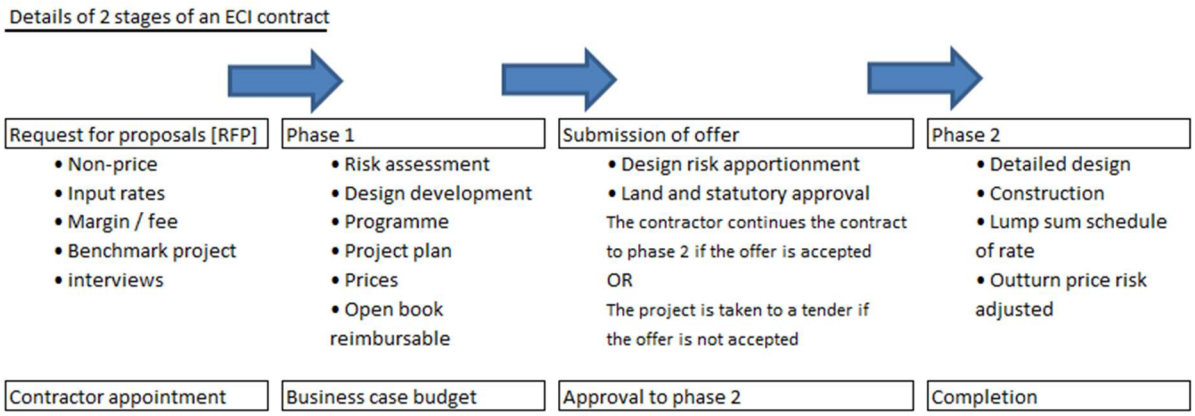

Figure 13 – Implementation of Early Contractor Involvement

Source: https://www.academia.edu/3193512/How_is_the_Early_Contractor_Involvement_ECI_being_implemented_within_the_Australian_construction_industry#

5.3.4 Risk assessment

Risk is always connected with the nature of forecasting. And forecasting is one of the most unpredictable function of the management (Waller, 2003). There have to be predicted budget, schedule, cash requirements, personnel needs, capacity of equipment, machines and buildings or plans for subcontractor (Patterson & Neailey, 2002). But there have to be strict focus on the responsibility of prediction. Every wrong prediction cost money and there must be set rules who has the responsibility for what and in which conditions.

The nature of forecasting of customer demand or other activity is one of the most inexact function in management. It is very important to understand and evaluate the external environment where there is considerable uncertainty, including the market, clients and changing technologies (Waller, 2003). The methodology for risk management was basically designed for Automotive Manufacturing Industry. However these techniques were extended into a process development. The original methodology is based on cyclic process (Patterson & Neailey, 2002).

These procedures has not changed and this is still very good way how to eliminate, reduce or get rid of the risks.

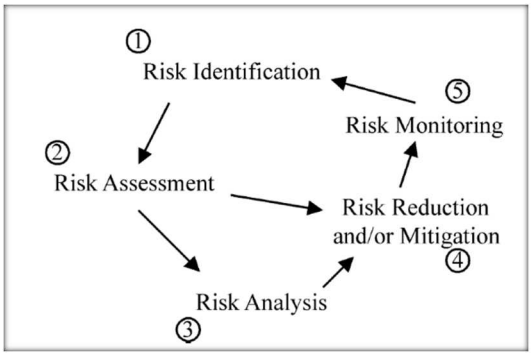

Figure 14 - Risk management

Source: (Patterson & Neailey, 2002)

All the activities which are connected with the project must be carry out and control within the project documentation. On-site and off-site activities must be controlled to ensure exactly same design which will be built and minimize conflict and misunderstanding (British Standards, 2006). Client must control the contractor's activities and his advisors should correct and lead the mistakes or misunderstanding for a good relationship and best value for money.

Improvements result in increase of organizational performance. Although with a time lag, the results of training will be seen in following projects. Improvement also results into an increase of motivation as well as management support, which leads to spending more time on improvement. This creates a positive feedback loop. On the other hand, when organizational performance increases, the work load typically increases too. The organization is more successful in getting more work. Increased work load and reduced need for improvement reduce the time spent on improvement (Aziz & Hafez, 2013). Effective improvements are harder to identify and implement. This reality creates another negative feedback loop. That means if improvements are based on training, motivation, and extra work load (such as additional inspections), the organization will have to increase its efforts simply to maintain the same level of performance.

5.3.5 Post project review (PPR)

After construction project activities, which are related to design, construction, communication, bidding phases and all others, the project team is spread all over the company and a project documentation is stored in an archive without any other later use. The most important activity at this point is evaluation of previous steps and procedures. It is called Post Project Review. The feedback will form the basis for the next project, success improvements, mistakes avoidance and improve performance. It will highlight current faults and do not include them in future requirements. The learned lessons can also be used in a future development. This is the area where the mistakes are carefully considered resulting in less defects in the future.

The feedback is shared and compared with a company's vision. The progress against previously specified performance provides a specific target at all levels of management. This feedback facilitates strategy review and learning. The company's reevaluation of the strategy is known as a double-loop learning. This learning is in contrast against a single-loop learning, where the feedback is used only to monitor a certain performance.

Post Project Review determines both positive and negative aspects and learning points and improve the planning and execution of future projects. Interactively coordinated meetings lead to greater innovations and better ideas. This communication is crucial for a project team.

According to Choudhary, et al. (2009), the benefits of this technique are divided into these five categories:

1. Facilitating collective learning:
   It provides involvement for all team members and examine what went right and wrong. It is a time for knowledge sharing, exchange ideas and brainstorming.
2. Provide utilizable knowledge:
   The feedback of a project is an outcome which can be utilized in a future project to prevent similar mistakes.
3. Benefit clients organizations:
   It provides a knowledge about development, construction and management of their assets. It is an insight into organizational management of its assets.

4. Better project phase management

   The Post Project Review provides a feedback on all project levels and for each particular level or phase it suggest ideal benefit.

5. Prevent knowledge loss:

   When the project is finished and a project team is relocated in another part of a company, the knowledge and learned procedures are kept on one place and in suitable form.

However the benefits of post project review are not achieved if there are not right people and the knowledge are not used.

6. Manufacturing advantages

Utilization of manufacturing techniques has many benefits against traditional construction. The significant cost savings are just one of many factors influencing the decision making process. Other key drivers for clients and contractors investing in modular technology is a speed of construction projects – with modular approach is typical shortening the time on-site and greater operational and energy efficiencies. It is suitable for highly build-up areas where are very expansive annexations. Increased efficiencies over traditional approaches are achieved thanks to the optimized and standardized design and techniques of modular solutions (DCD Intelligence, 2013). Several build-in design features ensure that modules have typically a more efficient approach to cooling down and for a power consumption. Many organizations claim that energy efficiency is one of the biggest motivation for their decision.

6.1 Competent design

Good design is essential to achieve good value for money (H M Treasury, 1999). Client has to deeply understand the design proposals and all the particular aspects, details and finishes have to be discuss with constructor. In construction there must be clear understanding of the proposals and future design that the client will more appreciate what the design will be like (Carmichael, 2002). For this purpose there must be clear functions of the facilities, design of the entire construction process and detailed design (H M Treasury, 1999). At completion off-site constructed buildings may have all the same visual attributes as a traditionally procured building. Opportunities for reducing the impact of a development grow as a result of the process that went into assembling the building. However, off-site construction constructed badly can perform worse than traditionally procured buildings. There are many opportunities for buildings incorporating off-site and module components or systems to improve the performance of traditionally procured buildings (Stirling, 2003). Off-site technique and lean approach can be used within the whole building or parts of it.

With fewer activities being undertaken on site than it is required with traditional construction that less time should be required for on-site activities. On site are less predictable and controllable conditions of the environment. On a projects where is much skill input off-site, it may be possible to de-skill the level of worker required on site (Stirling, 2003). The collaborative design and construction phase leads into better time and value management, construction procedures will follow one by one and the construction become a machine, not a chaos. The right design and repetitive procedures bring a lot of advantages, which the client apprises.

6.2 Motivation

Contractor's motivation is based on a choice of certain procurement system and project management (H M Treasury, 1999). But the key points are also job satisfactory or working with experienced and satisfied people. There are several ways for higher motivated labors and teams such as reduction of waiting walking time, having a safety environment, not so much overtime working, financial incentive or workforce skills.

In every organization there is a typical small percentage of employees who are actively looking for ways to improve work and initiate improvements. These are the champions who put a lot of personal time in improvement. Another group of employees is willing to try new ideas even if they do not make any particular effort to initiate changes. And finally, there is group that is not interested in improvement. Improvement results and employee motivation increase if:

- Efforts and successes are acknowledged and rewarded
- Positive results come fast.

If the results take a long time, the participants' motivation is reduced. However, many of the complex production problems may have a longer time lag between the start of improvement

effort and the result. Both management and employees involved in improvement process need to understand employees' motivation (Aziz & Hafez, 2013). Both off-site techniques and lean approach deal with motivation, productive time and waste time in pre-construction and construction procedures. It shorts the time of a whole project which results in a fast results and when the whole successful project is built in a shorter time, the employees are usually better financially and emotionally awarded.

6.3 Sustainability and energy consumption

As an example London Olympic Games in 2012 were built in collaborative approach with emphasis on sustainability. The contracts were based on target price which gave them a space for evaluating other designs. With this collaborative approach they achieved 27% of carbon savings and 31% of energy efficiency savings (Department for Environmental Food and Rural Affairrs, 2012). Client tend to have a higher impact on whole life cost and sustainability of the project. In this Olympic project the client with contractor reduced global warming emission and carbon footprint, improved the energy efficiency with efficient technologies and renewable energy technologies and reduced a consumption of natural resource (A Sustainable Housing Forum, 2003). This brought all architects, engineers, quantity surveyors, general contractor and sub-contractors together and with discussion they achieved the best option with big energy and carbon savings.

Transportation is one of the main attribute of construction industry. It is impossible to generalize the significance of transport. Particular cases depend on their location relative to manufacture and point of use. Off-site construction involves transport of materials from their initial point of manufacture to the fabrication factory and then transport of prefabricated components to their final point of use, sometimes over large distances (Stirling, 2003). Although traditional construction also requires materials to be transported from their point of manufacture, traditional construction transport huge amount of tools and raw material on site. However off-site construction assemble all the structure with details on one place and then they transport it all together. The impossibility of changes in a late phases and strict orders lead into

better planning and preparation phase. In addition better planning and more thinking about the structure mean less energy consumption and better sustainability of certain structure. Here are the examples of needs for off-site and lean approach for environmental friendly project:

- Minimize (eliminate) late substantial design changes.
- Carefully programed and planned all deliveries to the site, consider the skills necessary on site, any specialist needed and additional space that will be required to deal with the prefabricated components.
- Consider through-life performance and design for future maintenance.
- Encourage strategic alliances which extend beyond the life of single projects where the biggest opportunities for benefits arise on repeat projects.

(Stirling, 2003)

As it is seen in bullet points above, the process of sustainable project is a long term aim. It changes the philosophy of construction from the very inception and looking for life cycle cost as a whole project rather than only on separated construction phases. The systematic approach of construction project deliver less waste and packaging in construction phase. It is reasonable when the project is well prepared and all their phases are planned. The other advantage is a reduction of impact from construction that means for example the reduction of carbon footprint from transport or better engineering solutions. With this approach will also increase the adaptability in a pre-construction phase. The key point for the right sustainability is the whole collaboration with all project members who take a part in the project to improve product design, the process in construction phase and also the life cycle in the operational phase.

6.4 Time, cost, quality

As it was discuss above, the project success is based on time, cost and quality. These three unknowns in inception of the project make the project very risky. It is highly recommended to use as much procedures as possible to reduce the probability of risk appearance as possible. It is necessary to not think what has to be done right now, however to choose total different

approach to think what has to be done to avoid the risk and uncertainty. The off-site technique and lean approach has a significant impact on construction in a very inception and the project benefit from these knowledge. With these approaches there is a much more predictable cost certainty at an early stage of the project. It makes less risk for both client and contractor. There is also a significant reduction of abortive work and defects and reduction of site overheads. Cost planning and scheduling are also activities which are closely connected with budget (British Standards, 2006). Even the small changes, constraints or insufficient planning can have a significant impact on project cost and time completion (Carmichael, 2002). Because of the time pressure, there should be very detailed time and cost schedule for direct understanding. The design and construction phases should overlap over each other which will lead into big time savings. It was proved that systematic approach and better quality also leads in reduction of maintenance cost and reduction of construction time enabling earlier occupation. There is a minimum of 3% from capital cost which can be save every year on operational phase.

Primary every client wants a better quality with lower cost and shorter time. Lean and off-site gives the option. The pros of having manufactured or lean approach are several, such as faster processing, quantity discount, cost of quality or waste minimization. When the project has a controlled environment and it is not exposed to weather conditions, the workforce is able to more concentrate on the job with minimal interruptions from external and uncontrollable issues. The other very powerful advantage for the time process on-site is the ability to have platforms and fixtures to reach hard-to-reach places, it is faster to work standing on a platform then to dangle from a harness. One more reason for cost savings is the availability of skilled workforce. On a shopfloor workers are expected to work on one or two types of jobs and therefore they perform repetitive operations, which definitely results, over time, in faster processing, and an overall savings in the cost.

A manufactural process is a flow rather than a single project. A manufacturer has at any time orders for several weeks of production and therefore they can order material for several houses. Thus they take advantage of quantity discounts. Even for material in a smaller quantity, there is an impact on long-term relationship which results in benefits of cost discounts. It is appropriate that modular solutions offer significant cost savings in a number of areas, it is not for arguing that a modular approach always offers significantly lower costs (DCD Intelligence,

2013). According to Shahzad (2015) the significant cost savings depends on time and productivity of certain type of building which can be seen in Figure 10.

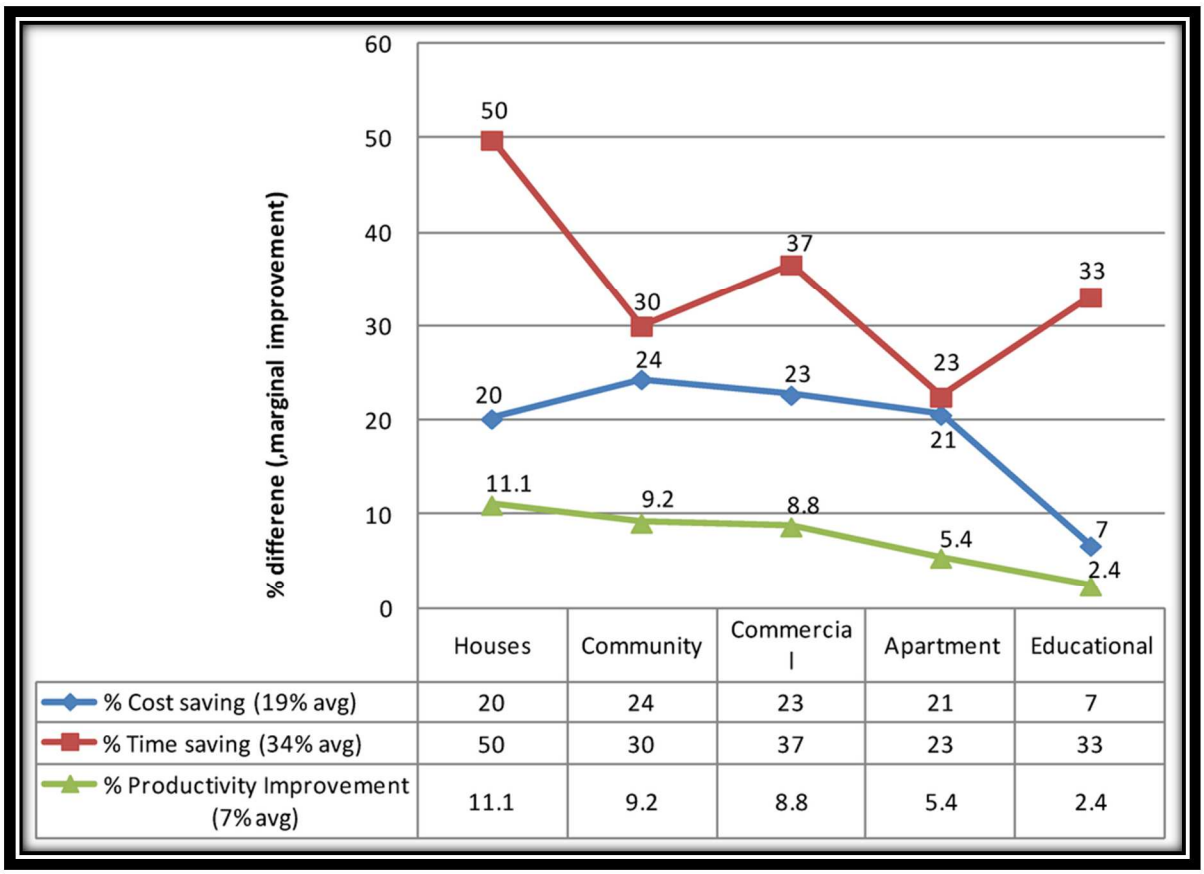

Figure 15 - Time, cost and productivity improvement achieved by the use of prefab in place of traditional building system

Source: http://www.mdpi.com/2075-5309/5/1/196/htm

Modular project's cost can be 5 to 20% less than comparable projects with approximately the same size on-site structures. Construction time can be cut up to 50% which in turn can allow for earlier use of the building and faster returns on investment.

Manufacturing techniques also requires a systematic approach. The systematic approach means in a conditions of construction a quicker design process, less time on-site and predictable completion date, which also save time and cost. The project do not depend on weather conditions, humidity, temperature, sunlight or snow when it is prepared off-site in a factory. There is also a big advantage in reduction of damages, which usually occur on-site when labors erect the building, handle and storage the project or construction parts.

It is much easier to monitor and manage quality control in a controlled and repetitive environment. However the quality has its own price too. The better quality means usually higher cost. On the other hand the cost involved with implementing quality control are much lower. In off-site construction type of environment the workers are trained in a very specific conditions and area. Therefore the quality issues can be connected to a few individual processes and correct action will ensure that they do not occur anymore. Significant cost savings regarding to optimization of processes lead to minimization of waste. By using leftovers from one house in other houses lead also in maximizing material usage.

7. Manufacturing abroad

The off-site techniques and lean approaches are used all over the world. These examples were chosen because of their uniqueness. The examples of off-site and Lean buildings are located in America, Singapore and China.

7.1 Disney's Contemporary Resort

Source: https://disneyworld.disney.go.com/resorts/contemporary-resort/

Disney's Contemporary Resort is a resort located at the Walt Disney World in Bay Lake in Florida. The resort was opened 1st October 1971. Contemporary's theme resort is a graceful 16 story high rise building with 1057 rooms. The design for the resort was a collaboration work among Walt Disney Productions, the United States Steel Corporation, and Los Angeles architect Welton Becket. Welton Becker was a friend of Walt Disney, so they work on friendly basis as a collaboration.

The resort was designed and construct in 4 years, from the idea in 1967 until the great opening in 1971. In theory, this off-site construction approach would cut the building time in half. The

company were battling tight deadlines to get the Contemporary resort built on time. Usually, contractor built a structure and then the rooms. By doing both together at the same time and then combining them, it would save time and money (Weis, 2011). However this project was a total prototype in this type of construction. This type of off-site construction has not been used in any other project that time.

7.1.1 Challenges

U.S. Steel Realty Company was eager in using and publicizing a unique construction method called “unitized modular construction.” For this resort, the contractor built a superstructure of thirteen steel-trussed A-frames resembling a skeletal honeycomb. The individual guest rooms were manufactured at a 150,000-square-foot floor-space factory several miles away from the resort’s foundation. The rooms were formed on an assembly line like conveyor belt system at the rate of about forty a week. As they passed through each station on the way to completion, the electrical, mechanical and plumbing facilities were added to the room (Weis, 2011). The idea of modular building was very clever and interesting. This was typical utilization of conveyor belt type production in construction project.

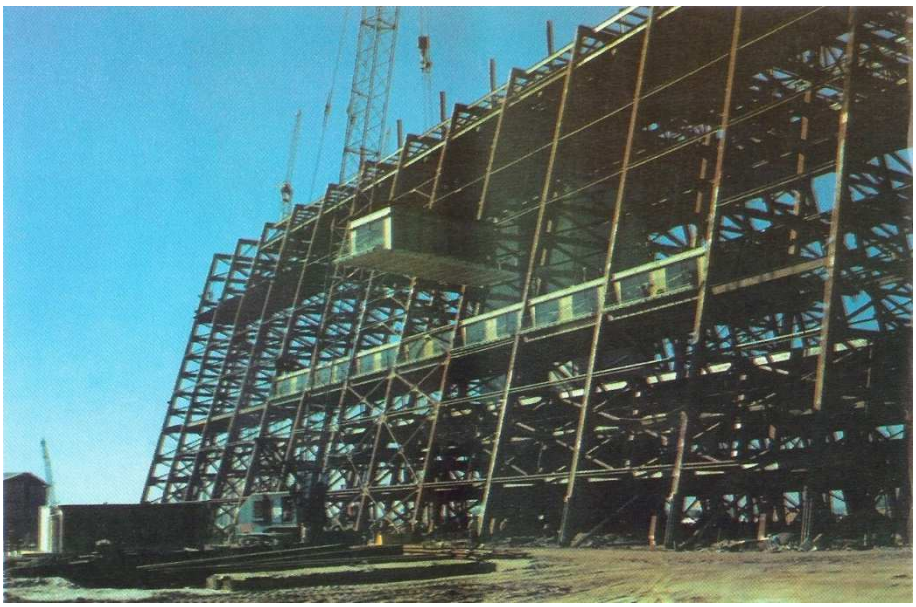

Figure 16 – Construction site of Disney’s Contemporary Resort

Source: http://disneymamas.com/tuesdays-timekeeper-prefab-ulous/

In a process of line production there was on average 35 rectangular units assemble per week. Before the units were driven on the hotel sites, they were already painted, almost fully furnished and ready to be hoisted into their predetermined spaces, where were required a minimal number of connections (Weis, 2011). This structure was a huge success of the client and also a huge step forward in building assembling. The resort started to write a new type of construction methodology and type of construction that is able to apply on a huge megastructures. This resort opened new possibilities and opportunities in construction of a huge residential, commercial, hotels and other types of buildings.

7.1.2 Time, cost, quality

The risks of time, cost and quality take place in both construction phase, where designers and engineers had never built similar project, and also in operational phase, where there are very unsure forecasts. These forecasts predict political, economic, financial, legal, managerial or cultural up to 30 years in the future (Edwards & Bowen, 1998). And the reliability of these forecast in a long future is very low. The predictability of events in operational phase are much smaller than predictability in construction phase, because all predictions are less reliable in the further future. In these types of predictions professionals make pestle and swot analysis, which can point out the main pros and cons of the project and settle it down in certain time period.

The contractor estimated the cost for $17,000 per room. However the final cost was over $100,000 a room in 1971 (Weis, 2011). In reality the theory of modular building did not work so properly in condition of cost. However this project was a prototype, the project met lots of constraints and risks, which the client and contractor did not think about. The quantity surveying procedures has moved forward a lot in off-site procedures and these off-site units and items has been implemented into computer software. Although this project was a prototype and a big challenge, it met the schedule in a high quality of construction and components. With the traditional approach the construction could take much longer.

7.2 Mini Sky City in China

Source: http://bgr.com/2015/06/19/skyscraper-built-19-days-timelapse-video/

Modular construction has a new height and a record time. The modular building called J57, which is also known as a Mini Sky City, is a work of Broad Sustainable Building, a Chinese firm that specializes in prefabricated buildings. This skyscraper was built in China, in a city Changsha. J57 is 207,8 m high, it has a 57 floors, 800 apartments and 1 090 parking spaces. The Chinese skyscraper remains a considerable structure with office space for 4,000 workers (EMPORIS, 2014). This building practically shows that a building can be build from 90% in factory.

At Modular Construction & Prefabrication 2015 summit was presented an exclusive case study on J57 Tower. It is examining in particular the use of modular prefabrication to increase the

rate of construction speed, reduce capital and operating costs and minimize the environmental impact.

7.2.1 Challenges

The contractor prepared more than 2,700 modules in a factory four months before site work began, so he was able to assemble the structure at the rate of three stories per day. With the traditional method they would have to build a skyscraper brick by brick, but with the off-site method the contractor needed to assemble large fully furnished blocks. The method was worth developing because it could become a safe and reliable way to build skyscrapers quickly. Mini Sky City has 19 atriums, 800 apartments and office space for 4,000 people, with space in the building going on sale in May. The structure is safe and is very stable that it can withstand earthquakes (The Guardian, 2015).

Figure 17 - Construction site of J57

Source: http://weburbanist.com/2015/03/28/record-breaking-57-story-chinese-skyscraper-built-in-19-days/

Although the rise of the building may make it doubt of the building's structural integrity. However Liu Peng, the associate director of the engineering consulting company ARUP Beijing said: "The method is worth developing because it could actually be a safe and reliable way to build skyscrapers rapidly. But it is not perfect, and it does not meet all kinds of personalized demands." From a sustainability and design point of view, the building is five times more energy efficient than other similar types of building. J57 features 20-cm thermal wall insulation, four-paned super white glass windows, 100% filtered fresh air 24/7 and a combined cooling, heating and power system that makes the building extremely energy efficient (The Skyscraper Center, 2015).

7.2.2 Time, Cost Quality

Broad Sustainable Building spent four and a half months fabricating the building's 2,736 modules before construction began. The company's technology speeded up its construction from two floors to three floors a day. "This is definitely the fastest speed in our industry", Liu Peng added.

J57 have six main advantages:

- 90% factory-made
- 5 times more energy efficient
- 99% of inside air pollution is eliminated
- the building will not collapse in a 9.0 magnitude earthquake
- material saving
- land saving and no land annexations

(The Guardian, 2015)

One of the biggest advantages of the J57 project was a quality control of the module prefab process in a factory environment. This approach allowed teams to control cost more precisely, eliminate construction material waste, prevent industry budget traps and operate against quick funding turnovers.

In this particular example of the J57 Tower the building costs reached up to 30 per cent in savings, while was also dramatically improved the construction quality. The architect/engineer involves standardized design, modular production, product management and highly-skilled workers (The Skyscraper Center, 2015). It is also important that only one reliable company is responsible for the whole structure.

7.2.3 Waste

According to the main architect Xian Min Zhang, the use of off-site technique in the construction of J57 Tower reduced the amount of concrete by 15,000 trucks, which is very important in both saving material and minimizing the environmental impact. Dust levels during construction were almost non-existent compared to traditional methods. The contractor's focus was on a green construction and one of the convincing argument is that all our beams are made of scrap (EMPORIS, 2014).

The J57 building has quadruple-pane glass. Zhang says, that it is so energy efficient that it will save more than 10,000 metric tons of CO2 emission compared to a conventionally constructed building of the same size and use.

7.3 Singapore – Marina Bay Sands

Source: https://en.wikipedia.org/wiki/Marina_Bay_Sands

The Marina Bay Sands is located in Southeast Asia in Republic of Singapore. It is situated on 15,5 hectares of land with the gross floor area of 581,000 square meters. In May 2006 the main contractor won the bid, the construction works commenced in early 2007 and the expected completion was by 2009. The first phase was opened on 27 April 2010 and official opening was pushed back to 23 June 2010. The rest of the complex was opened 17 February 2011. The 20-hectare resort was designed by Moshe Safdie Architects and engineering was provided by Arup and Parsons Brinkerhoff (Socialphy, 2012) and the main contractor was Ssangyong Engineering and Construction (Safdie, 2011). The total price was $5,7 billion (Hart, 2011).

The SkyPark is an architecture masterpiece which rest atop of three 55-story hotel towers of the Marina Bay Sands resort in Singapore. 9 million square foot program of Marina Bay Sands includes a 2 500-rooms hotel, convention center, casino, retail, dining, nightclubs, event plaza,

museum and all topped by the Sand Sky Park. The hotel is designed as a three tower structure with boat-shaped deck on the top (Hart, 2011). However the building are connected with other features which were built with the project. With Marina Bay were connected 101ha Gardens by the Bay, a 5,5 km long promenade linking all the major attractions around Marina Bay, the iconic Helix Bridge and separate vehicular bridge linking Marina South and Marina Centre, extension of roads linking the center and airport, five new underground MRT (Mass Rapid Transit) stations and Marina Barrage which makes from Marina Bay a 182ha heaven for all the people with their vehicles (ARUP, 2012). However the Sky Park makes from the Marina Bay Sands one of the most iconic building all over the world. The Sky Park has 12 400 square meters and it includes public observation (Safdie, 2011).

7.3.1 The Process

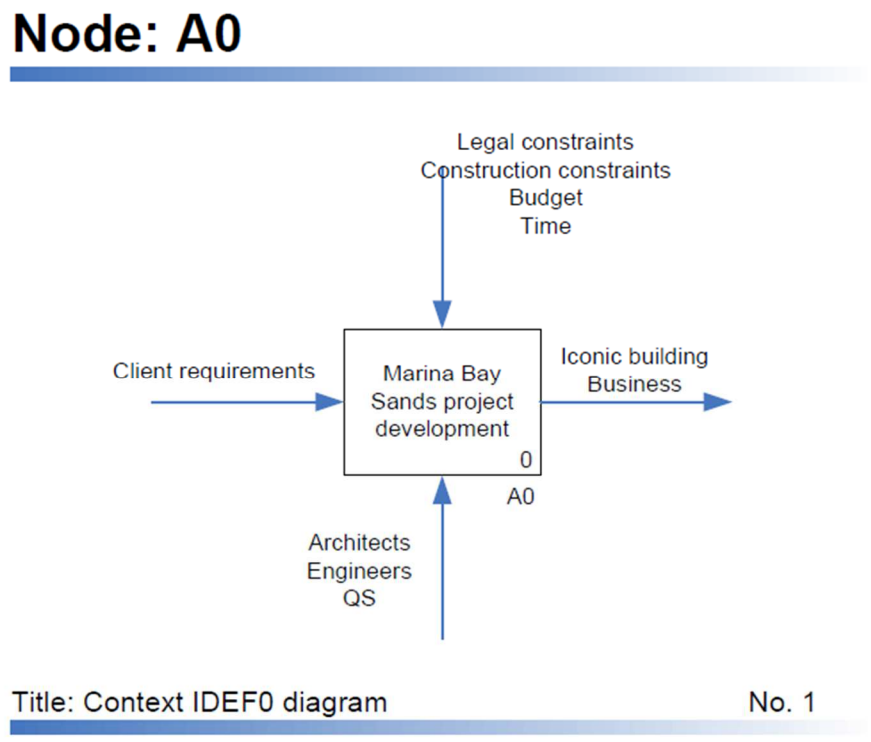

Figure 18 - Context IDEFO diagram of Marina Bay Sands project

The diagram describes the processes on the top level of Marina Bay Sands project. The client who was Sheldon Adelson, the CEO of Marina Bay Sands Corporation, and his team set the requirements of iconic building where he will operate his business. Into the project there are

talking experts such as architects, engineers and quantity surveyors who bring the clients' ideas and requirements into the reality. There is s control apparatus which is a guide to regulate the activity. On this level of IDEF0 diagram, the control apparatus is quite general. As a output of this big effort is the whole finished Marina Bay Sands project.

Single process in context diagram can be decomposed into subprocesses and modeled in a child diagram (Demirag, et al., 2004). This level 1 child diagram describes subprocesses of Marina Bay Sands project development.

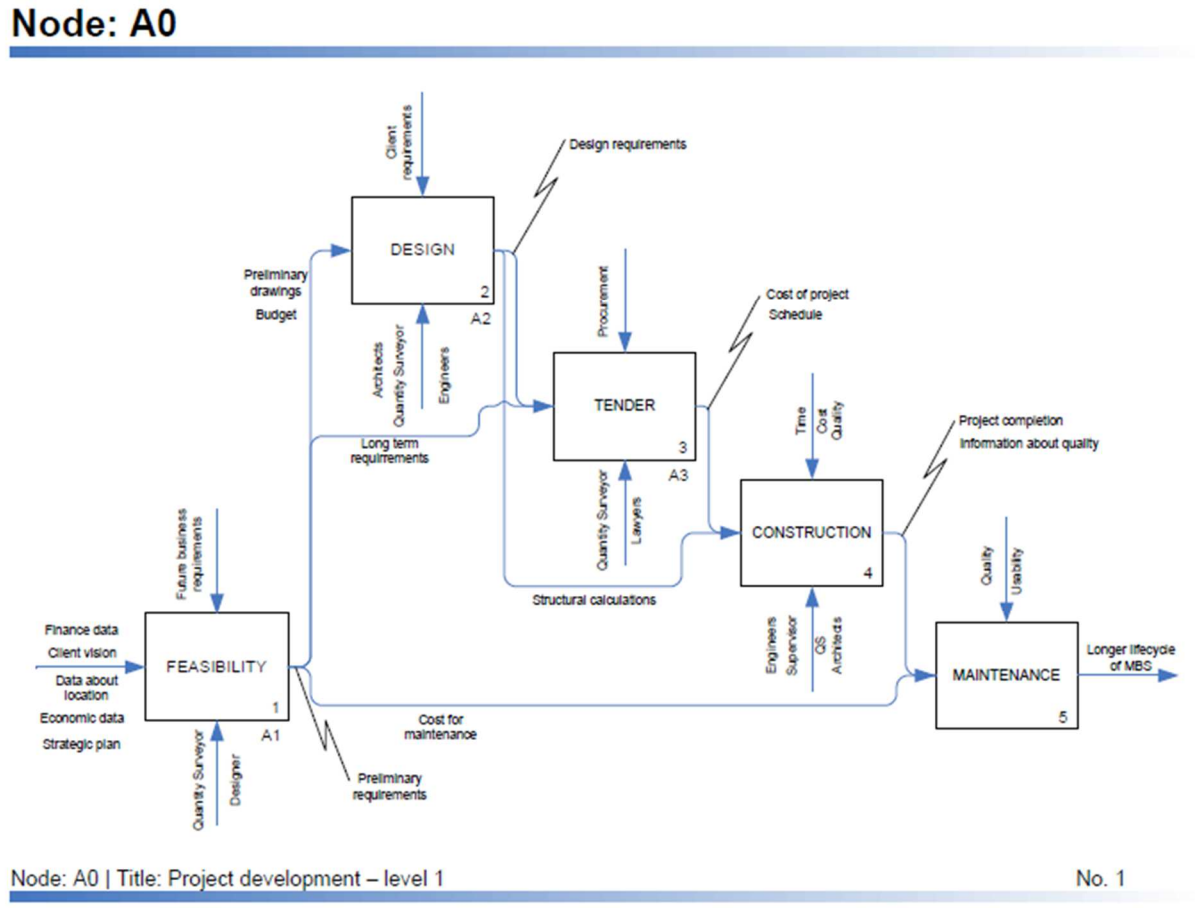

Figure 19 - IDEFO diagram - Project development

The first 3 phases of Marina Bay Sands development are pre-construction phases, than construction and operation phase. It is necessary to set all the strategic aims and plans based on solid financial data before feasibility phase. In this phase can be done the most significant cost

and design input. As it is seen in the graph that in feasibility study are set cost for both design and maintenance.

7.3.2 Challenges

With this structure there was a process of collaboration of architects and engineers. They both were pushing the boundaries on the edge of possibility with adopting new technologies, techniques and construction procedures. With this innovative approach they were able to respond to the client's vision and deliver this spectacular design (Lie, 2010). There are originally three towers of 55 floors and each tower is composed of two slabs of east and west facing rooms. As the problem with a large amount of heat gain, part of the design was developed to an innovative solution about the west glass façade to maintain energy efficiency without limiting the view from the hotel to Singapore downtown (Safdie, 2011). The architects had absolutely free hand and could make spectacular unique projects and do not have to focus on cost.

Figure 20 - Innovative approach

Source: http://www.marketoracle.co.uk/Article10900.html

The project aim was to be build more as a Singapore's pastoral tower than the core of the city. But the problem emerged when the architects recognized that they had no space left for the landscape. After that they realized to create a bridge among towers as a garden on the top of the roof (Safdie, 2011). The SkyPark has one of the world's largest public cantilevers (Minor, 2011). The rooftop superstructure is 200m high atop hotel towers and stretches 38m wide and 340m long (Lie, 2010). The challenge appeared in the construction of the SkyPark and in a way

how the engineers will get there the structure. The usage of lean approach is appropriate. Without a Just in Time technique the contractor could not be able to manage such a lot of amount of tools, materials and workers. Everything was deeply planned into the details day by day, hour by hour.

There are 2 approaches to evolution of craft-based industry to manufacturing industry. The first one is standardization of building. The second approach is to make the production process as flexible as possible. It allows a large variety of building with a small number of components (Crowley, 1998). Within the project structure, customer satisfaction is achieved by ensuring that drawings and specifications are communicated to the rest of the parties. The parties affected by the changes can then promptly adjust their information and help to reduce the amount of time wasted (Pheng & Teo, 2004). The Sky Park was not build for the lowest cost from repeated work. The most important condition was its uniqueness. The most important was the time saving and a good quality of the exact special design.

7.3.3 Management and quality management

The contractors generally agreed that the industry within which they work is associated with high risk and saw risk management as being essential to their overall construction activities in order to minimize business losses (Akintoye & MacLeod, 1997). In order to minimize the frequency of materials handling while focusing on the critical issues in the construction process, there have been serious attempts to apply the just-in-time (JIT) management philosophy to control the flow of construction materials (Ng, et al., 1994). Marina Bay Sands is a huge project with numbers of ongoing project. It is very difficult because each project can interrupt another. Each project is led individually, however on one site. This has a huge impact on material deposition and on labor. Managers have to find and put together a large number of qualified labor who should be able to speak or at least understand English. This is enormous number of people and there is a big difference between cheap local people and very expansive people from abroad whom the company have to pay travel and accommodation fees. Also the labors work in an extreme condition on the site, so they have to be in a good physical condition. There is a high probability of muscle injury. All labor should have a short stretching before the each work day.

In this collaborative BIM environment, team members would be able to solve problems before they manifest themselves onsite and require expensive solutions. For example, HVAC designers would be able to work with structural fabricators to solve interferences, long before any material was procured (Thompson & Miner, 2006). Unforeseen engineering problems on the structure are unknown which the engineers cannot count up. There were done some predictions, computer 3D models or real smaller prototypes for wind examination. All these scenarios are made for an understanding of the structure but it can never be understood for 100%. This uncertainty gives to the project quite high probability which can have a horrible impact.

Quality management is also very connected with sustainability. Marina Bay Sands is the largest single building which received Green Mark Gold Award for sustainability in energy efficiency, water efficiency, environmental protection, indoor environmental quality and green innovations (Marina Bay Sands, 2015). Quality management requires customer feedback system, continuous improvement, encourage teamwork, reduce number of suppliers, process management and improvement through productivity studies, effective communication system and top management to show commitment (Pheng & Teo, 2004). The environmental friendly ideas were in the pre-construction phase from where were developed into detailed solutions. This quality management brought to MBS a great added value during the whole operational phase. These kind of awards are the best feedback. This is a confirmation that MBS had a high level of quality management with encouraged teamwork.

8. Responses to hypotheses

Hypothesis No. 1

Off-site techniques and lean approaches can replace traditional construction procedures. With these approaches a project will be built in a shorter time with smaller budget than traditional building procedures.

Response:

Traditional construction has a lot of branches and all branches are not replicable. Off-site construction and lean approach can be used only in some cases. Off-site construction is a total change of construction procedures, where design concept must be ready with all the details in early inception of the project. It requires different thinking and different skills in designing, where the designer has to apply another techniques and technologies, and consequently also a skillful labor force experienced in the field. On the other hand lean approach is an improvement of traditional construction with implementation of manufacturing thinking and philosophy. The process of lean construction is defined as a group of activities which create and deliver value to a customer. Lean approach can be applied into particular processes therefore this approach is more universal.

The biggest advantage of off-site construction against traditional construction is the decrease of construction time on site. This factor is of particular benefit to contractors and also for client. There is also a significant increase of quality with an indoor assembling. More consistent product and reduction of defects and repairs make the building durable with client's satisfaction which is also an advantage in construction process and future warranty period (Goodier & Gibb, 2005). As it was seen at Disney's Contemporary Resort, the project was planned with a shorter construction time and lower cost. However the reality was different. This project was a prototype and it was built almost 45 years ago. The knowledge and skills has much improved

since then. For instance, as seen on one of the latest off-site project - J57 - the building was built in a much shorter time (only 19 days) and with lower cost than traditional building. Even though this is clearly an example of extremely successful project, it shows that this technique brings in huge advantages. Off-site construction has definitely the possibility to cut the construction time and cost with higher quality and it is best suitable in built-up areas where limited and very expensive annexations are.

Lean approach is also a manufacturing technique, which requires sophisticated approach and knowledge. Lean helps primarily in a long-term thinking. Lean brings what is the most important on a project – a certainty. Lean Construction is using the same principles as lean production which are waste reduction and improvement of productivity and effectiveness in construction. There are drivers for implementation lean construction, such as continuous improvement, pull production control, or continuous flow (Aziz & Hafez, 2013). This way of thinking fits to a larger project with higher uncertainty. As it is seen on Marina Bay Sands project, utilization of lean techniques, such as the collaboration of A/E, waste reduction, just-in-time, BIM and other approaches in all phases of a project eliminates the risk of the entire project. Even in such extremely unpredictable conditions the lean approach makes the project possible. Lean approach is an improvement of traditional construction with better certainty of time, cost and quality in extremely risky projects and it is also a long-term goal.

The construction technology has moved forward a lot. The biggest advantage of off-site construction against traditional construction is the decrease of construction time on site. Based on reasonable case studies, the conclusion is, that off-site projects are built within a smaller budget and in a shorter construction period than traditionally constructed projects. However, it cannot replace all segments of traditional construction. The hypothesis is incorrect.

Hypothesis No. 2

It is convenient to use off-site technique for residential buildings' construction, where utilizing repetitive types of units is very beneficial. However, off-site techniques can be utilized also in non-residential buildings.

Response:

Current clients are strongly influenced by negative perceptions of post-war 'pre-fab' that they resist any innovations in house construction. It affects what a 'traditional' house looks like (Goodier & Gibb, 2005). This is definitely not valid entirely and for all the clients and projects, but generally it is true. Different types of building where it is impossible to recognize the differences between traditional and off-site construction can be built with off-site techniques. It is the same with cars, everyone can choose their type with several specifications and options and no one complains that each car is the same. Good design is essential to achieve good value for money (H M Treasury, 1999). Client has to deeply understand the design proposals and it is good to discuss all the particular aspects, details or finishes with the constructor. In construction there must be clear understanding of the proposals and future design and the client will more appreciate what the design will be like (Carmichael, 2002). There are simply no limitations in off-site buildings. The constraints are only in architects, who have rules and regulations with off-site construction. The architects have to change the philosophy of creating the buildings.

There is a significant increase of quality with an indoor assembling. A more consistent product and reduction of defects and repairs make the building durable with client's satisfaction which is also an advantage in construction process and future warranty period. The systematic approach optimizes the combination of a predefined and engineered building system and the appropriate use of factory-made off-site solutions. This approach can be applied to whole buildings or to elements within a building. Excellent design can produce excellent results (Loughborough University, 2014). There are 2 approaches to evolution of craft-based industry to manufacturing industry. The first one is standardization of building. The second approach is

to make the production process as flexible as possible. It allows a large variety of building with a small number of components (Crowley, 1998). Disney's Contemporary Resort was built 45 years ago and its design is excellent. The systematic approach of the design and construction team led the project into a perfect design and cutting edge construction procedures. Also the example of J57 shows that off-site residential building does not have to be only social housing, however also skyscrapers and different types of residential buildings. The case studies clearly show that off-site projects are definitely not boring. Off-site construction is a very productive way with a broad variety of solutions. Off-site has several types and with each different approach of off-site can be built different type of building with different design and usage.

Off-site construction can be used on different types of buildings which vary based on their purpose such as residential, educational, health care or commercial. The utilization of off-site construction is very broad and it is still increasing. The amount of modular units depends on the size and architecture of the building and can vary from a few units to several hundreds of units. The hypothesis is confirmed and is correct.

Hypothesis No. 3

The idea behind off-site technique and lean approach is to collaborate with contractor during the pre-construction and construction phase. This collaboration results in higher productivity and quality of the project.

Response:

Collaboration is one of the main principles of off-site approach and lean thinking. It focuses on the team efforts, such as communication, repetitiveness and information flow. The utilization of these techniques enhance the productivity of the project (Aziz & Hafez, 2013). Procedures for collaborative and repetitive work are needed to support the whole project management leading procedures. Collaboration in off-site projects means that the entire design must be finished before manufacture begins and that the manufacture itself is a repetitive 'conveyor belt' type of process (UK commision for employment and skills, 2013). The advantage with

repetitive work is that there can be used the same type of procedures, tools, thinking or materials over and over again. Collaboration is a win-win solution. Collaboration increases the efficiency over traditional construction because this philosophy aims on the best result from all the parties involved.

The enhancement of functionality and quality is done by using collaboration during both the project and long-term aims. Collaboration is a philosophy, that the only aim is a project success. One of the most important technology regarding to collaboration is a BIM tool. BIM brings all parties together. BIM is about communication flow, so that each member of a team is involved in the communication. The connections among suppliers and contractors also extend behind one project and collaboration is a long term aim where the entities work together more than a one project.

Collaboration is clearly seen on a Marina Bay Sands case study. Some members of a project were chosen based on a previous collaborative jobs. And also collaboration of all parties during the process resulted in an architecture masterpiece. On this project were filled all the aspect together, the unique architecture was coordinated with engineering skills to fulfill the client's requirements and vision. Also on a one of a fist modular project Disney's Contemporary Resort, the collaboration resulted in an amazing project with an excellent design and pioneering technology and enhancement of project's quality. On a beginning of a project, all parties involved were pessimistic about the possibility of construction this kind of project. With collaborative work, this project is still iconic building nowadays.

The collaboration during a construction process higher the productivity and efficiency with a better quality of all parts in a project. The hypothesis is correct.

Conclusion

This diploma thesis primarily shows possible ways for enhancement of construction quality and productivity through the adaptation of Lean and off-site procedures. We compared these new techniques to classical construction methods both theoretically and in our case studies with all their pros and cons. The thesis also focused on the implementation of Lean and off-site techniques in current construction with emphasis on a process flow and utilization manufacturing techniques in construction procedures according to the client's satisfaction and success criteria.

In comparison with classical construction methods, the biggest advantage of off-site construction against traditional construction is the decrease of construction time on site. There is also a significant increase in quality with an indoor assembling in the conveyor belt type of process. These factors present valuable benefits for the contractors as well as for the clients. They also provide new building options for construction developers and general contractors, as well as for the suppliers of off-site systems and components. Off-site construction provides indisputable advantages in already built-up areas where there is a limited space and very expensive site cost and annexations. Off-site construction's advantages depicted in this study have a great potential and can be used on different types of buildings which vary based upon their purpose such as residential, educational, health care or commercial.

Knowledge is an essential part in implementing Lean construction. Lean construction is based on the same principles as lean production such as waste reduction, improvement of productivity, effectiveness and just-in-time philosophy. Lean approach definitely improve the construction process into the higher effectiveness and makes highly risky and complicated projects possible. Lean also enhance quality management and collaboration of main participants, such as general contractor, architect/engineer and client, in the construction process and therefore it minimizes business losses. On the other hand, Lean helps primarily on large and risky projects. This approach greatly eliminates risks and brings the certainty of time, cost and quality into a project. However, the utilization of lean procedures is a long-term aim.

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