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Master of Science in Management of Built Environment

TRADITIONAL AND LEAN CONSTRUCTION MANAGEMENT: A COMPARISON ANALYSIS

Supervisor: Prof. Mario Claudio Dejaco

Candidate: Giacomo Rampino

ID: 905461

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ABSTRACT

From early ‘60s, one of the main concerns in building sector focused on how a project should be in order to achieve the most efficient organization in terms of risks, liability, cost and profit. The project management aspect was to record and analyze site work in detail to find the most efficient production process. With the implementation of construction management, new management tools, like Critical Path Method (CPM) and Program Evaluation Review Technique (PERT), were introduced in construction industry, in order to have a clear vision of masterplans for all projects and control them in a better way than before. But as the building process turned to be more complex, traditional construction methods were found out to be not enough efficient to manage great projects. In this sense, the so called “Lean Construction” philosophy was introduced to identify in an efficient way all the activities which add value to the product or information and eliminate or improve reliability of non-value-adding flows like inspection, waiting, moving. The objective of this thesis is to make a comparison between Traditional and Lean construction management, with an initial description of the historical evolution of project management systems and several international standards. In particular, this literature review focuses on the methodology of Last Planner System (LPS), a flexible and simple aid to traditional techniques for project with a high level of complexity.

Keywords: Project Management, Construction Management, Traditional Construction Management, Lean Construction, Last Planner System.

SOMMARIO

Dall'inizio degli anni '60, una delle principali preoccupazioni nel settore dell'edilizia si è concentrata su come dovrebbe essere un progetto al fine di raggiungere l'organizzazione più efficiente in termini di rischi, responsabilità, costi e profitti. L'aspetto della gestione del progetto era quello di registrare e analizzare in dettaglio l'organizzazione del cantiere per trovare il processo di produzione più efficiente. Con l'implementazione del Construction Management, sono stati introdotti nel settore delle costruzioni nuovi strumenti di gestione, come il Critical Path Method (CPM) e il Program Evaluation Review Technique (PERT), al fine di avere una visione più chiara dei piani generali delle opere per tutti i tipi di progetto e controllarli in modo più efficace rispetto al passato. Ma quando i processi costruttivi iniziarono a diventare più complessi, i metodi di costruzione tradizionali si sono rivelati non abbastanza efficaci per gestire grandi progetti. In questo senso, è stata introdotta la cosiddetta filosofia "Lean Construction" per identificare in modo efficiente tutte le attività che aggiungono valore al processo o ai flussi di informazione ed eliminano o migliorano l'affidabilità dei processi "non-value-adding" (ovvero che non aggiungono valore al progetto) come ispezioni, attese e spostamenti. L'obiettivo di questa tesi è quello di confrontare la gestione tradizionale del processo edilizio con quella "lean", con una descrizione iniziale dell'evoluzione storica dei sistemi di gestione del progetto e dei diversi standard internazionali. In particolare, questa ricerca bibliografica si concentra sulla metodologia del Last Planner System (LPS), un'aggiunta flessibile e semplice alle tecniche tradizionali per progetti con un alto livello di complessità.

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CHAPTER ONE: THE EVOLUTION OF THE MANAGEMENT SYSTEMS IN CONSTRUCTION

1.1 Industrial revolution and scientific management

From about 1910, a number of theories and concepts were developed during the following 50 years, mainly in US, UK and some other European countries. Management in construction has its roots from manufacturing industries, but the principles need adaptation to the many explicit demanding challenges in construction. Even though, the evolution history of management in basic industries is an important background for reviewing the management in construction. In the early years of 1900, after a past century of industrialization, the workplaces became an object of scientific studies.

F.W. Taylor (1856-1915) in US started to focus on the productivity and payment rates documented by work-studies. This empirical and rational approach was the beginning of a scientific management era.

In parallel worked the team of Frank (1868-24) and Lillian (1878-1972) Gilbreth. Frank started out as an apprentice bricklayer and noted the diversity in methods and speed used by the workers. He developed and documented the best ways, even for concrete work, involving workers in improvement work without physical exertion.

Social theory and human relations came up even in parallel. The union-management cooperation was introduced as well as the employee participation in decision-making.

The German Max Weber (1864-1920) described in parallel a theory of bureaucracy. His seven essential elements were like: clearly defined authorities and responsibilities, a hierarchy of authorities and positions, selection of members on basis of formal qualification and examinations, appointed not elected officials, strict rules for conducting their duties.

Chester Barnard (born 1886) defined the nature of cooperative organizational systems. He saw a main goal in maintaining internal equilibrium whilst adjusting for external forces, including all sort of interesting parties.

Another American was Henry Gantt (1861-1919), who was a mechanical engineer. He built on Taylors elements and wrote about the mutuality of interests between labor and management, scientific selection of workers, incentive rate to stimulate performance and detailed instruction on work. He even made graphs with horizontal bars for each worker illustrating their progress related to the task standard time. During the World War I he served the US Government in scheduling the low productivity work in navy shipyards. He came up with the Gantt chart concept, which was revolutionary for this period.

People and motivation were the topic for Abraham Maslow (1908-70), who defined a hierarchy of needs like a ladder where one goes from the lowest level and upwards: physiological (food), safety, love, esteem and self-actualization.
An example of a specific motivation scheme is the Scanlon plan late 1930ies, named after Joseph Scanlon. The plan included joint committees with union and worker representatives proposing laborsaving techniques and a group reward based on reduced labor costs.
As the technologies became more advanced the managers even had to handle a more complex environment, so that, during and after the World War II, the management scholars turned from shop-level orientation to general management theory again. An increasing number of academies were involved, and practical advisors offered their service.

Frederick Herzberg published in 1959 "The motivation to work". He defined motivation factors in the job content like achievement, recognition, challenging work, responsibility and opportunities for growth. On the other hand, he described preventive hygiene factors in the environment like supervision, interpersonal relations, physical working conditions, salaries, company policies, benefits and job security. Those factors resulted not to higher motivation but declining under an acceptable level they led to job dissatisfaction.

Industrial Democracy came up in the 1960ies. It was soon experienced that the workers representation in the boardroom had to be extended to real influence on decisions on own work, so the groups were given more responsibilities for integrated tasks. F.E. Emery and E. Thorsrud at the Tavistock Institute launched the phrase "sociotechnical system". A main element is the reciprocal influence between the technical system (task, tools) and the social system (relation between people).
Finally, to mention is the evolution of numerical models developed to help managers in analyzing complex tasks. Mathematics and statistics have been utilized in a number of models to find "optimum" or "best way".

Walter Shewhart introduced Quality Inspection based on statistics in the 1920ies. During the World War II quantitative methods were used to solve various problems. Then followed the introduction of Operation Research in production management. Examples are proper stocking level of inventories, scheduling and controlling production, manufacturing in economical batches, quality control and capital acquisition. The modelling techniques were based on statistics, probable theory, linear programming, queuing theory and game theory. The evolution of computing aids was important in performing the calculations.

1.2 Evolution of management of building projects

The interest for the scientific management tools in construction come up after the word war 1940-45. There was a shortage of dwellings and other buildings in many countries, but the rebuilding was difficult anyway because of scarcity of the most needed materials, machinery and fuel. On the other side there was manpower enough, eager to get paid work. It took some years to organize and fund R&D and then the goal was simply to find rational building methods at lowest possible costs.

The management aspect was to record and analyze site work in detail to find the most efficient production processes. From mid 1950ies came work-studies of various kinds into use on construction sites, with the introduction of new instruments like special sort of clocks, frequency/interval studies and elapse photo camera, followed then by the modern bar-coded registration sheet with optical reading transferred to a computer and later video camera.

This development of study methods covered a period of 15-20 years. The Norwegian Building Research Institute (NBI) took actively part in this R&D together with some interested main contractors, and the studies resulted in a detailed understanding of obstacles and core rational principles as well as a reliable and valuable data bank. A technical outcome was the analysis of various building methods and use of materials, comparing at the same time with the use of manpower. It was important to base the analysis on the spending of production factors, and to leave the unit prices open for each project and the change over time. It is general known that that relatively high material costs related to low manpower costs lead to other optimum production methods than the opposite. Planning methods were based on the process knowledge and time data of all kind of operations. The goal was a production flow with a minimum of waiting times for workers and a maximum of repetitions. The NBI served the industry with a set of printed forms for planning and monitoring (Sjøholt 1970). This manual system required a great deal of work; on the other side it gave the planner a rather good insight in the problems and possibilities for a rational production flow. Courses of two weeks were arranged for production site managers from contractors, both for site studies and for the detailed work planning. But far more helpful was the establishing of clubs of contractors, coached through a two years program for their establishment of their own production management system (Sjøholt 1974). Some examples exist also on adapting numerical techniques in construction, as described in the scientific management chapter. Even though some experiments showed benefits they were mostly promoted by academias and had little root in companies' need.

1.3 Management of the design process

The traditional organization of a building project was in the 1950-60ies based on the client engaging designers and contracting contractors. Design and production were the two main phases, whilst use or operation including maintenance was a separate topic.

The focus on site rationalization led in the 1960ies to an understanding of the need to design for smooth production. About 1965 raised the interest of systematic studies of user needs or requirements. Researchers communicated through CIB (International Council for Building) working commissions and came up with a theoretical framework, both about functional requirements and the assessment of necessary properties of materials and structures in a building. Classification and coding were a part of the concept. However, this basic approach took a long time to mature and to put into practice.

In between the Value Engineering concept was offered in the mid 1970ies to construction by industrial consultants as a quantitative tool to find optimum design. The idea was to connect cost to needed functions and assess values, but it had little practical application in construction.

A similar idea came up again around 1990, when the concept of Quality Function Deployment (QFD) was introduced in construction. A matrix is used to analyze client's functional requirements versus design features, and to use weights for priorities or importance. Experiments showed some relevance, but the calculations were time consuming and the use diminished.

Life Cycle Analysis (LCA) has also been introduced as a technique but remains most as a principle. In the beginning of the 2000 it seems as the very first design phase (user needs) again comes in focus. One final remark on the functional concept is that it has radically changed authorities' regulations from prescriptions to functions, starting from about 1990.

The incorporation of rational production principles and other requirements into the design process is continuing challenge. The design and decision process need to have data and to balance all sorts of requirement or wishes (weigh them together and even to search minimum cost). One problem is about what and how, the other problem is about the organization of the process.

1.4 Organization of the building process as a whole

From early 1970 one of the main concerns focused on how a project should be to achieve the most efficient organization in terms of risks, liability, cost and profit and in fact there has been a continuous implementation of various organization models for procurement. Design/build means one organization being responsible for the total delivery. The performance requirements concept was adapted to be used in specifications. Various other ways have been used for competitions and contracts.

As the building process turned to be more complex, so did also the contracts. Lawyers appeared in the business and disputes came about.

Construction Management (CM) is more or less the opposite of design/build. The client is contracting one company to coordinate the whole process and manage directly both designers and contractors by means of subcontracts. The client may even perform this concept on his own.

The development trend has been that contractors have searched for models that could position them direct to the client from the early beginning of a project. Teambuilding and partnering was launched to instigate cooperation between client and project members, but without essential contractual implications.

In parallel the structure and business character of the industry is changing. General contractors have from the 1980ies reduced labor forces and use instead subcontractors and specialist enterprises. Designers are employed or hired by contractors. Family and private owners of companies sell to investors (financing business units). The new sorts of contractors or developers invest in land as well as in past industrial areas and construct for the open market. The local markets have extended to global markets including international cooperation. This has in the 1990ies opened for the concept Build-Operate-Transfer (BOT) as a way of reducing governmental investment. Consortiums take all responsibility even for financing. This is another indication of the rapidly growing influence of finance business units in the construction sector and means that an even stronger focus on return on investment and profit margins. The continuity of the owner as the top manager is outdated since the 1990ies.

1.5 Introduction of computers for network planning and project management

Computers were within reach in many countries around 1960, though most in service centers. For management systems this resulted in programs for planning according to the network principles. The Critical Path Method (CPM) was launched in 1957 as a computerized arrow diagram, allowing finding critical activities and total time. Next followed the Program Evaluation Review Technique (PERT), a network based on three time estimates for each activity, pessimistic, most probable and optimistic. The calculation was based on statistical probability theory.

In short time in the mid 1960ies this new management tool was introduced in the construction industry. The vision was to make master plans for all projects and to really be able to control in a much better way than before. Planning consultants were hired to make the plans, as they were linked to computer centers. They were in general little familiar with the construction process and based the planning on interviews. It took some time to get the calculation and the result back and, worst of all, the first versions were difficult to understand, mostly listing with tables and complicated networks. In addition is the nature of a building project difficult to transform into a network of this conventional first version. The risk was that it could not fulfil the expectations or even delay further improvements of management systems.

The development from computer centers in 1960ies up till today's hardware is like a revolution. The construction industry has (with some time lag) followed the stages from stationary company computers to personal computers, then portable computers and even handheld computers (palm). The use of pencil changed slightly from 1985, experiencing the efficiency of text writing, calculation, diagrams and illustrations. The communication evolved in parallel from phones to fax in the 1980ies. Data were transmitted by diskettes. The computer connection via telephone cable net and local wiring opened for directly transmittance around 1990. From 1995 the Internet was launched and gradually improved to serve for email, websites, information retrieval, trade, project communication etc. The

improvements have all the time been followed by new software developed for the open market and the evolution of management programs and tools in the 1990ies resulted in a second generation. Planning tools and CAD design programs (AUTOCAD) were considerably improved. Communication ways changed to wired network between computers and next via Internet. But the necessary adaptations to construction processes took long time, mainly due to the small and fragmented market.
Materials flow has been much concerned in management of construction. In the late 1980ies there were proposals to transfer methods from manufacturing and trade business, resulting in a few development projects.

In Japan the *Just In Time* (JIT) concept was demonstrated by Toyota in a successful manner. In the mid 1990ies some studies were performed on materials administration and logistics for building sites (Denmark, Norway). At the same time the structure amongst wholesalers changed to larger groups of retailers. They invested in computerizing of stocks and deliveries, which fit very well to the rising interest from contractors in logistics. The Supply Chain became a motto, even leading to partnering as a lasting cooperation between suppliers and buyers. Material need and delivery was integrated in the scheduling and automatically monitored. Materials ordering in the 1980 from the catalogues with barcodes and optical readers moved over to Internet in the late 1990ies. Orders and payment became online between the supplier, buyer and the bank. In Japan the large general contractors were leading the development, offering design and build. A sort of partnering was the culture since long, including subcontractors. The contractors had own research institutes with 2-300 researchers (Takenaka). One example of development work concerns logistics for a specific site in Tokyo 1999 (Shimizu). A computerized schedule showed the actual needs of deliveries for all trades. The manufacturers were connected through a project information sharing server. The carrier subcontractor chose the optimum route to pick up deliveries from each supplier to deliver just in time. The trucks were controlled via satellite navigation. After delivery on site the trucks loaded sorted rest materials and brought them to their respective return places.

Benchmarking has been introduced to construction during the 1990ies in the UK. It means a systematic comparison between own and other’s processes and products, leading to concrete following up measures. The concept, promoted by researchers and consultants, has not been widespread, but it led to some groups of companies exchanging key performance indicators.

Business process reengineering (BPR) was another word spreading to construction about 1995, aiming at innovations more than incremental improvements. It gave opportunities to consultants but did not set roots in the first hand. It came up again within CIB around 2000 under the headline Business and Process Re-Engineering.

The so called “SWOT” analysis (Strength, Weaknesses, Opportunities, Threats) was launched for companies in the 1990ies. This was a process for developing strategies and business plans, but hardly used in construction.

Concurrent engineering involves the parallel analysis of design and production methods. Design may be carried out simultaneously for several disciplines, resulting in system packages. The goal implies a better total result and shorter total time by starting production earlier. The concept was introduced in construction in the 1990ies.The ideas are continuously developed further in combination with new ICT (Information and Communications Technology) means.

Lean construction is a still wider concept for improving productivity, including several rationalization principles (Alarcón 1997). During the 1970-80ies some manufacturing and automobile industries had achieved impressive improvements by combining a collection of philosophies. The ideas were adapted to construction in the 1990ies. The International Group of Lean Construction gathered researchers and industry for collective development. The main idea is to make more efficient the conversion activities which add value to the product or information and eliminate or improve reliability of the non-value-adding flows like inspection, waiting, moving. The movement might lead to a revitalization of the industrial scientific management from early 1900 as well as the adaptation to construction in the 1950ies.

1.6 Traditional methods of designing with the help of CAD systems

Architectural and engineering design is a task for large teams consisting of specialists, such as architects, constructors, installation engineers, quantity surveyors, project managers. For many centuries the bases of the projects were (and are) 2D drawings (plans, sections, elevations) of designed building in a symbolic manner, in accordance with the principles accepted by all participants in this process. Usually the architectural concept is fundamentally different from the final design and structural design. Architects mainly use sketches of bodies (3D elements shown in perspective) whereas civil engineers - plans or details drawings. Another source of confusions or mistakes are two types of plans: architectural projection shows what is below the cut surface, which is usually located at a height of 1 m above the designed floor, as an architect is interested in the layout of the designed story. In contrast, a building (construction) plan shows what is under the ceiling of the floor considered by architect, since constructor is interested in the substructure supporting the floor considered by architect. In the classical method of designing each of the specialists work on separate industry drawings (prepared on tracing papers) with only those elements for which they are responsible. Tracing papers produced by specialists are imposed on each other during the coordination meeting to check the compatibility of the project.

CAD (Computer-Aided Design) systems modernized the process. Instead of tracing papers the separate layers in the CAD program are used by each of the specialists. However, designer works in CAD on plans of the same building and the interdisciplinary collisions (e.g. structure-installation) are inevitable. The coordination meeting and correspondence are devoted mainly to solve the conflicts. The use of the CAD systems makes this process easier although it is time consuming and not always successful. When on one layer with installation something is changed then quite often it is not on 2D drawings not only with plans, but also with cross-sections or elevations, which should be changed both in architectural and structural design.

In parallel with CAD software CAE (Computer-Aided Engineering) systems have been developed to support the calculation of the structure. Special programs have been developed for installations. Nowadays functionality of available CAE programs is very high - starting from simple programs for static or dynamic analysis of specific elements or structure, including checking the requirements specified by standards. Complex calculation systems (such as Autodesk Robot) collaborating with CAD/BIM systems are developed steadily. They allow for comprehensive modelling of the structure; the load patterns combination module supports thousands of different variants. Final results of analysis can be easily transferred to CAD/BIM systems in order to adjust the 2D/3D model and produce structural drawings (dimensioning and reinforcement drawings, detailed design of steel connections etc.).

1.7 Building Information Modeling – BIM

As previously said, over the past 100 years the design and building industry has changed exponentially: buildings have become much more complex with many more interrelated and integrated systems. During this period, it has been added a huge number of building systems and other layers of design that either did not exist to the same level of complexity they did before or simply did not exist at all. These increase in the project's complexity generates also an improvement in competitions, so a higher specialization, but it has added time and cost to the process and lifecycle of the building. With this new way of operating architects, owners, and contractors have had to adapt to these changes: data transmission cannot remain as fragmented as usual and cannot be more on paper, because this type of data communication could imply lots of error and incomprehension among building process' parties, and from these problems could rise cyclically late in delivery time, increasing in costs, and legal dispute. For what concerns the decision-making process the data exchange basing on 2D information generates problems because analysis about management and maintenance costs, energy consumption costs and load bearing efficiency are not easily forecastable and transposed in the reality even though after the building construction, but at that time is too late to make some important change in the building. All the CAD Systems generates digital files, compose by vectors, lines and layers, with no significant innovations in the design stages and project's organization.

With the 3D design tools is not only possible to manage the geometrical information as a real object (parametric design), but also it could be possible associate to a specific element some features that could not be represented graphically. In particular BIM is a modeling methodology that allow the creation of a data base specific for the building: drawings are not simple geometrical representation of the spaces, but operative tools able to talk about several aspects of the construction (from the spatial organization to the construction costs, from the used materials to the maintenance plan).

The potentiality of this modeling method is the capacity of reducing errors due to the ability to reflect automatically an eventual change in an aspect of the project in the entire design flow. This also produce a sort of revolution within the design approach to the project and how people involved in the entire life cycle of the building interact.

It is possible to say that BIM generates a new way of communication among all the participants, allowing a bigger amount of data exchange than with the classical design approach. For that reason, it is possible to handle more complex buildings and projects.

Recapping, BIM is defined in the BIM Handbook as a modeling technology and associated set of processes to produce, communicate, and analyze building models. Sometimes it is easy to hear that BIM is a software, but, conversely, BIM is a methodology and makes changes in the core of the design modifying the logics and revolutioning the traditional and static workflow.

Figure 1 Main features of BIM technology (source: siemens.com)

1.8 Comparison between traditional and BIM methodology

Figure 2 and Figure 3 represent the graphic design approach of traditional and BIM methodology, briefly compared in Table 1.

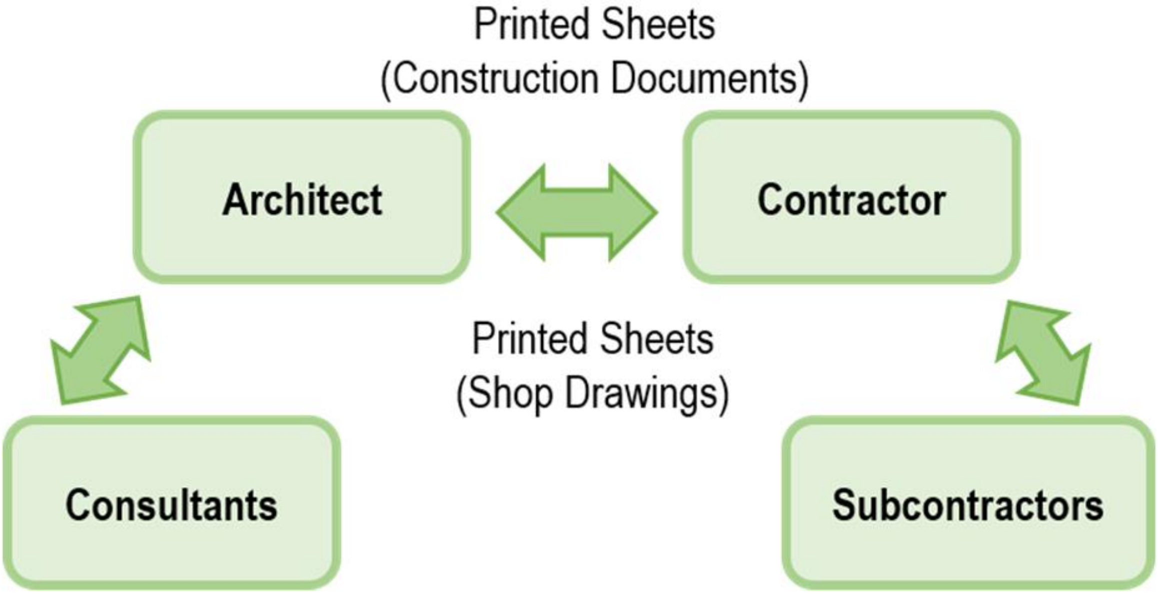

Figure 2 Traditional design approach (Krygiel et al. *2008)*

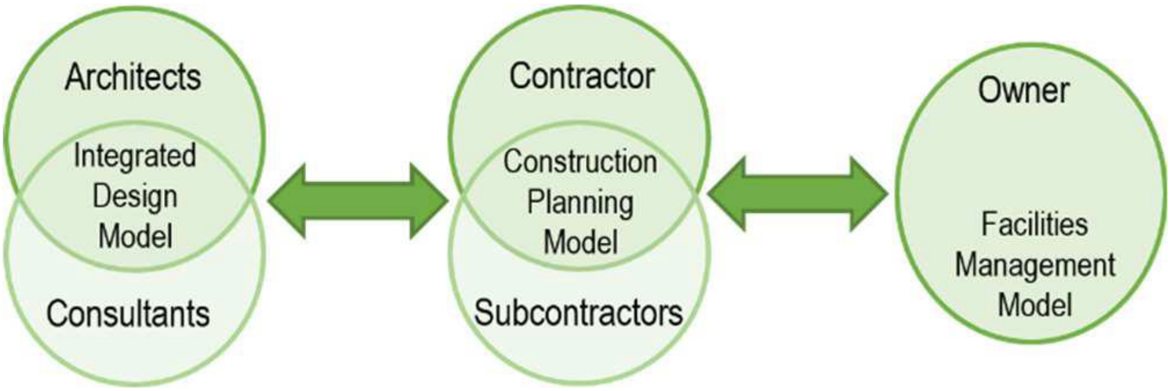

Figure 3 BIM design approach (Krygiel et al. *2008)*

Traditional methodology	BIM approach
1) Architect starts drawing the building with the collaboration and information coming from consultants; 2) Consultants start working on the architect's drawing on their own for what concern their specialized field; 3) Architect collect the consultant works, put them together re-elaborating them with the architectural set; 4) All the project's documents (usually printed) are presented to the contractor, who will eventually spread them to different subcontractors; 5) The contractor creates a new series of drawings based on the originals but with more detail.	1) Architect start working on the project with the consultants, it could be done on a unique model or a model composed by interconnections and parts; 2) The model goes to the contractor, who, helped by building team, embellish and enrich the project; 3) Once the building is built, the model can be adjusted in order to reflect the reality; 4) The BIM model is still useful for the owner users, future maintenance interventions, evaluate performances, assess building impact on the environment and facilities management, because it contains data about object, materials element's installation, costs and performances.

Table 1 Comparison between traditional and BIM methodology (elaboration of the author)

CHAPTER TWO: REGULATORY FRAMEWORKS OVERVIEW

2.1 Italian regulatory framework

2.1.1 Merloni law (Legge 109/94)

The Merloni law (law 11 February 1994, n. 109) was the first reference to be introduced as the main law for public works and explains how the public work must be carried out. According to it, to carry out a public work it is necessary to present projects for three phases *(preliminary project, final project and executive project).*

The Merloni law (law 11th February 1994, n. 109) and the D.P.R. December 21, 1999, No. 544 identify the documents to be presented in each project for each phase.

Documents composing the *preliminary project*

The preliminary project already identifies the characteristics of the work. It is composed by:

- Explanatory report;
- Technical report;
- Environmental pre-feasibility study, which introduces the environmental impact study;
- Preliminary geological, hydrogeological and archaeological surveys;
- General planimetry and graphic schemes;
- First indications and provisions for drawing up security plans;
- Calculation of expenditure summary (with this paper we begin to identify a total amount of the work).

Documents composing *the final project*

Once the preliminary project has been approved, the next step is the final project. It contains all the documents necessary for the issuance of the building permit, the urban compliance assessment or an equivalent document. It consists of the following documents:

- Descriptive report;
- Geological, geotechnical, hydrological, hydraulic, seismic report;
- Specialized technical reports;
- Plano altimetric surveys and urban planning study;

- Graphic drawings (planimetry, etc.);
- Environmental impact study;
- Preliminary calculations of structures and installations;
- Descriptive and performance specifications of the technical elements;
- Particle expropriation plan;
- Bill of quantities;
- Economic framework.

Documents composing *the executive project*

The executive project constitutes the engineering of all the processes and, therefore, fully defines and in every architectural, structural and plant detail the intervention to be carried out. Only the site operational plans and temporary works (scaffolding, excavation, etc., which are done until shortly before they are made) remain excluded. It consists of the following documents:

- General report;
- Specialist reports;
- Graphic drawings including those of structures, plants and environmental restoration and improvement (environmental restoration and improvement, that is, the graphic drawings also include the final step of the work, also showing the green area, etc.);
- Execution calculations of structures and plants;
- Maintenance plans;
- Safety and coordination plans;
- Final bill of quantities and economic framework;
- Chrono program;
- List of unit prices;
- Framework of the percentage incidence of the quantity of labor for the different categories of which the work or work is composed (indicates the cost of labor)
- Contract outline;
- Special tender specifications;

2.1.2 D Lgs. 18 April 2016, n. 50 "Code of public contracts"

The code of public contracts is a rule of the Italian Republic issued by legislative decree 18 April 2016, n. 50, which regulates the matter of public works contracts, supplies, services and concessions, and the related public contracts. Upon its entry into force, it repealed the previous code of public contracts pursuant to Legislative Decree 12 April 2006, n. 163 and Merloni Law 109/94.

Art. 23 - Design levels for tenders, works concessions and services
The article governs design levels, providing that it is articulated:

- on 3 levels in the case of works contracts: project of technical and economic feasibility (which is the new one name of the "preliminary project"), final project and executive project; the latter two preferably carried out by the same subject. One or both the first two levels can be omitted if the next level contains all the expected elements for the omitted level.
- as a rule, in a single level, for the design of services and supplies. […]

Article. 23, in paragraph 2, also identifies the subjects who they can carry out design-related activities (feasibility, final and executive) establishing that:
- for jobs of particular relevance in terms of profile architectural, environmental, landscape, agronomic and forestry, historical-artistic, conservative or technology, provide internal professionalism, as long as in possession of appropriate competence in the subject matter of the project, or recourse to design competition procedure or ideas contest;
- for all other jobs the rules in apply design of public works, referred to in subsequent art. 24 of the Code.
For service contracts, the design is articulated by rule in a single level, is generally carried out by contracting service employees. In the case of design contests, the same can be divided by the contracting station by one or more levels of depth. The service procurement project must contain, among other things: the technical-illustrative report of the context in which the service is inserted, the documents related to security, the calculation of amounts, including security charges, the specifications special. The cost of labor for work contracts, services and supplies is identified by tables from issued annually by the Ministry of Labor e of social policies. […]"

Concerning BIM, in Italy the current progress in its introduction into building processes is still in the early stages. Although methods and tools related to BIM have already achieved a great deal success in Europe, particularly in Germany and Great Britain, in Italy they are still affirming (EdilPortale, 2017).

However, the adoption of BIM is expected to speed up over the next decade. In fact, it is recent news (December 2017) that the Italian government has issued the *"BIM Decree"*. After indirect quotation of BIM in Article 23, paragraph 13, of Legislative Decree 18 April 2016, n. 50 *("Code of public contracts"*), which reported: *"Contracting authorities may request for new works as well as for recovery interventions, redevelopment or variants, primarily for complex jobs, the use of specific electronic methods and tools referred to in paragraph 1, letter h. These tools use interoperable platforms through non-proprietary open formats [...]"* (D. Lgs. 16 April 2016, n.50, 2016), the Minister of Infrastructure and Transport Graziano Delrio has signed Ministerial Decree of 1st December 2017, n.560. In fact, this Decree will oblige the contracting authorities for the use of methods and tools that are part of the BIM system.

The BIM Decree *"defines, for works contracts and works concessions, the methods and timing of progressive introduction, by the contracting authorities, of the granting administrations and of economic operators, of the obligatoriness of electronic methods and specific tools, such as those modeling for construction and infrastructure"* (Ministerial Decree of December 1, 2017, No. 560, 2017).

In the same text, reference is made to the resolution of interoperability problems, but not before having given a set of definitions on BIM environments; interoperability is thus treated in Article 4 of Decree 560/2017:

1. Contracting stations use interoperable platforms via non-open formats owners. All data in the process must be connected to three-dimensional models object-oriented [...].

2. The information flows concerning the contracting station and the related procedure take place within a data sharing environment, where digital process management takes place information, made explicit through a process of correlation and optimization between flows digitalized information systems and decision-making processes concerning the individual proceeding." (Ministerial Decree 1st December 2017, No. 560, 2017)

Furthermore, the Decree issues directives regarding the maximum timing of adoption of BIM in building works by the contracting authorities; the timing is as follows (article 6, Decree 560/2017):

"*a) for complex works relating to works based on a tender equal to or greater than 100 million euro, starting from 1 January 2019;*

b) for complex works relating to works based on bids of 50 million or more a starting from 1 January 2020;

c) for complex works relating to works based on a tender equal to or greater than 15 million euro as from 1 January 2021;

d) for works based on a tender amount equal to or greater than the threshold referred to in article 35 of the code public contracts, starting from 1 January 2022;

e) for works based on a tender amounting to 1 million euros or more, starting from the 1st January 2023;

f) for new works with a tender-based amount of less than 1 million euro, starting from the 1st January 2025". (Ministerial Decree 1 December 2017, 560, 2017)

Therefore, this law will oblige the approach towards BIM platforms also at national level and, inevitably, it will ensure that this approach will be relatively fast.

2.2 Project management standards

2.2.1 ISO 21500

The ISO 21500:2012 is the first of a family of ISO standards for portfolio, program and project management, and Governance. These standards serve as an internationally recognized overall framework that defines project, program and portfolio management. Also it defines the interaction between PPP processes and the organization they serve, including the governance dimension and the links to ongoing operations.

The ISO 21500 presents this content and structure:

- Clause 1 Scope, describing the scope of the guideline;
- Clause 2 Terms and definitions, containing 16 project management terms and their definitions;
- Clause 3 Project management concepts, describing key-concepts in most projects, Project, Project management, Organizational strategy, Environment, Project governance, Projects and operations, Stakeholders, Competencies, Project Life Cycle, Project constraints, Relationship between concepts and processes.
- Clause 4 Project management processes, listing 39 processes with key-inputs and outputs

2.2.2 The PRINCE standard/method

This standard is, in fact, a structured method, based on product, for effective project management. The PRINCE method was adopted in the UK, in 1989, when the standard for UK government information systems projects named PROMPTII has suffered some changes and has transformed in PRINCE. Starting with 1996 this method was replaced with PRINCE2. The PRINCE was updated in 2002, 2005 and in 2009. In present, the PRINCE2 methodology is the UK de facto standard for project management (Office of Government Commerce 2009).

In terms of content, the PRINCE standard/method considerate that the project management can be described by two models: the process model and themes (subject area) model.

In the process model, 7 processes can be identified:

a. Starting up a Project
b. Initiating a Project
c. Directing a Project
d. Controlling a Stage
e. Managing Product Delivery
f. Managing Stage Boundaries
g. Closing a Project

At present, the standard contains two distinct parts:
- Managing Successful Projects;
- Directing Successful Projects.

In principle, the Prince2 standard says what must be done in project, when and how it must be done and by whom.

2.2.3 The PMBOK® Guide/Standard

This guide (2012) provides guidelines, rules and characteristics for project management. “The Project Management Body of Knowledge” (PMBOK) is considered the American national standard for project management. It presents basic practices and key tools and techniques that can be applied for the good management of a project.

The PMBOK® Guide treated the project management based on project management processes which form five process groups. Also, this guide considered that project management can be covered by several knowledge areas (see Table 2).

Table 2 Process Groups and Knowledge Areas Matrix of PMBOK (re-elaboration of the author from PMBOK® guide)

Knowledge Areas	Project Management Process Groups				
	Initiating	**Planning**	**Executing**	**Monitoring and Controlling**	**Closing**
Integration	4.1 Develop Project Charter	4.2 Develop Project Management Plan	4.3 Direct and Manage Project Work	4.4 Monitor and control Project Work 4.5 Perform integrated Change Control	4.6 Close Project or Phase
Scope		5.1 Plan Scope Management 5.2 Collect Requirements 5.3 Define Scope 5.4 Create WBS	Activity Cost Estimate	Deliverables Status	Change Log
Time		6.1 Plan Schedule Management 6.2 Define Activities 6.3 Sequence Activities 6.4 Estimate Activity Resources 6.5 Estimate Activities Durations 6.6 Develop Schedule		6.7 Control Schedule	
Cost		7.1 Plan Cost Management 7.2 Estimate Costs 7.3 Determine Budget		7.4 Control Cost	
Quality		8.1 Plan Quality Management	8.2 Perform Quality Assurance	8.3 Control Quality	
Human Resources		9.1 Plan Human Resource Management	9.2 Acquire Project Team 9.3 Develop Project Team 9.4 Manage Project Team		
Communication		10.1 Plan Communication Management	10.2 Manage Communication	10.3 Control Communication	
Risk		11.1 Plan Risk Management 11.2 Identify Risks 11.3 Perform Qualitative Risk analysis 11.4 Perform Quantitative Risk 11.4 Plan Risk Progress		11.6 Control Risks	
Procurement		12.1 Plan Procurement Management	12.2 Conduct Procurement	12.3 Control Procurement	12.4 Close Procurement
Stakeholder	13.1 Identify Stakeholders	13.2 Plan Stakeholder Management	13.3 Manage Stakeholder Engagement	13.4 Control Stakeholder Engagement	
Processes	**2**	**24**	**8**	**11**	**2**

2.2.4 RIBA Plan of Work

The RIBA Plan of Work is published by the Royal Institute of British Architects and organizes the process of briefing, designing, constructing and operating building projects into eight key project stages, detailing the tasks and outputs required at each stage.

It was first available in 1963 as a guideline demonstrating the roles of participants in design and construction in the format of a simple matrix. It has evolved through its history to reflect the increasing complexity of projects, ever-changing regulatory requirements and industry demands, and government criticism.

The eight key stages of the Plan of Work are:

Stage 0: Strategic Definition

During this first stage, the client's business case, strategic brief and other core project requirements are identified. Initial considerations are made for assembling the project team. The Project Programme is established after a review of several sites. The consultants, in collaboration with the client, can properly define the scope for a project and the Preparation and Briefing process can then begin.

Stage 1: Preparation and Brief

In order to maximize the productivity of Stage 2 Concept Design, several parallel and significant activities need to be carried out throughout Stage 1.

This includes the development of the initial Project Brief and any related feasibility studies. The Project Team is assembled, and each party's roles are defined. When preparing the initial Project Brief, it is necessary to consider the desired project outcomes (potentially derived following feedback from earlier and similar projects), the project's budget, and the site itself (by undertaking site appraisals and collating site information).

A project risk assessment is required at this stage, and the procurement strategy and Project Programme should be developed.

Stage 2: Concept Design

The Concept Design represents the design team's initial response to the project brief. Throughout Stage 2, the initial Concept Design is produced in line with the requirements of the initial Project Brief. The Project Team develops several Project Strategies including the sustainability, maintenance, operational and handover strategies. These strategies consider post-occupancy and operational issues along with the consideration of buildability. Third party consultants are essential at this stage. The brief is revisited, updated and issued as the Final Project Brief, as part of the Information Exchange at the end of Stage 2.

Stage 3: Developed Design

Concept Design is further developed, and the design work of the core designers is progressed. By the end of Stage 3, the architectural, building services and structural engineering designs will all have been developed and will have been checked by the lead designer. The Cost Information is to be aligned to the Project Budget.

Project Strategies that were prepared in Stage 2 should be developed and detailed, allowing the client to signed them off once the lead designer has checked each strategy and verified that the Cost Information incorporates enough allowances.

Stage 4: Technical Design

The lead designer co-ordinates the preparation of the technical design, as this may involve design by specialist subcontractors as well as the client's core design team. By the end of this stage the architectural, structural and mechanical services design and specifications should describe all main components of the building and how they fit together, and any performance specified work should be defined.

Stage 5: Construction

During this stage, the building is constructed on site in accordance with the Construction Programme. This includes the erection of components that have been fabricated off site. The procurement strategy will have set out the designer's duties to respond to design queries from site generated in relation to the design.

Stage 6: Handover and Close Out

The project team will facilitate the successful handover of the building in line with the Project Programme and conclude all aspects of the building contract. Other services may be required at this point which will be dictated by the project specific schedules of services. This should be aligned with the procumbent and handover strategies.

Stage 7: In Use

This new stage of the RIBA Plan of Work acknowledges the potential benefits of harnessing the project design information to assist with the successful use and operation of the building.

2.2.5 Other reference standards

In Table 3 some of the many international project management reference standards are listed.

Source	**Name**	**Year**
AFNOR	X50-115 – Le Management de projet	2017
APM	APM Body of Knowledge, 7th ed.	2019
BS	BS 6079 – Project management. Principles and guidelines for the management of projects	2019
DIN	DIN 69901 Projektmanagement	2009
IPMA	ICB V.3	2006
ISO	UNI ISO 10006 – Sistemi di gestione per la qualità – Linee guida per la gestione per la qualità nei progetti	2017 (italian edition 2018)
ISO	UNI ISO 10007 – Linee guida per la gestione della configurazione	2017 (italian edition 2018)
ISO	ISO 31000 – Risk Management – Principles and Guidelines	2018
PPMAJ	P2M – A Guidebook of Project & Program Management for Enterprise Innovation	2005

Table 3 Project management reference standards (elaboration of the author)

CHAPTER THREE: LEAN PRODUCTION

3.1 Lean thinking

In this chapter there are described the main principles of *Lean Thinking*, which is an operational strategy born from the automotive sector, but now universally applied in different sectors and fields to increase efficiency and eliminate waste.

It is an operational strategy because it contains, together with the framework of thought and organizational theories, also the practical approach (the human work that is needed to achieve the lean conversion). The whole company is involved in an overall vision through the flow of the main processes, from design to order management:

- from the idea of marketing, through the process of developing new products, we arrive at a validated pre-series,
- from the customer's request, through the information management process and order management, we get to give the customer what he asked for,
- from the suppliers, through the production transformation process, the finished packaged product is reached
- from the warehouse and from the finished products, through the distribution/installation and delivery process, the customer is given the availability of the finished product.

All these processes also involve the organization, industrial accounting and quality management to minimize the use of resources committed.

3.2 Lean production

Lean Production was coined by Womack *et al* (1990) to describe the implementation of the ideas inherent in the Toyota Production System. It was based upon their studies of the car manufacturing industry in Japan and other countries. Womack and Jones (1996) moved from the automotive industry to look at manufacturing in general and established the five principles for Lean Production (Figure 4); this theoretical foundation is called *Lean Thinking* by them:

1) *Value*: value can only be defined by the ultimate customer, where the customer can be considered as all downstream operations. This is the first step to waste recognition, defined as everything that adds no value from the clients' perspective.

It can be applied in the construction context in which end customers are multiple and the construction client can rarely be considered as the single ultimate customer.

2) *Value stream*: value stream analyses three types of actions along with the value stream: first, activity creating value; second, activity creating no value but is unavoidable with current technologies and production assets; third, activities creating no value and are determined to be avoidable;

3) *Flow*: The concept of flow is one of the core elements of Lean Thinking philosophy to achieve complete removal of waste. Once a company has reduced or eliminated waste and variation from a single process and streamlined the value stream, the next step is to make the remaining process steps flow. It is the opposite of batch and queue. The goal of this principle is to have a product move from concept to customer without interruption or delay;

4) *Pull*: this principle is closely related to the "pull" system which the TPS firstly created. The end users pull the production such that it is only produced to suit their requirements;

5) *Pursue perfection*: this principle indicates "the complete elimination of muda so that all activities along a value-stream create value" (Womack and Jones 1996). The lean concept associated with perfection is kaizen, a Japanese word which is interpreted as continuous improvement in the West. By applying the previous four principles each time, the organization gains more and finds more hidden wastes that can be eliminated.

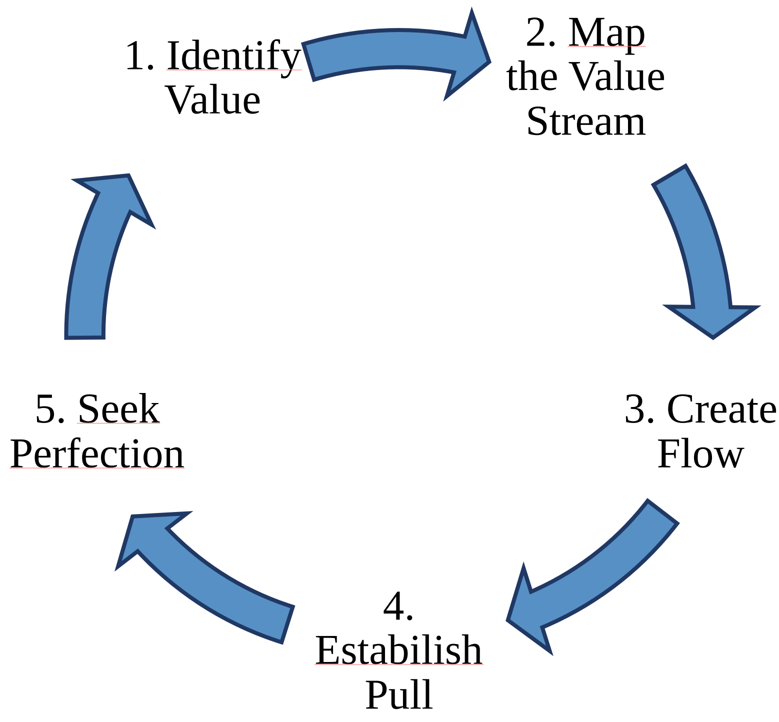

Figure 4 The five principles of Lean Thinking (re-elaboration of the author)

The five principles make it obvious that the optimization of the flow – of value towards the costumer – is the guiding principle. The three middle principles focus directly on this, whereas the first and the fifth can be seen as general objectives. The principles have thus derived from an ordered situation with a well-known product and customer base, a production process that is precisely defined and a well-established supply chain.

Not an unusual situation in manufacturing, and the principles have also proved themselves valuable in increasing productivity in several western manufacturing industries and are thus very useful. But that does not at all prove their usefulness for a special kind of production such as construction, because their use should then be argued by showing that construction is a production similar to manufacturing, which it indeed is not.

According to Koskela (1992) instead, *11 important principles* are essential to the lean philosophy, including:

1) Reduce the share of non-value-adding activities

Value-adding and non value-adding activities can be defined as follows:

- Value-adding activity: activity that converts material and/or information towards that which is required by the customer.
- Non value-adding activity (also called waste): activity that takes time, resources or space but does not add value.

2) Increase output value through systematic consideration of customer requirements

The organizational and control principles of the conventional production philosophy have tended to diminish the role of customer requirements. In many processes, customers have never been identified nor their requirements clarified. The dominant control principle has been to minimize costs in each stage, and this has not allowed for optimization of cross-functional flows in the organization. The practical approach to this principle is to carry out a systematic flow design, where customers are defined for each stage, and their requirements analyzed.

3) Reduce variability

There are two reasons for reducing process variability. First, from the customer point of view a uniform product is better. Secondly, variability, especially of activity duration, increases the volume of non-value-adding activities. Standardization of activities by implementing standard procedures is often the means to reduce variability in both conversion and flow processes.

4) Reduce cycle time

A production flow can be characterized by the cycle time, which refers to the time required for a particular piece of material to traverse the flow. The cycle time can be represented as follows:

Cycle time = Processing time + inspection time + wait time + move time

The basic improvement rationale in the new production philosophy is to compress the cycle time, which forces the reduction of inspection, move and wait time. Simplify by minimizing the number of steps, parts and linkages; In addition to the forced elimination of wastes, compression of the total cycle time gives the following benefits (Schmenner 1988, Hopp *et al.* 1990):

- faster delivery to the customer;

- reduced need to make forecasts about future demand;
- decrease of disruption of the production process due to change orders;
- easier management because there are fewer customer orders to keep track of;
- shorter the cycle time, the more cycles are affordable;

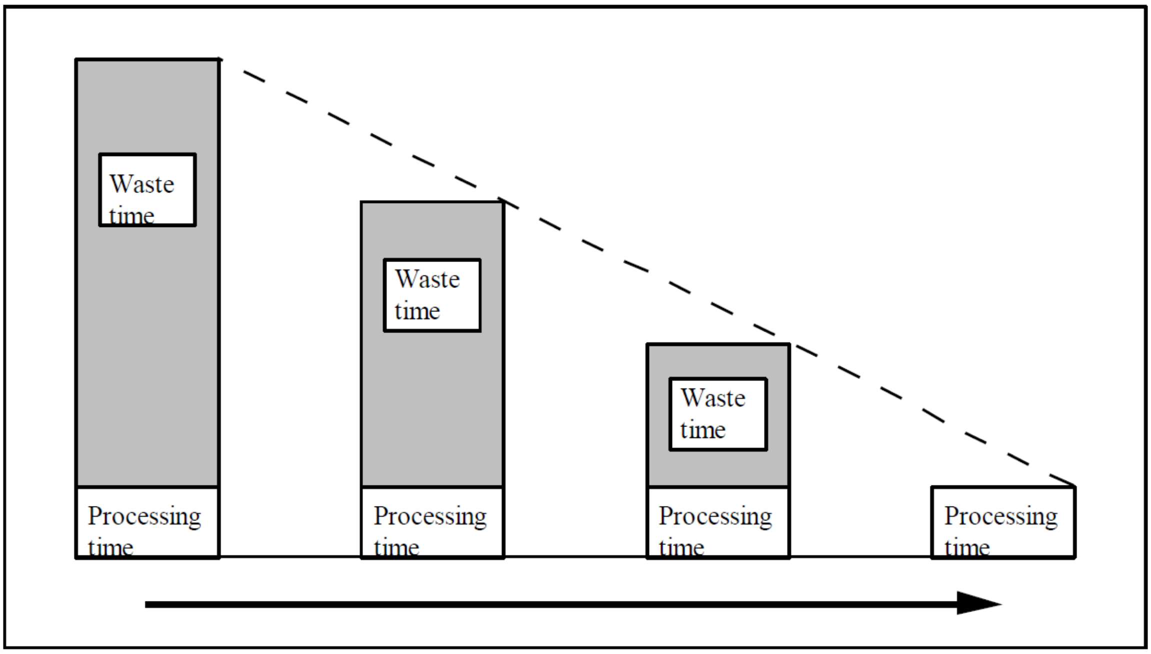

Figure 5 Cycle time can be progressively compressed through elimination of non-value adding activities and variability reduction (Berliner & Brimson 1988)

5) Simplify by minimizing the number of steps and parts

The very complexity of a product or process increases the costs beyond the sum of the costs of individual parts or steps. Another fundamental problem of complexity is reliability: complex systems are inherently less reliable than simple systems. Also, the human ability to deal with complexity is bounded and easily exceeded. Simplification can be understood as

- reducing of the number of components in a product
- reducing of the number of steps in a material or information flow

Simplification can be realized, on the one hand, by eliminating non value-adding activities from the production process, and on the other hand by reconfiguring value-adding parts or steps.

Organizational changes can also bring about simplification. Vertical and horizontal division of labor always brings about non value-adding activities, which can be eliminated through self-contained units (multi-skilled, autonomous teams).

Practical approaches to simplification include:

- shortening the flows by consolidating activities
- reducing the part count of products through design changes or prefabricated parts
- standardizing parts, materials, tools, etc.
- decoupling linkages
- minimizing the amount of control information needed.

6) Increase output flexibility

Increase of output flexibility seems to be contradictory to simplification. However, many companies have succeeded in realizing both goals simultaneously (Stalk & Hout 1989). Some of the key elements are modularized product design in connection with an aggressive use of the other principles, especially cycle time compression and transparency. Practical approaches to increased flexibility include (Stalk & Hout 1989, Child & al. 1991):

- minimizing lot sizes to closely match demand
- reducing the difficulty of setups and changeovers
- customizing as late in the process as possible
- training a multi-skilled workforce.

7) Increase process transparency

Lack of process transparency increases the propensity to err, reduces the visibility of errors, and diminishes motivation for improvement. Thus, it is an objective to make the production process transparent and observable for facilitation of control and improvement: "to make the main flow of operations from start to finish visible and comprehensible to all employees" (Stalk & Hout 1989). This can be achieved by making the process directly observable through organizational or physical means, measurements, and public display of information.

Practical approaches for enhanced transparency include the following:

- establishing basic housekeeping to eliminate clutter: the method of 5-S7
- making the process directly observable through appropriate layout and signage
- rendering invisible attributes of the process visible through measurements
- embodying process information in work areas, tools, containers, materials and
- information systems

- utilizing visual controls to enable any person to immediately recognize standards and deviations from them
- reducing the interdependence of production units (focused factories).

8) Focus control on the complete process

There are two causes of segmented flow control: the flow traverses different units in a hierarchical organization or crosses through an organizational border. In both cases, there is a risk of sub optimization.

There are at least two prerequisites for focusing control on complete processes. First, the complete process has to be measured. Secondly, there must be a controlling authority for the complete process. Several alternatives are currently used. In hierarchical organizations, process owners for cross-functional processes are appointed, with responsibility for the efficiency and effectiveness of that process (Rummler & Brache 1990). A more radical solution is to let self-directed teams control their processes (Stewart 1992).

For inter-organizational flows, long term co-operation with suppliers and team building have been introduced with the goal of deriving mutual benefits from an optimized total flow.

9) Building continuous improvement into the process

The effort to reduce waste and to increase value is an internal, incremental, and iterative activity, that can and must be carried out continuously. There are several necessary methods for institutionalizing continuous improvement:

- Measuring and monitoring improvement.
- Setting stretch targets (e.g. for inventory elimination or cycle time reduction), by means of which problems are unearthed and their solutions are stimulated.
- Giving responsibility for improvement to all employees; a steady improvement from every organizational unit should be required and rewarded.
- Using standard procedures as hypotheses of best practice, to be constantly challenged by better ways.
- Linking improvement to control: improvement should be aimed at the current control constraints and problems of the process. The goal is to eliminate the root of problems rather than to cope with their effects.

10) Balance flow improvement with conversion improvement

For any production process, the flow and conversion aspects each have a different potential for improvement. As a rule:

- the higher the complexity of the production process, the higher the impact of flow improvement
- the more wastes inherent in the production process, the more profitable is flow improvement in comparison to conversion improvement.

The crucial issue is that flow improvement and conversion improvement are intimately interconnected:

- better flows require less conversion capacity and thus less equipment investment
- more controlled flows make implementation of new conversion technology easier
- new conversion technology may provide smaller variability, and thus flow benefits.

11) Benchmark

Often benchmarking is a useful stimulus to achieve breakthrough improvement through radical reconfiguration of processes. The basic steps of benchmarking include the following (Camp 1989):

- knowing the process; assessing the strengths and weaknesses of subprocesses
- knowing the industry leaders or competitors; finding, understanding and comparing the best practices
- incorporating the best; copying, modifying or incorporating the best practices in your own subprocesses
- gaining superiority by combining existing strengths and the best external practices

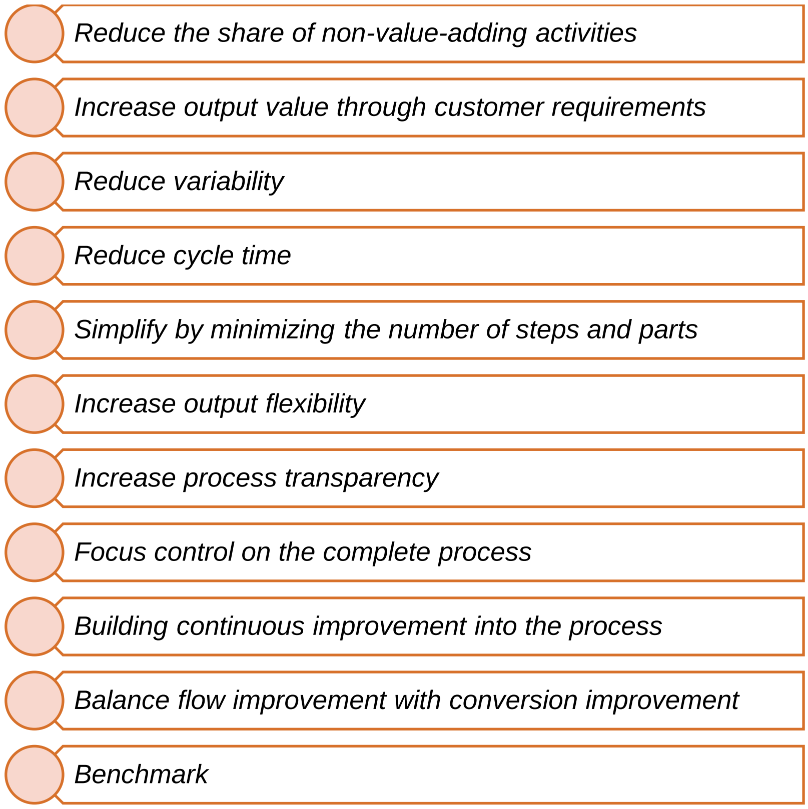

Figure 6 The 11 important principles of lean philosophy according to Koskela

3.3 Shingo's theory

The *lean* concept in general is a western interpretation of the Japanese production philosophy. Some fundamental principles were extracted from the works of Shigeo Shingo as one part of the basis for Lean Construction.

Shingo (1988) considers minimizing waste as the central element in the development of the manufacturing process. The value generation, on the other hand, plays only a minor role in his thinking. Indeed, the term *value* is very hard to find in his works.

Single piece flow is his strategy in obtaining minimal waste because this forces the system to make no errors and to be flexible. Consequently SMED (Single Minute Exchange of Die) is a central issue for Shingo. Stock on the other hand is a phenomenon, which can be seen as waste, but – more importantly – is considered a narcotic, hiding errors in the process flow. This is contrary to the Western thinking where a certain amount of stock is accepted as a buffer, offering protection against the flow variation.

Shingo also puts emphasis on the involvement of the individual worker in solving process problems and undertaking product inspection – *poka yoke* – just as communication between workers along the process line is seen as a means for improving the flow of work. This can be seen as the recognition of the process not being totally ordered and foreseeable and that the approach to this should be cooperation and learning.

3.4 Toyota production system

Toyota first drew the world's attention back in the 1980s, when it became clear that there was something special in terms of Japanese quality and efficiency. It began with Eiji Toyoda's determination to implement American manufacturing methods (mass production techniques) when he studied in the USA in the 1950s. It then took considerable time for Toyota to find ways to maintain economies of scale in manufacturing and procurement with small-lot production. One principle that was considered as worthwhile to adapt from Ford's production system was the *continuous flow*. On the basis of continuous flow, Toyota created a one-piece flow with a unique flexibility to satisfy the customers' demands.

Toyota learnt from the essence but did not follow the mass production approach blindly, so that Toyota led the way in developing what is now called the TPS (Toyota Production System).

TPS's goal is to reduce cost without increasing production volume and the basis to achieve is the elimination of waste.

It has been widely acknowledged that the two pillars of the Toyota Production System are Just-in-Time and Jidoka (Autonomation).

Just-In-Time manufacturing prescribes the required units needed to produce the required quantities at the required time, wasting neither raw material nor time. A manufacturing company establishing this flow throughout can ideally approach zero inventories. Just in time is hardly an easy task, as it requires the coordination of potentially thousands of components/parts arriving where and when needed in just the right quantities, with all parts meeting the quality parameters.

Autonomation, often known as its Japanese abbreviation "jidoka", means "never let a defect pass into the next station". In all Toyota manufacturing plants, most machines, whatever old or new, are equipped with such devices as well as various safety devices to prevent defective products. The idea is to build quality in the process by distinguishing between normal and abnormal conditions, stopping production line once there is a problem being detected. It calls attention to the abnormal to ensure that its root cause is found and eliminated.

In the TPS house, “people and teamwork” are in the center of the system because only through continuous improvements the operation can ever attain the needed stability. People must be trained to identify waste and solve problems at the root causes. Finally, there are various foundational elements, which include the need for standardized, stable, and levelled processes.

CHAPTER FOUR: LEAN CONSTRUCTION

4.1 Definition of Lean Construction

A simple definition of lean construction was given by Koskela (2002):
"Lean construction is a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value."
Lean construction principles and practice have been examined and developed in two interacting research streams.
The practical stream started with Howell and Ballard's (1995) observations that typically only half of the tasks in a weekly plan get realized as planned on site. In a series of experimental work, a new approach to production control, called the Last Planner System, was developed (Ballard 2000). Whilst Last Planner covers production control and improvement, methods for production system design have also been developed (Ballard *et al*. 2001).

The theoretical stream started with Koskela's (1992) analysis of the application of the new production philosophy to construction. The question is about the interpretation of generic principles of operations/production management. In (Koskela 2000) the discussion on the principles was deepened and theoretical explanation for the principles was presented, based on current theories in operations management.

Construction is obviously a production, and Koskela (2000) establishes a theory for production and demonstrates its use in construction.
The basic idea is that construction should not be seen as transformation only but understood as a flow of work and a creation of value as well.

In understanding the nature of construction, it should also be recognized that construction makes one-of-a-kind products and do so on the site by cooperation within a multi-skilled ad-hoc teams. A general definition of the nature of construction from a production point of view may thus be:

"Construction is a complex production of a one-of-a-kind product undertaken mainly at the delivery point by cooperation within a multi-skilled ad-hoc team." (Bertelsen and Koskela 2004)

The above definition of construction indicates at least four characteristics. Construction is *production* and it produces a *one-of-a-kind product;* it is also *complex* and undertaken through *cooperation*.

4.2 Construction as production

Koskela (2000) introduces three basic conceptualizations of production: transformation, flow and value generation. Bertelsen and Koskela (2004) consider these three aspects from a management point of view as outlined in the following.

4.2.1 Managing Transformation

Managing transformation is the kind of project management most project managers are familiar with. It takes place by managing contracts, establishing quality and safety requirements and procedures, and it frequently leads to what seems to be an increase in productivity but in truth is sub-optimization only.

It is necessary to manage the transformations in construction if for no other reason than because of the huge contract values involved, but this simplistic kind of project management is not adequate in the complex and dynamic system the project usually represents.

4.2.2 Managing Flow

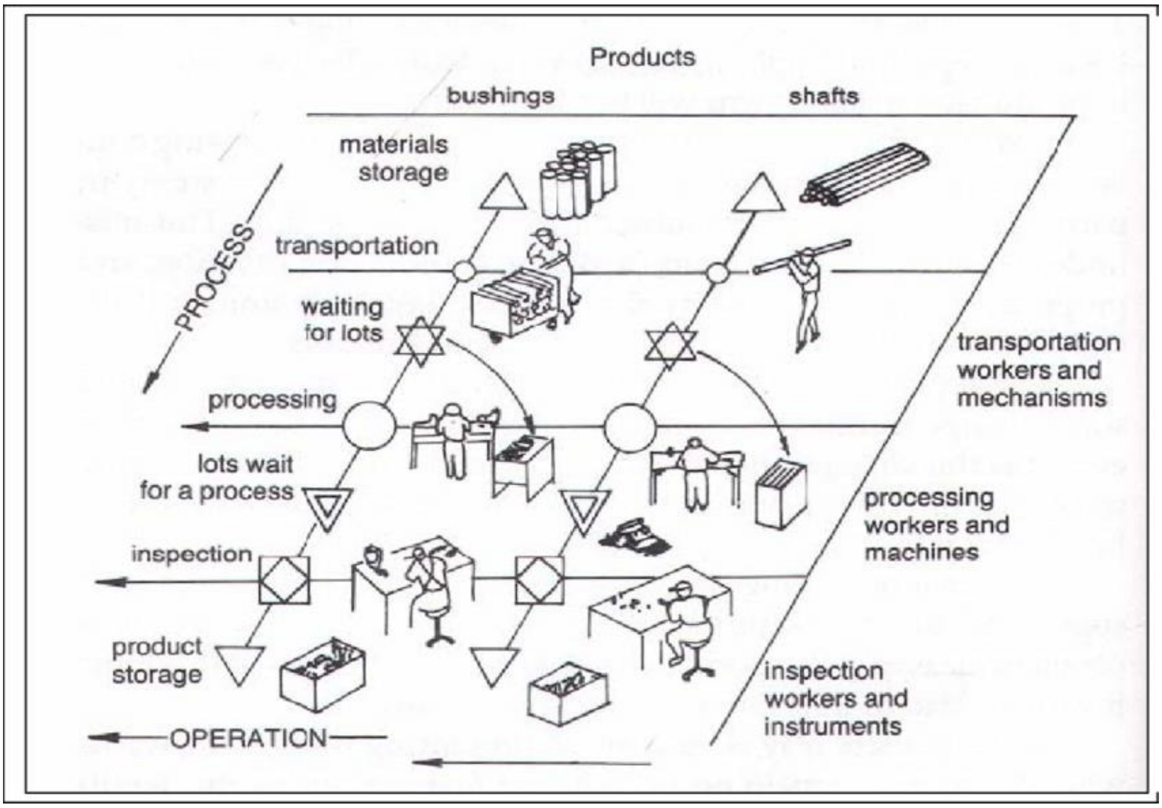

Figure 7 Flow of process and operations (Shingo 1988)

Managing flow in the construction industry introduces several new management activities. One should be to establish a closer cooperation along the supply chain – Supply Chain Management has this been coined in the manufacturing industry. This kind of cooperation should not only comprise cooperation between main contractor and trade contractors but should comprise the manufacturers and suppliers of construction materials as well. Another activity should be setting up the logistics for materials and information.

The method of Last Planner (Ballard 2000) can be seen as an important tool in managing this cooperation and the logistics during the construction phase.

4.2.3 Managing Value Generation

The concept of value is probably the most difficult to approach in the new way of managing construction projects. Green (1996) proposes an understanding of the value generation during the early design phases as a learning process between the client and the design professionals. Both parties learn and through this a joint understanding of client's value parameters and their realization in the design is reached.

Christoffersen (2003) reports the successful implementation of a systematic value management as proposed by Bertelsen *et al* (2002) in order through the project life cycle to make sure the specified value is delivered, whereas Green (1996) introduces value engineering as the task of generating the specified value with the lowest costs.

4.2.4 Uncertainty in Construction Flows

Koskela (2000) suggests that construction embodies assembly activities requiring several input flows. As Figure 8 shows, he distinguishes at least seven flows including: previous work, information, material, equipment, workers, space, and external conditions.

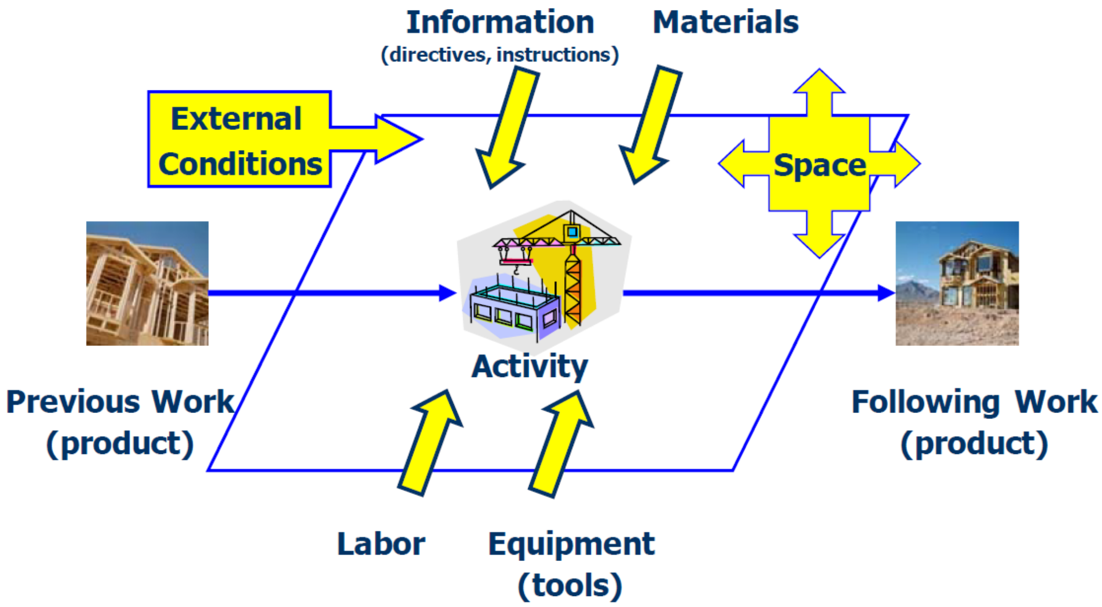

Figure 8 Flows involved in a construction activity (Koskela 2000)

Since activity completion depends on the intersection of these flows, this forms a matching problem or a merge bias. A merge bias can be defined as a variability impact on a successor activity by predecessor activities or prerequisite inputs flowing into that successor activity. As an example, assume that activities E and F (each with a duration of 3 days) are predecessors to activity G (finish-to-start relationship). Assuming E and F would finish in is less than 3 days (E and F will finish at time 3) with a 60 % chance. Then the chance that activity G will start at time 3 is only 36% (60% x 60%). This comes as a result of the merge bias and the impact of E and F on G (Tommelein 2006). This matching problem or merge bias results from several flows combining to support an activity. Thus, the realization of a successor activity relies on the synchronization of these flows. Accordingly, flow synchronization is contingent to variability in each of these flows. While activity completion depends on these flows, the advancement of these flows into other activities downstream is contingent on activity completion. In other words, prerequisites or resources freed from a predecessor activity can now flow to a successor activity, while at the same time product output from the preceding activity can serve as previous work for the successor activity as shown in Figure 9.

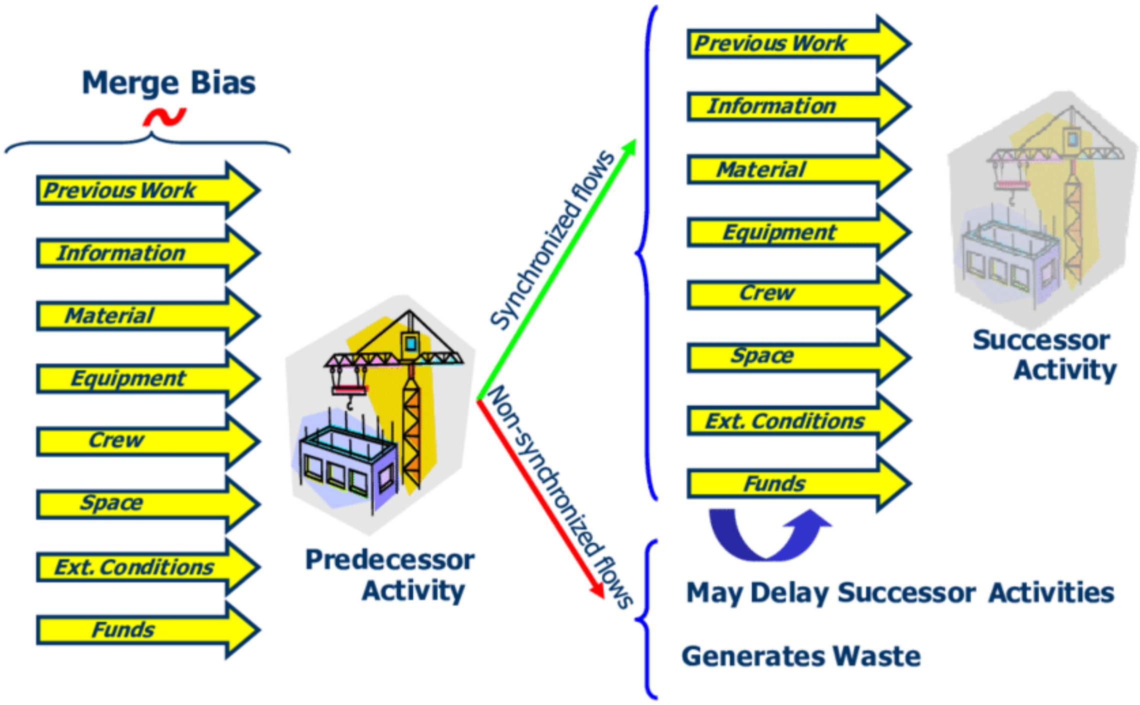

Figure 9 Effect of synchronized flow on successor activities (Koskela 2000)

4.2.5 Complexity in Construction

Generally, project management understands the project as an ordered and simple – and thus predictable – phenomenon which can be divided into contracts, phases, activities, work packages, assignments etc. to be executed independently. The project is also seen as a mainly sequential, assembly- like, linear process, which can be planned in any degree of detail through an adequate effort and executed in accordance with the plans. As a consequence, project management acts top down, mainly by management-as planning as proven by Koskela and Howell (2000). The plans and schedules present an idealized linear picture of what *should* take place, but not of what actually does take place.

According to Bertelsen (2002), the perception of the project's nature as ordered and linear is a fundamental mistake, as the dynamics of the surrounding world is not considered. Project management must perceive the project as a complex, dynamic phenomenon in a complex and non-linear setting. This can be seen already in the wicked nature of the building design process, which is caused by the fact that there is no optimal solution to the problems faced, and where preconditions are defined in parallel with the solutions. Very often the results of this complexity of the design process overflow to the next stage, construction, in the form of delays, deficient information and poorly constructible design solutions.

However, the same kind of wickedness is often found in the construction phase, which is characterized by the close succession of:

- production system design;
- production system realization;
- operation of the production system;
- dismantling of the production system.

Thus, the possible, and in practice frequent, problems in production system design and realization get inevitably entangled with the operation of the system. Note that in manufacturing, production system design and realization are infrequent events, and the focus is on the operation of the production system in the framework of a stable, existing production system.

A further complication in the construction stage is that when the production system is temporary, there are usually several projects competing for the resources of any subcontractor (O'Brien 1998). Thus, disturbances in one project are easily transmitted to other projects. This phenomenon exists also in the design stage.

A construction project may look like a sequential assembly-like process, and so it is in a distant perspective. But in detail, the process is highly parallel. Many project activities are not interdependent and may be executed in any sequence or even simultaneously without any effect on the overall result. Starting from the bottom, it is up to the individual craftsman to choose his way of doing the job at hand. No formal process description is normally provided, and the industry practice of not interfering across contractual boundaries with the way work has to be carried out, enhances this informality in the low-level process design. But also at higher levels is the process not sequential. The trade contractor may have his own way of executing the job. The weather may change the sequence, and unforeseen events may enforce further changes in the sequence, which to a great extent can be made without any impact on the general schedule. This potential for non-sequential progress is used for buffering the variability caused by the complex nature of construction, although often further problems are simultaneously created. (Koskela 2004)

The different stakeholders participating in the construction process have different targets and objectives as well but have to collaborate in order to complete the project successfully. Compromise is the way ahead in great many cases.

4.2.6 **Waste in construction**

A simple way to define waste is *"that which can be eliminated without reducing customer value"*. (Chen *et al*., 2002)

The basic idea of lean production is eliminating all kinds of waste for fulfillment of customer requirements in a better way. Koskela (1992) defined waste as *"any inefficiency that results in the use of equipment, materials, labor or capital in larger quantities than those considered as necessary in the production of a building"*.

Pheng and Tan (1998) defined waste as "*the difference between the value of those materials delivered and accepted on site and those used properly as specified and accurately measured in the work, after the deducting cost saving of substituted materials and those transferred elsewhere"*.

Waste can be classified as *unavoidable waste* (or natural waste), in which the investment necessary to its reduction is higher than the economy produced, and *avoidable waste*, in which the cost of waste is higher than the cost to prevent it. The percentage of unavoidable waste depends on the technological development level of the company.

According to Bajjou *et al.* (2017), there exist nine basic types of waste, classified as follows:

1) **Over-production**. Over produce is the fact of producing more than the demand (internal, external), for example, a work that will not be used, and will be a short term demolished because it has no added value for the customer (or end user). According to Dupin (2014), overproduction is using more material than necessary, more resources than necessary and / or oversized equipment for the task to perform.

An indicator of overproduction is the amount of waste thrown into dumpsters and which are evacuated monthly, weekly or daily depending on the size of the project. Dumpsters are most often filled with waste in all type: pieces of plates of plaster, concrete, scrap metal, wood, cables, and used equipment…sign of a push flow. Furthermore, overproduction has a tendency to generate other types of wasting. Namely, it causes the creation of the stock of materials, which consumes more space in addition to the excessive cost of storage and the transport actions required in this case.

2) **Inventory**. It is the storage of materials (raw materials, equipment…) that represents an immobilized value source of loss of value for the company. Excessive inventories are usually generated because of the large quantity supply, based on the principle that more the truck is loaded more the cost of transport will be optimized. But the disadvantages of this approach that the materials delivered on site, which will not be used in the short term, are sources of various expenses: the cost of storage, stock management, and a waste of time to search for the material sought. In addition to that, the free surfaces become smaller on the sites, and the space occupied by these materials eliminates the possibility to use them for other tasks which contribute on blocking and interrupting the flow of production.

3) **Unnecessary Transportation**. The unnecessary transportation is having a non-optimized logistic flow, which produces actions of transportation for delivery of the raw material, the displacement of materials from a station to another using the crane or the operators. According to Dupin (2014), the success of most construction projects is due in large part to the ability of the project team to organize its logistics flows (Delivery, evacuation of equipment and materials). Transport is a vital process for production. In contrast, unnecessary transports actions may contribute to the generation of additional waste in the production chain, and do not add value to the final results of the end product.

4) **Displacements**. Studies conducted at a major global construction showed that a worker was walking between seven and nine kilometers per day (Bajjou *et al.* 2017). These displacements may be due to several factors such as searching for information (plan, orders, details...), tools, materials or transition from a work area

to another one (Dupin 2014). Unnecessary displacements of the operators to look for the equipment generate a negative effect on the quality of the moved products (damage, degradation…), as they promote the risk of having accidents of work on a construction site.

5) **Over-processing**. Over-processing are the unnecessary tasks performed on the product without being requested by the client. In addition to that, over-processing also includes the use of tools and instruments too expensive and more robust than necessary to satisfy the internal and external customer need. Unnecessary work is considered as sources of waste because they do not add value to the final product (Sieng 2012). Dupin (2014) defines over-processing as the level achieved when the cost and energy spent on a system systematically exceed the risk that the quality approach aims to eliminate. Over-processing is a too complex process, implementing too many materials, quality, or information in comparison with the selling price. The useless treatments are those that do not add value to the end product. For instance, the use of two packing instead of one, the excess of meetings or dashboards with too many indicators, is considered as over-processing.

6) **Defects**. The deadline for completion of construction projects can quickly increase if companies encounter defects in the construction phase, which produces actions of repairing of what was already accomplished. The defects are sources of generation of direct and indirect waste. Directly, by the resources consumed to implement (materials, equipment, labor…) and indirectly by the revenue not generated during the repair phase. Defects generate negative effects on the rentability of the companies (desynchronization of the rest of the work, disorder, danger for the personnel security, lack of motivation of the operators as well as more penalties) (Dupin 2014). According to Dos Santos (1999), the lost cost to solve the problems of nonconformity, errors and changes in the construction projects is approaching 10% of the total project cost.

7) **Waiting**. Waiting is a very important source in the ocean of waste. Actually, waiting does not add value for the customer. The action of waiting most directly visible, obviously, the fact of not being able to immediately perform a task because of a lack of material, equipment, labor, information, plan, validation, etc. It can be

linked to poor synchronization of sequences of work or breakdowns. According to the studies carried out by Dupin (2014), waiting is the largest portion of all sources of waste, representing 29% of the time spent on the site of construction.

8) **Unused employee creativity**. In a traditional system based on the classic scheme of command / control, the orders given by the superior hierarchical do not leave a large margin for initiative and creativity, whether individual or collective (Dupin 2014). So, little information circulates transversely, and operators must always carry out their work without giving feedback or proposal for promoting the performance and the reliability of the company. The non-use of staff skills is considered as the eighth source of waste because the companies do not take advantage of a great potential that is available and that can produce creative ideas and generates added value for the customer.

9) **Work accidents**. The improved performance in relation to the safety of personnel, such as reducing injury and fatality rates, is an example of reducing waste. Death or injury of skilled and experienced workers represent a loss of reliability of the process and certainly create additional costs such as the cost of lost time, the cost of insurance, the high cost of medical treatment in addition to a rehabilitation program. Economic losses also include indirect losses such as administrative costs, a decrease in productivity and a reduction of staff motivation. It follows, then, that the protection of workers against occupational accidents would be a primary goal in the process of eliminating waste.

Waste can also be categorized according to the stage in which the root causes of waste occurs. Waste may result from the processes preceding construction, such as materials manufacturing, design, materials supply, and planning, as well as the construction stage. The main waste sources in construction in 6 sources can be classified in:

1) Design
2) Procurement
3) Materials Handling
4) Operation
5) Residual
6) Other.

4.3 Application channels of lean construction

4.3.1 Value Stream Mapping (VSM)

Value Stream Mapping is a graphic visualization tool that has its roots in Toyota's production philosophy. It means the graphic mapping of all that set of processes and activities that contribute to the creation of a product, starting directly from the supplier, passing through the entire assembly line up to the delivery of the finished product (Figure 10).

Some adaptations have been applied in construction industry by using a Value Stream Mapping as a lean construction tool. VSM was adapted to reduce the high percentage of non-value-added activities and time wastes during each construction stage. (Gunduz *et al.* 2018)

The assumption on which to base the analysis of the value chain is not the improvement of the single process, but the global and continuous optimization.

The peculiarities of the process mapping are two:

a. Current State Map: describes the situation of the product in the flow of value.
b. Future State Map: indicates the way in which you want to see the product within the flow of value.

The aims of VSM are:

a. not focusing on the single process but on the flow;
b. finding the causes of waste within the flow;
c. giving all staff the tools to read the flow;
d. having a visualization of the aspects that have made the process more efficient;
e. implementing a Lean Manufacturing system.

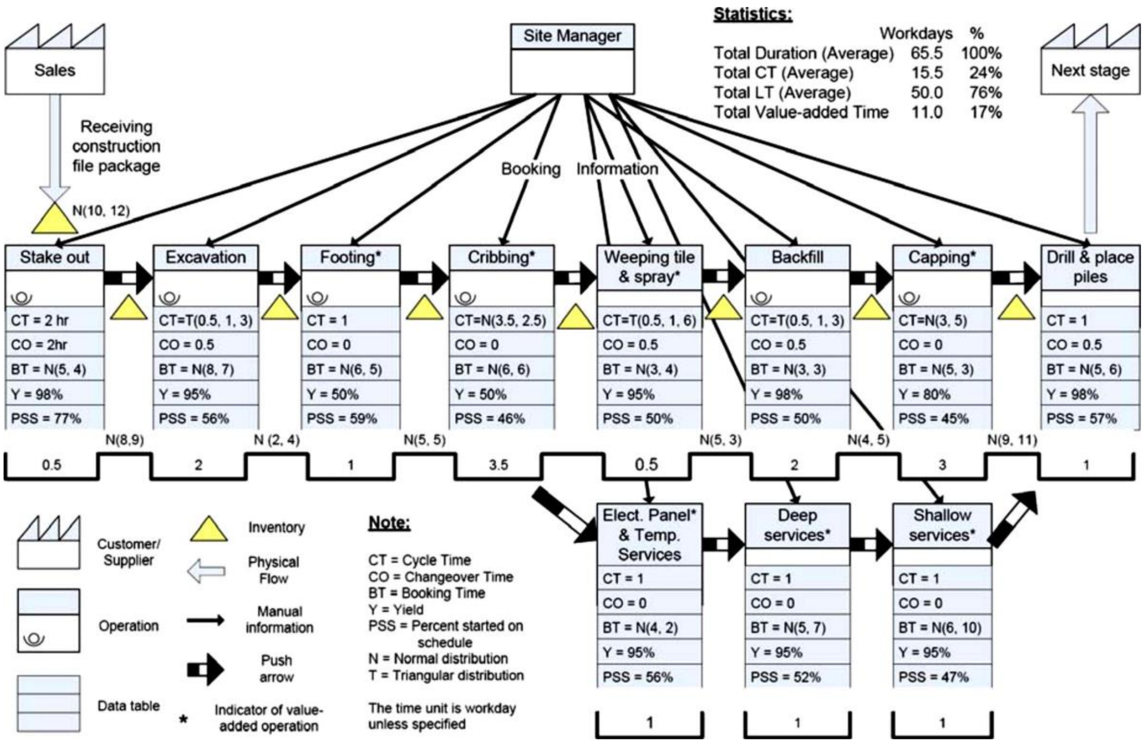

Figure 10 Example of a Value Stream Mapping scheme (Yu et al*. 2009)*

4.3.2 Lean Project Delivery System (LPDS)

The Lean Project Delivery System is a set of interdependent functions, rules of decision making, procedures for execution of functions, and as implementation aids and tools, including software when appropriate, and is a conceptual framework developed by Ballard (2000) to guide the implementation of lean construction on project-based production systems.

LPDS was depicted as a model with five main phases, where each phase is comprised of three modules. The interdependence between the phases was represented by sharing one module between two subsequent phases. Production control and lean work structuring were both shown to extend throughout the five main phases. Learning was introduced to underscore the need to document lessons learned from one engagement to another.

The LPDS model consists of 15 modules, 11 organized in 4 interconnecting triads extending from project definition to design to supply and assembly, plus 2 production control modules and work structuring module, both conceived to extend through all project phases, and the post-occupancy evaluation module, which links the end of one project phase to the beginning of the next:

1) Project Definition:

a) Needs and Values Determination;

b) Design Criteria;

c) Conceptual Design;

2) Lean Design:

a) Conceptual Design;

b) Process Design;

c) Product Design;

3) Lean Supply:

a) Product Design;

b) Detailed Engineering;

c) Fabrication/Logistics;

4) Lean Assembly:

a) Fabrication/Logistics;

b) Site Installation;

c) Testing/Turnover;

5) Production Control:

a) Workflow Control;

b) Production Unit Control.

Work Structuring and Post-Occupancy Evaluation are thus far only single modules.

Essential features of LPDS are as follows:

1) Structure and management of a project are aimed at creating value;
2) Cross-functional teams, involved in front end planning and design, include members from all areas of production process;
3) Project control would be a tool executed throughout the project as opposed to reliance on after the fact variance detection;
4) Optimization efforts are focused on making workflow reliable and not to focus on improving productivity;
5) Pull techniques are used to govern the flow of materials and information;
6) Capacity and inventory buffers are used to absorb variability in the production process;
7) Feedback loops incorporated at every level, are aimed at a rapid system adjustment and learning;

8) Work structuring of the entire process increases value and reduces waste at the project delivery level.

Efforts to improve performance at the planning level increases performance at project level.

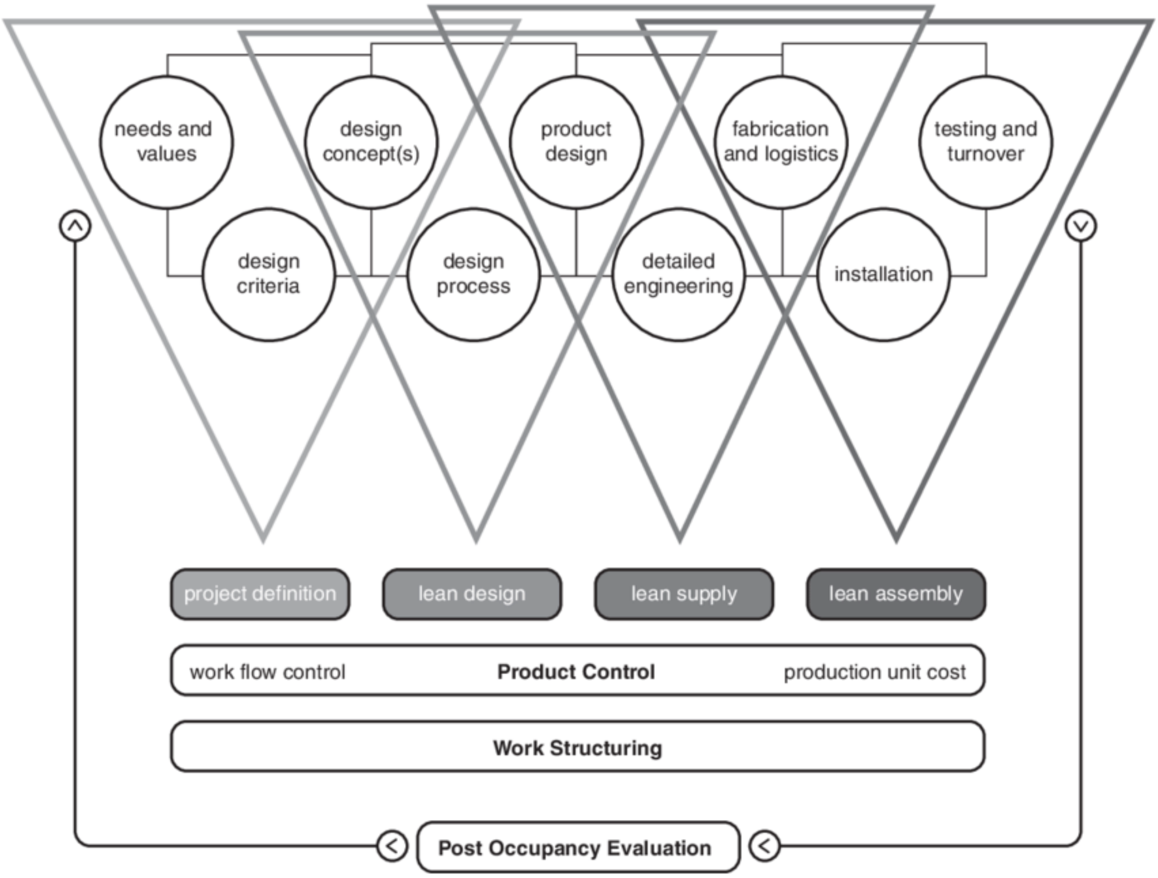

Figure 11 Triads of the LPDS (Koskela et al. *2002)*

4.3.3 Last Planner System (LPS)

One of the most effective ways to increase efficiency of construction industry is to improve planning and control process.

In Lean Construction, planning and control are considered to be complementary and dynamic processes maintained during the course of the project. Planning defines the criteria and creates strategies required to reach project objectives; control makes sure that each event will occur following the planned sequence. Re-planning must be done when the previously established sequences are no longer applicable or convenient. Feedback facilitates learning when the events do not occur as planned.

One of the best-known Lean techniques is the Last Planner System which has been demonstrated to be a very useful tool for the management of construction process, and continuous monitoring of the planning efficiency, to assist in developing foresight, smoothing workflow variations, and reducing/removing uncertainties plaguing construction processes.

It consists of workflow control and production unit control. Workflow control is accomplished primarily through the look-ahead process, while production unit control is accomplished primarily through weekly work planning.

Last Planner System aims to shift the focus of control from the workers to the flow of work that links them together. The two main objectives of LPS are to make better assignments to direct workers through continuous learning and corrective action and to cause the work to flow across production units in the best achievable sequence and rate.

Ballard (2000) introduces the figure of the "Last Planner" as the person or team that produces construction assignments of work to be carried out. The "assignment plan" is unique by being a production plan that drives direct work, not production of other plans. Ballard argues that Last Planner production control system "is a philosophy, rules and procedures, and a set of tools that facilitate the implementation of those procedures". He conceptualizes the procedure part to make up two components: production unit control and workflow control. The first addresses assignment of work organized as a process of continuous learning, while the second addresses improvement of flow of work in the best achievable way across production units in term of sequence and rate.

In concrete terms, the Last Planner concept is summed up as follows:

1. The weekly assignment plan (production plan/work plan) is made up by selecting, sequencing and sizing of work the last planners know can be done, which is carried out on basis of a workable backlog of production activities. It is also a part of the concept that the production plan is evaluated every week by measuring percent plan completed (PPC), which gives a feedback to continuous learning from reasons why the plan possibly was hampered. The weekly assignment plan is updated every week for 2-3 weeks' time period, such that the first week is the production plan.

2. The lookahead plan is a schedule covering 3 to 12 weeks beyond the assignment plan. The output of the lookahead process is the maintenance of a workable backlog (sound

activities) for the weekly production plan. It is based upon decomposing master schedule activities into work packages and operations aiming at shaping flow sequence and rate, capacity planning and developing detailed methods for executing work. Each assignment in the lookahead process is subject to constraint analysis to identify what must be done in order to make it ready for execution and flow. The main coordination between the general contractor and subcontractors is handled in the lookahead process. Ballard (2000) also mention that it is often beneficial to bridge the master plan and the lookahead plan by a "phase schedule" that serves to coordinate actions that extend beyond the chosen lookahead time window, as the lookahead schedule is not a simple derivate from the master schedule. A phase schedule is best done collectively by a team that is to do the work. This element of the Last Planner concept is, however, not emphasized in the outline by Ballard.

The Last Planner System has four levels:

1) Master Schedule: setting milestones and strategy identification of long lead items;
2) Phase Schedule: Pull planning (specifies handoffs; identify operational conflicts);
3) Look-ahead Plan: Make Work Ready Planning (to ensure that work is made ready for installation; re-planning as necessary);
4) Weekly Work Plan (WWP): commitments to perform work in a certain manner and a certain sequence, and Learning (measuring percent of planned completed PPC), deep dive into reasons for failure, developing and implementing lessons learned.

PPC is a measure key of the Last Planner System success and does not measure productivity or production, only planning effectiveness. But of course, the values of PPC are related to production and productivity indirectly; it is assumed that when a project team improves its planning it reduces variation, and, thus, can become more productive by matching its production resources more closely to the demand for them, so reducing waste. When the weekly work plan is executed, an analysis of the previous week report is made, and the PPC is calculated by dividing the quantity of works effectively completed by the total quantity of works that had been planned. A note explaining the reasons justifies any work that had been planned but was not completed.

When the PPC is calculated, a re-programming of the services is made, indicating the services that had already been executed and those that had been planned but were not executed. The immediate result of this reprogramming is the calculation of a new date for finishing the construction. Companies utilizing the LPS have been able to maintain project on time and at budget, as well as having a stress-free production planning and control process.

Benefits attributed to LPS implementation are as follows:

1) smooth workflow,
2) predictable work plans,
3) reduced cost,
4) reduced time of project delivery,
5) improved productivity;
6) greater collaboration with field personnel and subcontractors.

Test case projects also reported certain challenges faced by project participants when applying LPS:

1) lack of leadership,
2) organizational inertia,
3) resistance to change,
4) lack of training,
5) contractual issues,
6) lack of experience and knowledge, among others.

Last Planner System (LPS) has four main elements:

1) Programming Workshop: Collaboratively creating and agreeing production sequence (and compressing it if required);
2) Make-Ready: Making tasks ready so that they can be done when we want to do them;
3) Production Planning: Collaboratively agreeing production tasks for the next day or week; and
4) Continual Improvement: Learning about and improving the project, planning and production processes.

The Last Planner System is based on a traditional planning system and is performed by field foremen; the condition of (SHOULD-CAN-WILL-DID) is implemented.

A reliable assignment, one that gets done at the required time, determines what WILL be done, after considering both what SHOULD from higher-level schedules and what CAN be done based on the situation at hand. Assignments are likely to get done when they are well defined, resource sound, in the right sequence, and within the capacity of the crew. The last planner’s job is to make certain task in the assignment that meets these criteria and to reject assignments that do not. Last planners can reasonably commit to completing the tasks on weekly work plans that meet these criteria. To be effective, production management systems must tell what should be done, what can be done, and what will be done; then, they compare what was done to improve planning.

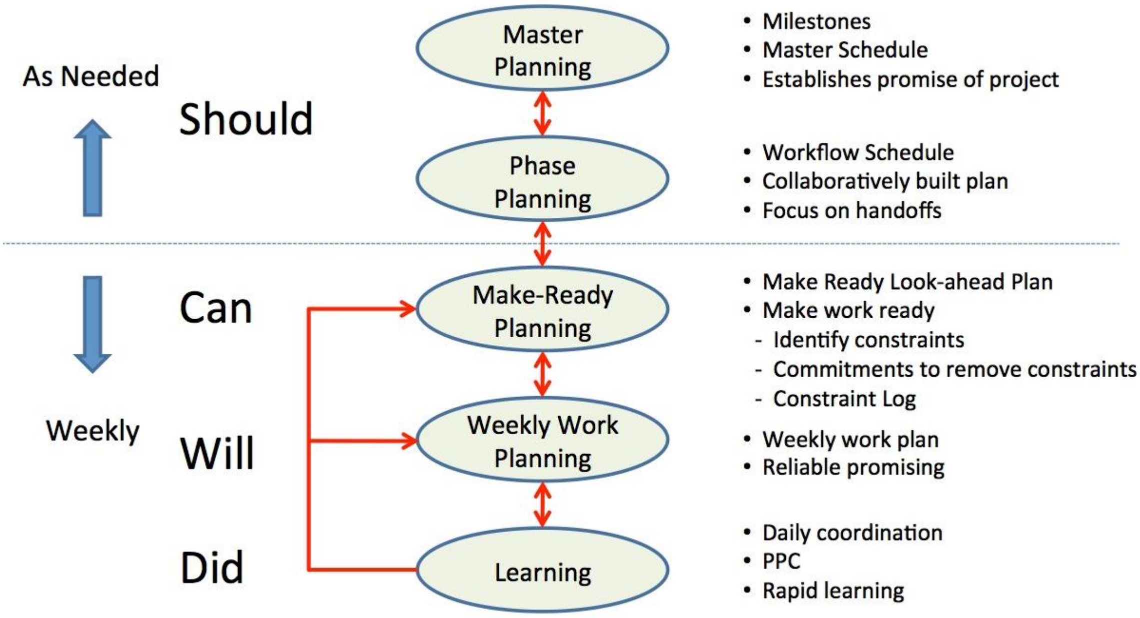

Figure 12 Last Planner System (Lean Construction Blog, 2017)

4.3.4 Big Room

The Lean "Big Room" technique is a solution to the communication problems arising from the multiplicity of designers and working teams in the construction process. Especially for technicians who use traditional CAD technologies this communication problem becomes greater, since the number of requests for information is higher (Dave, *et al*., 2013).

This technique consists of physical and communicative cooperation between the designers involved in the process. They work side by side in the same position (a room). This allows one more effective sharing of information with respect to different job positions. The information can be asked to "face to face" instead of using distance communication tools or waiting for scheduled meetings. This involves a shortening of the overall time of design. Big Room is best suited for large construction projects where designers can work only on a single project (Tauriainena, *et al*., 2016). This technique could be further improved through weekly video conferences. An effective Big Room supports the cross-functional and functional collaboration of the teams move forward quickly. Enables teams to understand their impact on other groups of work. (Lean Construction Institute, 2015)

Figure 13 Example of Big Room layout (source: https://www.tradelineinc.com/)

4.3.5 Knotworking

The Knotworking method represents a collaboration between designers from different planning disciplines with the objective of pursuing a common task. The basic idea of Knotworking is that designers meet physically at the planned critical points of the current project or when cooperation can benefit the most (Tauriainena, *et al*., 2016). This technique is born from the need to integrate the knowledge of experts from various companies into the processes of construction, since they involve phases and tasks that cannot be solved in one organization. Through the Knotworking, groups of people, activities and tools are designed to work intensively for a short period of time to solve a problem or perform a task. At the end the participating designers return to the original tasks. The Knotworking requires intensive collaboration between the participants. (Kerosuo, *et al*., 2013)

4.3.6 Target Value Design (TVD)

A potentially assumable Lean technique in the integrated BIM approach is Target-value Design (TVD). This technique is a radically different design method than traditional approach. It refers to the objective of "delivering the value" of the building. For this purpose, it "transforms" the current design activity by reversing some design and work principles (Macomber & Barberio, 2007):

- not estimating based on a detailed project, but do a project based on a detailed estimate;
- not evaluating the constructive feasibility of a project but design for what is constructable;
- not designing individually and then discuss but work together to define the issues and produce decisions that lead to the definition of design choices.
- not working alone in separate rooms but work in pairs or a group.

The TVD is based on practices such as the involvement of key participants from the beginning of project, the implemented collaboration (through BIM, IPD (Integrated Project Delivery), Big Room, meeting, Co-location, Knotworking), the development of goals and requirements in collaboration with the client, the pursuit of continuous improvement, concentration on design for the purpose of achieving value. In the approach to this design method the process is therefore customer-oriented; the contract and the project management risk are the basis of the Target Value Design (Tauriainena, *et al.*, 2016). Figure 14 shows an example of Target Value Design process.

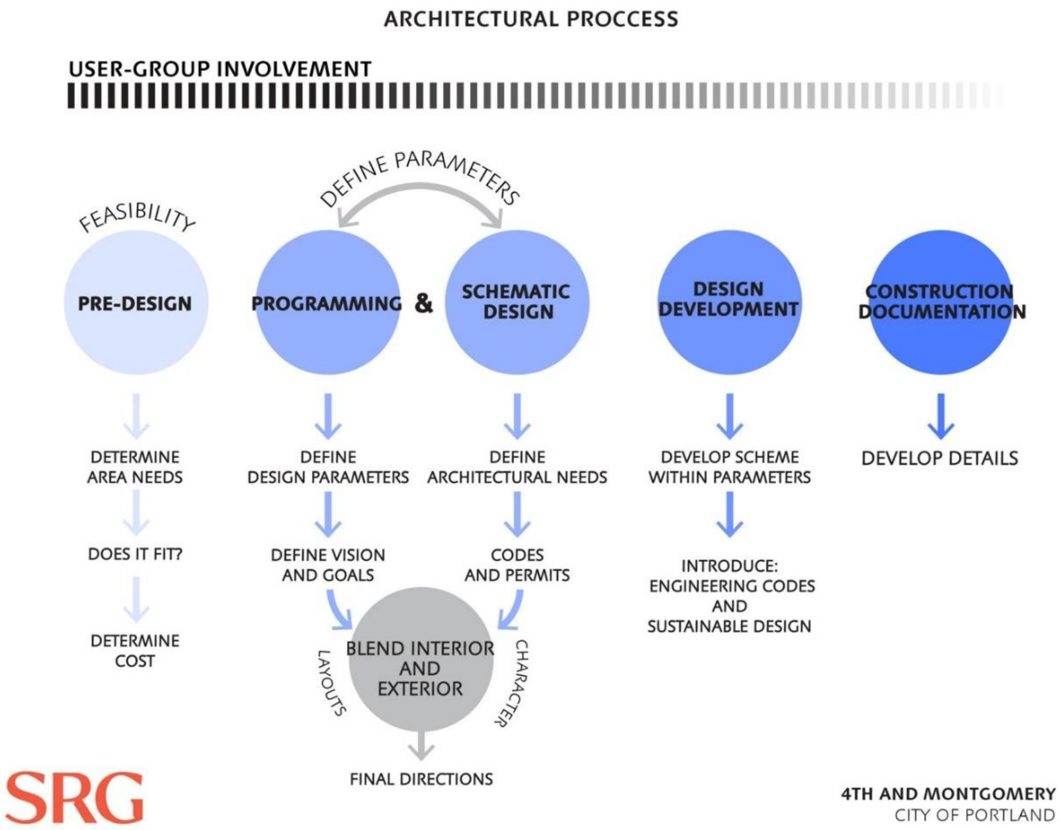

Figure 14 Example of Target Value Design process (source: https://www.srgpartnership.com/*)*

4.3.7 Location-based system (LBS)

In this technique, locations of the project are hierarchical and are defined by a location breakdown structure (LBS). Each task is defined at a hierarchy level and includes one or more locations. (Kenley & Seppanen 2010)

The bill of quantities of a task explicitly defines all the work that must be completed before a location is finished and the crew can move to the next location. Quantities by location are required as a starting data for location-based plan. Durations are calculated by multiplying the quantities in each location by a labor consumption factor (manhours/unit) and dividing by crew size. Because quantities can be different in locations, and each task can contain multiple quantity items with different productivity rates, Location Based Management System (LBDS) is not restricted to repetitive projects only.

LBDS integrates the Critical Path Method (CPM) into flowline scheduling. Logic can be automatically generated by considering tasks composed of multiple locations. There are many different ways that logic generation can be automated, and therefore the resulting logic is called *layered logic*. LBMS (Location-based Management System) includes an augmented CPM algorithm which allows the planning of continuous labor flow by delaying the start date of tasks such that work can be implemented continuously. An additional important logic component is the explicit handling of buffers, in addition to lags, which are a well-known component of CPM logic. The buffer operates in the same way as lag in planning but can be absorbed during controlling. The goal of location-based planning is to optimize the labor flow so that work does not wait for workers and workers do not wait for work.

Location-based planning requires a lot more data than CPM scheduling, including quantities by location, and productivity rates for subcontracted tasks. Location Breakdown Structure needs to be decided before starting the planning. These facts have been seen as limitations by CPM schedulers who are used to a more free-form planning approach.

In LBMS, there are four stages of information: baseline, current, progress and forecast.

The baseline schedule sets constraints to current, more detailed schedules and functions as an Owner reporting tool in the same way as the baseline in a CPM schedule.

The current stage enables the changing of quantities, productivity rates, logic and plans during production. Each current task, or detail task, is linked to one baseline task for comparison purposes. The progress stage monitors the actual performance of the project for each location and task. The actual dates do not replace the planned dates in LBMS – they are rather used for detecting deviations from commitments. In addition to start and finish dates, information about days when tasks were suspended, and actual resources are required to calculate the actual resource consumption (manhours/unit) and actual production rate (units / day) for each trade.

The forecast combines the information from the current and progress stages to give early warnings of problems. The forecasts assume that production will continue with the same productivity, with the planned resources and follows the current logic. If the forecast of a predecessor delays the forecast of a successor, an alarm is generated. LBMS tries to prevent cascading delays by concentrating production control resources to prevent these alarms from happening by correcting the production rate of a predecessor or by slowing down the successor. In many cases, alarms can be given two weeks before the problem, giving enough time for planning and implementing corrective action (Seppänen 2009).

Location-based controlling requires weekly or daily progress reporting. Instead of just recording activity start and finish dates, accurate productivity calculations require information about actual crew sizes, quantities in place and days on which tasks were suspended. Thus, implementing location-based controlling requires a significant process change and a major shift from monthly CPM updates to real-time controlling using the schedule. Figure 15 shows an example of LBS.

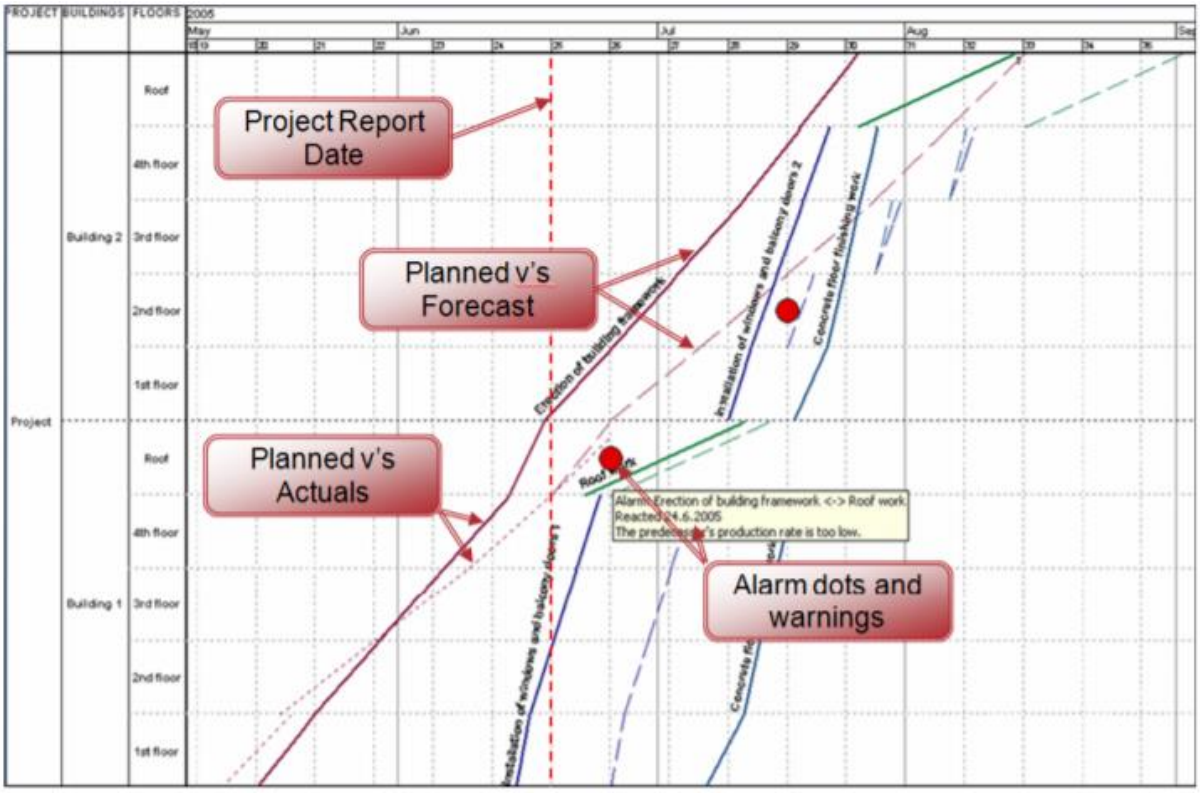

Figure 15 A flowline figure with the plan (solid line), actual (dotted line), forecast (dashed line), and alarms (red dots) shown (Olli et al.*, 2010)*

4.4 Lean and BIM integrated approach

As previously explained, the traditional approach model is linear, with the subjects involved in the design that do not work synergistically simultaneously but in sequence; therefore, the final result becomes difficult to predict. The integrated model, however, although more difficult to implement, is a synergic approach among the subjects involved that contribute to a univocal result; such

goal is kept under control through feedback and constant data analysis, allowed from communicative and visual collaboration between models, software and characters present in the whole process.

The integrated Lean and BIM approach therefore defines a *workflow model* which covers the entire life cycle of the project. (Dave, *et al*., 2013)

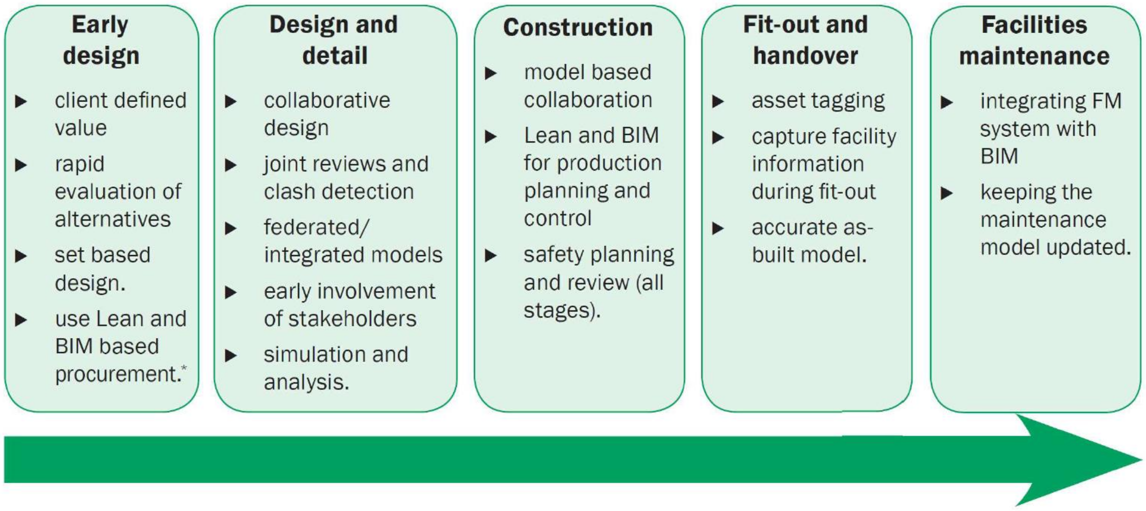

Figure 16 Lean and BIM integrated workflow (Dave, et al. *2013)*

Early design

In this phase the function that BIM methods and processes satisfy is defining, maintaining and communicating the value of the construction from the customer's point of view, to allow the strategic decisions.

Traditional design methods do not support sophisticated and accurate visualizations and hence the decision-making assessment would not help the customer in the final option to select. Lean and BIM processes and tools not only provide more accurate and sophisticated 3D visualization capability, but also help to evaluate options thanks to a series of criteria set in the software. Through parametric design and the processes of collaboration, the loss of value is minimized. (Dave, *et al*., 2013)

Design and Retail

In the design and retail phase, there are two functions that are implemented thanks to the integrated use of Lean and BIM: maintenance/value generation and minimization of waste in subsequent operating phases.

Maintenance and value generation is a problem closely related to the type of chosen approach. In traditional management, tools based on the method of the critical path and the "earned value" method (EVM) are largely ineffective (Koskela & Howell, 2002). In the method of the critical path the activities are represented by nodes, but the flow of crews and materials between the activities are not modeled. This method therefore acts as an effective tool for the management of contract with customers, but not a resource for time management of the process. The Earned Value method, on the other hand, tends to focus on those jobs with high productivity, neglecting the need to complete those activities with low income, and therefore lacking in consideration of the whole workflow. (Brodetskaia, *et al.*, 2011) However, the EVM could be integrated with Lean tools in the economic-temporal management of the project through an approach integrated with the BIM.

In addition to the problem of value control, the Lean processes, together with the BIM Toolset, contribute to minimize waste (due to inactivity, waste, overabundance, etc.) throughout the design phase. In addition, collaborative design processes help to reduce delays and compress the time spent in each phase. (Dave, *et al.*, 2013)

Construction phase

The primary function of Lean and BIM during this phase is to minimize waste and reducing the potential for errors and conflicts (Eastman, *et al.*, 2008). This helps to compress the overall time used and, therefore, to maintain and improve the quality of the object in construction (maintenance and value generation).

The applications of BIM in this phase are varied for companies:

- clash detection;
- quantity take-off and cost estimating;
- constructability analysis and planning (through visualization and 4D);
- integration with cost and schedule control and other management functions;
- off-site fabrication;
- verification, guidance and tracking of construction activities. (Dave, *et al.*, 2013)

Fit-out and handover (delivery phase)

At this stage, i.e. in the final phase of a project, a large number of activities are involved parallel and sequential. During construction, it is therefore important to monitor the progress of construction work to compare planned activities with the work actually performed and allow stakeholders to focus on activities that are late (Harty, *et al.*, 2010). This is often complicated in the delivery processes of traditional projects, where communication is based on 2D drawings. In addition to minimizing time, further objectives to be achieved at this stage, in the integrated approach, are the reduction of programming time, the guarantee that there is a margin of minimum time delivery and the assurance that the quality is maintained. Through tools such as visual monitoring and fine-grained visual scheduling with Lean and BIM tools it is possible to obtain a delivery phase without problems. (Dave, *et al.*, 2013)

Facilities Maintenance

During a construction project, information is generated during each phase of the project. Generally, at the end of the project all the "as-built" information is sorted and archived by the companies and can be linked in the BIM models for the management of the building. This can help the facility maintenance process and can shorten the time of answer in the case of maintenance calls. (Dave, *et al*., 2013)

However, these procedures are quite informal and depend on the knowledge gathered by the experienced staff members of the facilities maintenance companies.

4.5 Lean and Sustainability

4.5.1 Challenges of sustainable development

The quest towards sustainable development in our societies puts the spotlight on the built environment and the construction industry. Construction, buildings and infrastructure are the main consumers of resources: materials and energy. In the European Union, buildings require more than 40 % of the total energy consumption and the construction sector is estimated to generate approximately 40 % of the man-made waste (Sjöström 1998).

Environmental burdens caused by construction can be minimized and construction technology can be used to remedy the environment. Sustainable construction is the response of the building sector to the challenge of sustainable development.

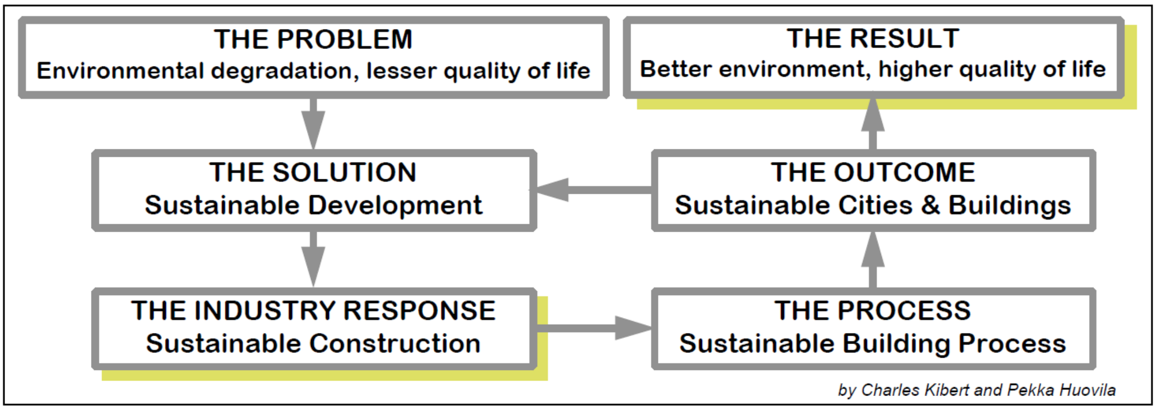

Figure 17 A simplified road map for sustainable construction (Bourdeau et al. *1998)*

Sustainable development can be defined as "*development that meets the needs of the present without compromising that ability of future generations to meet their own needs*" [the Brundtland Report, WCED, 1987]. Sustainable objectives often emphasize environmental burdens. However, environmental issues often cannot be tackled if the problem of poverty remains unsolved. Hart (1997) separates different economic spheres (Figure 18) when identifying major challenges to sustainability.

	Pollution	*Depletion*	*Poverty*
DEVELOPED ECONOMIES	▷ greenhouse gases ▷ use of toxic materials ▷ contaminated sites	▷ scarcity of materials ▷ insufficient reuse and recycling	▷ urban and minority unemployment
EMERGING ECONOMIES	▷ industrial emissions ▷ contaminated water ▷ lack of sewage treatment	▷ overexploitation of renewable resources ▷ overuse of water for irrigation	▷ migration to cities ▷ lack of skilled workers ▷ income inequality
SURVIVAL ECONOMIES	▷ dung and wood burning ▷ lack of sanitation ▷ ecosystem destruction due to development	▷ deforestation ▷ overgrazing ▷ soil loss	▷ population growth ▷ low status of women ▷ dislocation

Figure 18 Major challenges to sustainability (Hart 1997)

While traditional design and construction focuses on cost, performance and quality objectives, sustainable design and construction adds to these criteria minimization of resource depletion, minimization of environmental degradation, and creating a healthy built environment (Kibert 1994). The shift to sustainability can be seen as a new paradigm where sustainable objectives are within the building design and construction industry considered for decision making at all stages of the life cycle of the facility. *Figure 2* outlines the evolution and challenges of the sustainable construction concept in a global context.

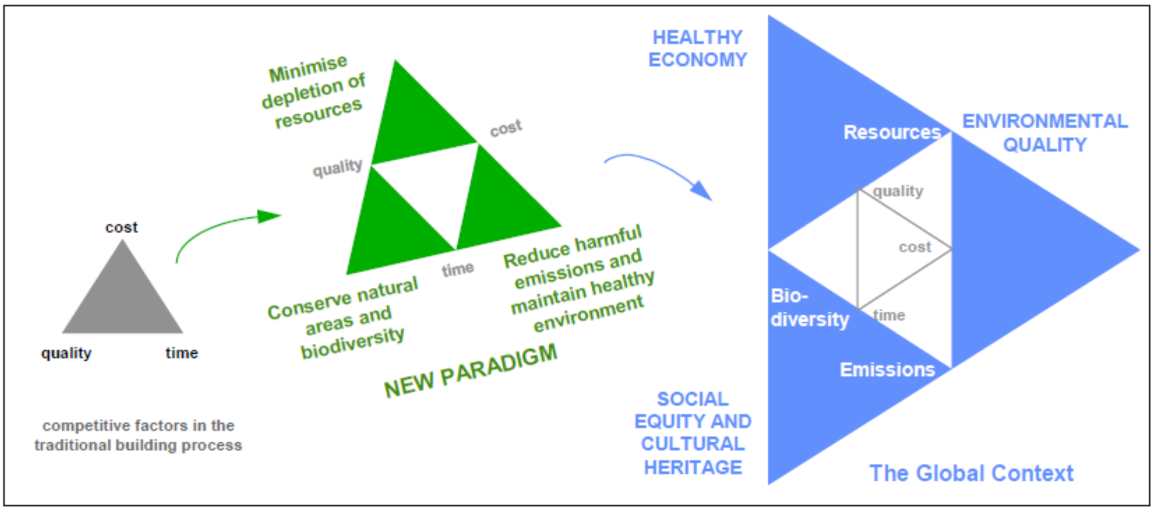

Figure 19 Challenges of sustainable construction in a global context (Huovilla et. al *1998)*

In addition to the “common” sustainability criteria, such as energy efficiency, non-toxics or recyclability many other important sustainable measures can be listed. Some examples of that kind are preserving property value, flexibility, long service life, use of local resources, information dissemination, use of by-products, immaterial services, mobility consideration or supporting local economy (Bourdeau *et al*. 1998).

The building industry has to adapt to these new and emerging construction markets which have environmental and social dimensions. Construction businesses are expected to integrate into, and consider more fully, the issues valued by others at national, regional and community level where the driving forces will be a mixture of political, social and market forces, requiring products which respond to genuine needs and concerns.

Bourdeau *et al*. (1998) selected some examples of sustainable construction implementations from different countries such as:

- National package for sustainable building (the Netherlands)
- Ecological criteria for experimental construction (Finland)
- Habitat for humanity (United States)
- Straw bale farmhouse (United Kingdom)
- Internet office and eco house pavilion (Ireland)
- The recycled house (Belgium)
- Environmental symbiosis building (Japan)
- Passive design (South Africa)
- Urban regeneration and rehabilitation (Romania)
- Energy saving elementary school (Italy)
- Energy and water management (France)
- Air conditioning system (Spain)

4.5.2 Contribution of lean construction

Conventional engineering and production approach are based on the conversion view. The concurrent engineering approach (Table 4 Conceptualization of engineering and production (Koskela 1998)), applying the principles of lean production (Koskela 1998), stresses the flow view and the value generation view, in addition to the conversion view (Koskela & Huovila 1997). Lean design, or concurrent engineering, is mainly dealing with information processes, whereas lean production emphasizes material processes. Therefore, the sustainability contribution of the flow view (eliminating waste), is crucial in production, whereas in engineering, the value view is crucial.

	Conversion view	*Flow view*	*Value generation view*
CONCEPTUALIZATION	As a conversion of requirements and constraints into product design	As a flow of information, composed of conversion, inspection, moving and waiting	As a process where value for the customer is created through fulfillment of his requirements
MAIN PRINCIPLES	Hierarchical decomposition; control and optimization of decomposed activities	Elimination of waste (non-conversion activities); time reduction	Elimination of value loss (achieved value in relation to best possible value)
PRACTICAL CONTRIBUTION	Taking care of what has to be done	Taking care of that what is unnecessary is done as little as possible	Taking care of that customer requirements are met in the best possible manner
SUGGESTED NAME FOR PRACTICAL APPLICATION	Task management	Flow management	Value management
SUSTAINABILITY NOTICE	**Management of the life cycle requirements**	**Waste elimination**	**Environment is the customer**

Table 4 Conceptualization of engineering and production (Koskela 1998)

In the traditional conversion view, the requirements are converted into product design. It is then essential to meet the requirements and add value to the customer. In the flow view, the waste activities are eliminated. Elimination of material waste meets directly the sustainability objectives. In the value generation view, the process aims at adding value to the customer. The key question is: who is the customer?

The principles of lean construction converge to the sustainability objectives:

- Eliminating (material) Waste with minimization of resource depletion and minimization of pollution;
- Adding Value to the Customer with minimization of resource depletion and minimization of pollution, matching business and environmental excellence.

One example of different priorities of different customers is illustrated in Figure. In some projects it may be most important:

- from the owner's and user's point of view to emphasize:
  Conformity to business processes; Location; Life cycle costs; Indoor conditions, because the decision of investment is based on these criteria;
- from the environment's point of view to concentrate on:
  Environmental burdens in operation; Service life and risks for deterioration; Convertibility and flexibility, because they form the major burdens to the environment during the life span of the facility;
- from the contractor's point of view to look at:

Safety; Comfort; Embodied environmental burdens in building elements, because they may have the strongest direct influence on the construction costs in some cases.

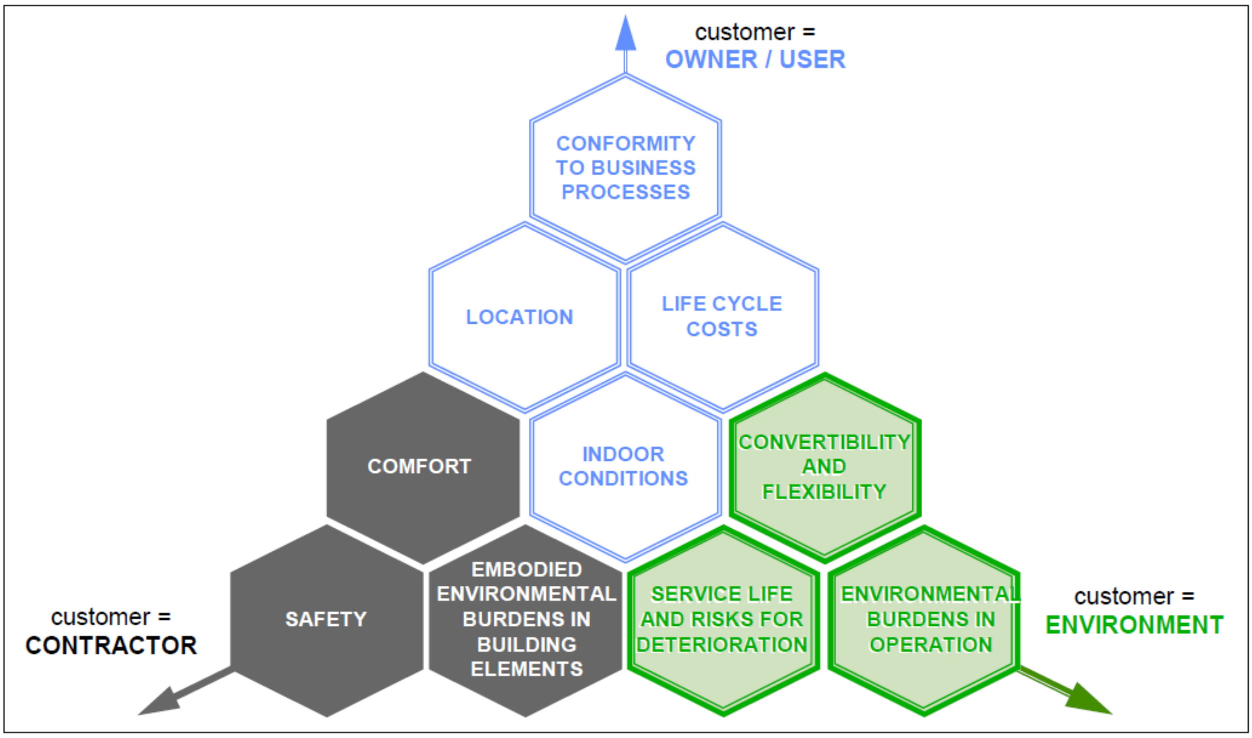

Figure 20 Classified requirements for a facility and their possible priorities for different customers (Huovila et. al *1998)*

A requirements framework that is developed at VTT Building Technology, VTT ProP, is presented in Table 5 as an example of related development. The framework is generic, well applicable also for sustainable buildings.

The objective is to use a classified list of required properties of a facility in order not to miss the requirements early in the process. The higher-level requirements are opened and explained in more detail at a lower level. Each property is expressed in the form of specified requirements and an indication of the process phase when those requirements should be set. Values and classes of the requirement are referred to, and methods for verifying the conformity both in building design, and in the constructed facility, are suggested. The framework can be applied for all kinds of buildings and materials, its lower level content altering correspondingly.

required property	specified requirement	process phase	value or class	verifying method
CONFORMITY TO BUSINESS PROCESSES ☆ core processes ☆ supporting activities ☆ image				
LIFE CYCLE COSTS ☆ initial costs ☆ administrative costs ☆ maintenance costs ☆ costs from fundamental improvement				
LOCATION ☆ site properties ☆ traffic communications ☆ services ☆ environmental impact from land use				
INDOOR CONDITIONS ☆ indoor air quality ☆ sound insulation and noise reduction ☆ lighting				
SERVICE LIFE AND RISKS OF DETERIORATION				
CONVERTIBILITY AND FLEXIBILITY				
ENVIRONMENTAL BURDENS IN OPERATION ☆ energy and water consumption and emissions of building ☆ energy and water consumption and emissions caused by users				
EMBODIED ENVIRONMENTAL BURDENS IN BUILDING ELEMENTS ☆ energy, raw materials and emissions ☆ recycling				
SAFETY ☆ constructional safety ☆ fire safety ☆ safety in service ☆ burglar safety ☆ safety against natural catastrophes				
COMFORT				
EFFECTS ON NEIGHBORING SURROUNDINGS				

Table 5 Requirements framework named VTT ProP (only main titles presented) (Huovila et. al *1998)*

4.6 Barriers in lean implementation in the construction industry

The use of Lean thinking in construction projects has already proven its benefits. These benefits include but are not limited to productivity improvement, increased reliability, quality improvement, increased customer satisfaction, realistic schedules and reduced durations, less waste, and design as well as safety improvements (Mossman 2009). However, industry practitioners still find Lean implementation challenging due to lack of information related to Lean principles. This proves that there are certain barriers in adopting

Lean concepts and successfully apply them (Mossman 2009, Sarhan and Fox 2013). Several other studies also pointed out that Lean implementation is challenging for the construction industry (Wandahl 2014).

Demirkesen *et al*. (2019) analyzed and identified twenty-seven barriers for Lean implementation. These barriers are identified as the key barriers causing challenges in Lean implementation in construction projects. Most of the detected barriers can be found in the socio-cultural area consisting of the managerial, cultural, communication and workforce barriers.

4.6.1 Political barriers

a) *Stringent requirements and approvals*: Information flow and procedural documents might take time and lead to deficiencies in Lean processes. This makes governmental organizations hesitant about the benefits and applications of Lean practices. Hence, stringent requirements and approvals might be a burden for governmental organizations (Almanei *et al*. 2017).

b) *Lack of knowledge in Lean*: The Lean philosophy is still not yet entirely understood by most of governmental authorities, so benefits are not conceived in turn. This might negatively affect investment decisions in construction projects, where Lean practices are planned to be applied (Sarhan and Fox 2013).

c) *Lack of government support for research and collaboration in Lean*: Limited funding opportunities for research and collaboration in Lean practices lead to a narrower spectrum of Lean activities and scarcity of project specific applications of Lean (Shang and Pheng 2014).

4.6.2 Economical barriers

a) *Inventory costs*: Inventory costs refer to the cost of storing the inventory. Often the inventory is calculated based on predictions and compensates uncertainties. The bullwhip effect even increases inventories. High inventories lead to slower processes in Lean implementation negating Lean activities (Kumar 2013, Jadhav *et al*. 2014, Almanei *et al*. 2017). Pulling (according to the Lean philosophy) the materials and information to the next work step allows the reduction of the inventory but requires a higher flexibility in the whole value chain.

b) *Dimensional variation cost of Lean tools*: Some Lean tools and methods lead to design variations resulting in extra cost. This might trigger the reluctance in implementing Lean tools (Kumar 2013, Jadhav *et al*. 2014).

c) *Consulting costs in Lean*: Consulting costs sometimes appear as financial burden for Lean implementation in construction projects, especially in smaller construction projects. This might lead to lower efficiency in implementation processes (Sarhan and Fox 2013, Ogunbiyi 2014).

d) *Market conditions*: Lean implementation brings the need to clarify objectives in terms of successful project execution and thus a stable construction process is sought. However, fluctuations in market conditions demand a constant flexibility of all involved companies. A communication structure supporting stability as well as flexibility in all processes is difficult to set up for companies implementing Lean construction the first time. This has potential to negate firms' willingness towards applying Lean practices and achieving excellence in their projects (Aziz and Hafez 2013, Sarhan and Fox 2013, Jadhav *et al*. 2014, Okere 2017).

4.6.3 Workforce barriers

a) *Problems in teamwork and diverging aims in Lean:* Lack of coordination and collaboration among team members might be observed when there are diverging aims within the firm. This results in inefficient processes in Lean practices (Aziz and Hafez 2013, Sarhan and Fox 2013, Shang and Pheng 2014, Jadhav *et al*. 2014).

b) *Language problem for non-native speakers*: Language is a barrier for most of the construction workers. This makes e.g. some safety tips difficult to understand and results in lower safety performance (Demirkesen and Arditi 2015). Educating construction workers about language barriers and providing some tips might lead to enhanced Lean performance. Thus, firms might develop ways to integrate non-native speakers in Lean processes to overcome this barrier (Jadhav *et al*. 2014).

c) *Employees' resistance to Lean*: Employees might resist to changes and this leads to inefficient performance in Lean practices. Some lean tools such as poka yoke devices or Kanban cards might be of interest to employees for the fact that they are not beware of benefits of using these tools. Thus, resistance to change is a major barrier for firms aiming to enhance Lean implementation performance (Aziz and Hafez 2013, Jadhav *et al*. 2014).

d) *Stress and pressure in deadlines*: Struggling with deadlines might create stress and pressure for construction workers. This might lead to wrong or missing practices in Lean (Aziz and Hafez 2013, Sarhan and Fox 2013, Howell *et al*. 2017).

4.6.4 Cultural barriers

a) *Resistance to change*: Lean is a relatively new concept in the construction industry, and this makes Lean adoption lower than expected by the industry practitioners. This also leads to lack of knowledge about the benefits of using Lean practices. Therefore, employees develop resistance to change for the fact that they are either unfamiliar with the Lean tools or its benefits. A company and project culture that is open for changes is required in order to lead all employees in the Lean transformation process. The resistance to change stems generally from the cultural background and is therefore listed as a major cultural barrier (Kumar 2013, Sarhan and Fox 2013, Jadhav *et al*. 2014, Ogunbiyi 2014, Shang and Pheng 2014, Almanei 2017).

b) *Diversity in adopting Lean culture*: Diversity in cultural background generally leads to different learning curves for differing groups. This leads to different levels of knowledge about Lean practices. Some construction workers have a hard time to adopt a Lean culture due to their diverse backgrounds and therefore they prefer to apply the conventional working practices they are familiar with. Therefore, diversity might appear as a cultural barrier for Lean implementation (Jadhav *et al*. 2014, Almanei *et al*. 2017).

c) *Lack of long-term Lean philosophy*: The adoption of the Lean philosophy is difficult for industry practitioners due to the dynamic nature of the construction industry. Industry practitioners mistrust the benefits that they will get by the use of Lean tools and this makes Lean implementation rare due to challenges with time and budget (Ogunbiyi 2014, Shang and Pheng 2014).

d) *Insistence on mass production*: Mass production is affected by its repetitiveness. Here, nearly automatically, a "Lean" structure is built in the project-planning phase and a Lean implementation seems obvious (Demirkesen and Tommelein 2016). In contrast most of the construction projects are unique and complex. Therefore, the rules of mass production cannot be applied easily. This reluctance towards Lean implementation is embedded in a firm's culture.

4.6.5 Managerial barriers

a) *Misperception about Lean practices*: There is a common perception that Lean practices are costly to apply. This makes firms reluctant towards adopting the Lean way considering that the practices also require special expertise (Jadhav *et al*. 2014, Almanei *et al*. 2017).

b) *Risk aversion in Lean implementation*: Firms might have concerns in terms of investing in Lean applications, which might be in a transparent and pre-aligned form due to uncertainties in construction projects. This might stem from the fact that benefits of Lean are not well understood by the majority of firms (Sarhan and Fox 2013, Shang and Pheng 2014, Jadhav *et al*. 2014, Almanei *et al*. 2017).

c) *Lack of top management support*: Top management's support for Lean practices is of utmost importance in terms of successful application of Lean in construction projects. When top management is reluctant towards adopting Lean thinking, some deficiencies might arise in Lean implementation (Kumar 2013, Sarhan and Fox 2013, Ogunbiyi 2014, Shang and Pheng 2014, Jadhav *et al*. 2014, Almanei *et al*. 2017, Okere 2017).

d) *Inefficiency in resource planning*: Inefficient planning of resources has the potential to generate waste and negatively impact Lean practices. Therefore, resource planning takes an important part in the successful management of Lean activities. When managed inefficiently, resource planning acts as a barrier for Lean implementation from a managerial perspective (Jadhav *et al*. 2014, Demirkesen and Tommelein, 2016).

4.6.6 Communication barriers

a) *Stakeholder issues in communication*: Stakeholder engagement is crucial for the success of construction projects. Failure to engage stakeholders in project processes might lead to ineffective communication resulting in lower Lean performance (Sarhan and Fox 2013, Jadhav *et al*. 2014, Shang and Pheng 2014, Okere 2017).

b) *Lack of organizational communication*: Organizational communication is an effective way to circulate Lean concepts and terms. Lack of organizational communication leads to lower performance in Lean implementation (Salem *et al*. 2005, Kumar 2013, Jadhav *et al*. 2014, Ogunbiyi 2014, Howell *et al*. 2017, Okere 2017).

c) *Lack of information sharing and integrated change control*: Managing uncertainties and changes in the project are only possible with effective communication channels and lack of information sharing can break the Lean learning chain resulting in defective processes (Okere 2017, Howell *et al*. 2017).

4.6.7 Technical barriers

a) *Complexity of Lean philosophy and terms*: There is still lack of understanding in Lean construction terms and philosophy. A common understanding of concepts to better practice Lean and perform more effectively in construction projects is needed. Hence, firms might need to remove this barrier in order to experience higher rates of performance in Lean projects (Salem *et al*. 2005, Kumar 2013, Sarhan and Fox 2013, Shang and Pheng 2014, Jadhav *et al*. 2014, Ogunbiyi 2014).

b) *Complexity in design*: Designing for Lean and safe operations is more challenging than traditional methods and this might lead to complexity in design, which makes design a barrier for Lean projects (Aziz and Hafez 2013, Sarhan and Fox 2013). Nevertheless, it has to be considered, that higher effort in design due to Lean practices results into stable working processes on site since design and processes are accordingly aligned from the beginning.

c) *Inefficiency in Takt time planning*: Multiple stakeholders and numerous interfaces might lead to poor planning in terms of Takt time (i.e. manual working time necessary to complete the analyzed process). This negates Lean activities for the project and appears as a barrier for construction operations (Sundar *et al*. 2014).

d) *Failure in operational excellence*: Operational excellence is one of the objectives of Lean practices. Failure in operational excellence is likely to yield deficiencies in Lean processes. Therefore, it is considered as a technical barrier that firms need to address to better perform in Lean implementation (Salem *et al*. 2005, Sarhan and Fox 2013).

e) *Lack of knowledge in Last Planner implementation*: Last planner is a critical tool of Lean construction and failure to apply Last planner leads to unsuccessful operations in Lean implementation. Thus, it is listed as one of the technical barriers that firms need to consider aiming to achieve higher performance in Lean implementation (Aziz and Hafez 2013, Salem *et al*. 2005).

POLITICAL

- *Stringent requirements and approvals*
- *Lack of knowledge in Lean*
- *Lack in government support for research and collaboration in Lean*

ECONOMICAL

- *Inventory costs*
- *Dimensional variation cost of Lean tools*
- *Consulting costs in Lean*
- *Market conditions*

WORKFORCE

- *Problems in teamwork and diverging aims in Lean*
- *Language problem for non-native speakers*
- *Employees' resistance to Lean*
- *Stress and pressure in deadlines*

CULTURAL

- *Resistance to change*
- *Diversity in adopting Lean culture*
- *Lack of long-term Lean philosophy*
- *Insistence on mass production*

MANAGERIAL

- *Misperception about Lean practices*
- *Risk aversion in Lean implementation*
- *Lack of top management support*
- *Inefficiency in resource planning*

COMMUNICATION

- *Stakeholder issues in communication*
- *Lack of organizational communication*
- *Lack of information sharing and integrated change control*

TECHNICAL

- *Complexity of Lean philosophy and terms*
- *Complexity in design*
- *Inefficiency in Takt time planning*
- *Failure in operational excellence*
- *Lack of knowledge in Last Planner implementation*

Table 6 Summary of barriers in lean implementation in the construction industry (elaboration of the author)

CHAPTER FIVE: TRADITIONAL CONSTRUCTION MANAGEMENT

5.1 The beginnings of traditional project management

Traditional project management is a universal practice which includes a set of developed techniques used for planning, estimating, and controlling activities. The aim of those techniques is to reach a desired result on time, within budget, and in accordance with specifications.

Although project management was first introduced as a discipline during the 1950's, it has been around for thousands of years and has been used in creating some of the biggest projects, from the Great Pyramids to the Transcontinental Railroad.

Those large-scale projects changed the face of the history and mankind forever. However, as time went by, business owners and entrepreneurs found it hard to keep up with the fast pace of technological development and ever-increasing demands of the market.

Business leaders realized that they needed a system that will help them manage large-scale projects. They needed a well-structured methodology that would help them bridge gaps and ensure a consistent work pattern. As a result, traditional project management was developed. Its ultimate goal was to make sure all the tasks are carried out in predetermined orderly sequence.

5.2 Phases overview

Traditional project management is mainly used on projects where activities are completed in a sequence and there are rarely any changes. The concept of traditional project management is based on predictable experience and predictable tools.

Each project follows the same lifecycle, which includes five stages: initiating, planning, executing, controlling, and closing (Figure 21).

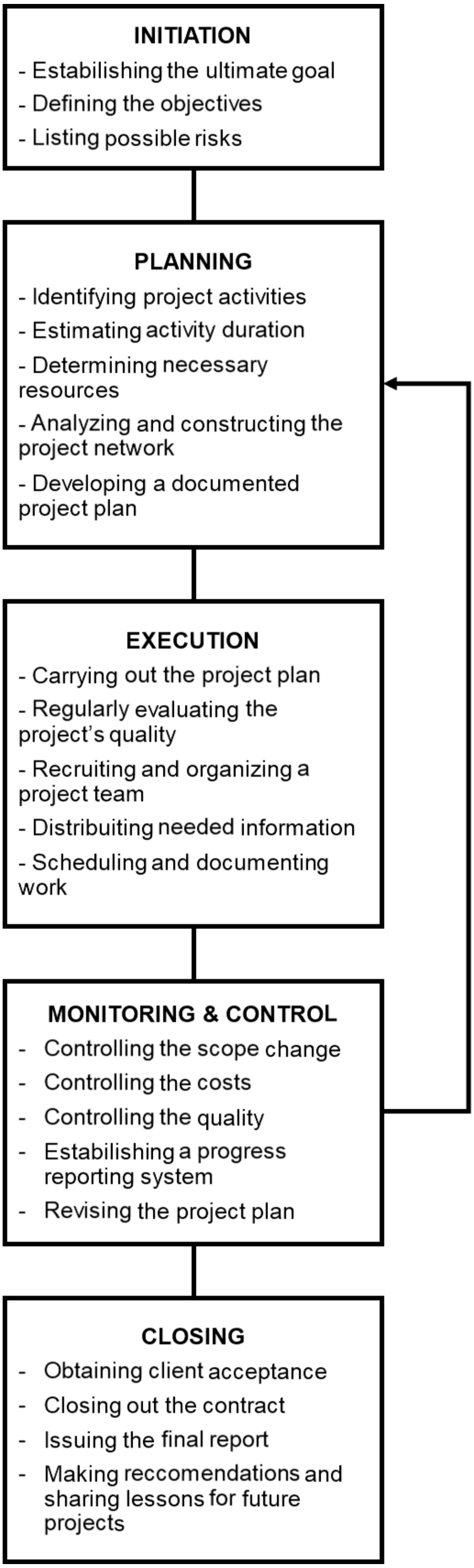

Figure 21 Project life cycle stages (elaboration of the author)

5.2.1 Initiating

The initiation phase is needed to identify the business problem and, after carefully investigating all the options, come up with the most meaningful solution, establishing the ultimate goal and defining all the objectives. Then the project manager initiates the project and starts recruiting the team. Initiating is the most critical stage in project management, because if it is not precisely defined the project and built the solid foundation, the risk of a project failure is very high, that consequently will create a domino effect, disrupting all the following stages as well as the final outcome. For this reason, it is fundamental to draw up a list containing all the possible risks and obstacles that can be encountered during all the phases of the project.

5.2.2 Planning

After carefully defining the scope of the project, the next step is planning. Planning is the second most important phase of every project's life cycle because each project is unique and requires special approach.
The planning phase is an ongoing process which continues throughout the entire project.

In its core, the main activities in planning phase are:

1) Identifying project activities;
2) Estimating activities' duration;
3) Determining necessary resources;
4) Analyzing and constructing the project network;
5) Developing a documented project plan.

5.2.3 Executing

Executing is the part of the project management life cycle where the project team is recruited and organized, and the deliverables of the project plan are physically constructed and presented to the customer, who then decides whether to accept them or not. It is usually the longest phase, depending on the length of the project. Activities, resources, and costs (together with the quality of the project) are regularly monitored by the project managers while teams are performing the work identified in the plan. All the works are scheduled and documented during all the execution.

5.2.4 Monitoring and controlling

Despite meticulous planning and careful execution, projects fail if they lack control processes. In order to be able to identify any pitfalls and plan changes, all the relevant activities must be monitored and measured. Controlling will allow to take any preventive measures and make any necessary adjustments to the plan, and, ultimately, keep the project on track.

To keep everything under control, you need to:

a. Collect data from timesheets and completed tasks (i.e. a progress reporting system)
b. Compare the data against the plan (like task completion, budget, and time estimates)
c. Check if all the ambitious objectives have been achieved.

The ultimate goal of this phase is to meet the requirements and make clients happy.
Traditionally, controlling process should include the following activities:

a. Time management
b. Cost management
c. Quality management
d. Change management
e. Risk management
f. Issue management
g. Procurement management
h. Acceptance management
i. Communication management

5.2.5 Closing

Project closure allows the team to obtain the client acceptance by evaluating and documenting the project in a final report.

In the closing phase, the activities to perform are the following:

a. Assess project performance (in terms of objectives, scope, deliverables, schedule, and expenses identified during the previous stages)
b. Rate the works carried out by the teams of each project phase
c. List project achievements and failures
d. Share lessons learned for the future projects

The closing process is an excellent opportunity to praise any team members who contributed to the successful outcome.

5.3 Gantt chart

Gantt chart is the most important technique in the traditional project management. Its creator was Henry Gantt, which is considered the father of traditional project management. Gantt chart gives a simple overview of a project. It is one of the most useful ways of presenting tasks and activities of the project on a timeline.

In the beginning, people used to create Gantt charts by hand or by using magnetic blocks and Lego. As technology progressed, Gantt charts started to be designed in Excel in a matter of seconds. Left part of the Gantt chart shows the project activities and the top shows the time scale. Each activity is presented with a bar. The position of a bar explicates the beginning, duration, and end of the activity (Figure 22).

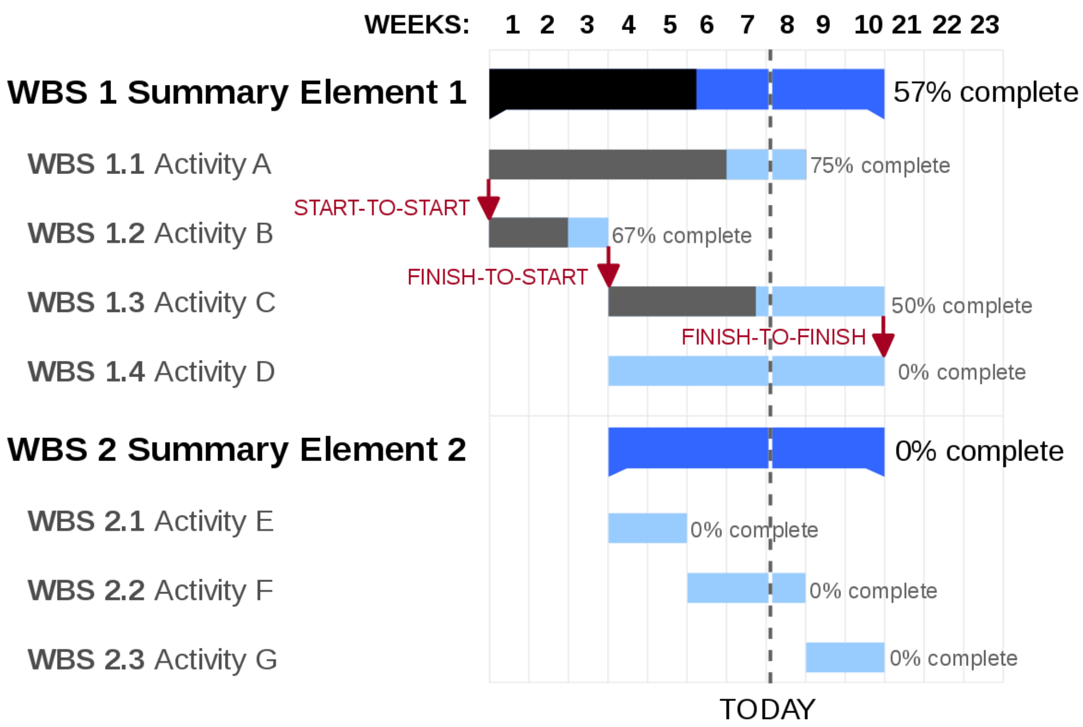

Figure 22 Example of Gantt chart structure (source: Wikipedia)

By looking at a Gantt chart, it is easily defined:

1) What the project tasks are;
2) Who is working on each task;
3) How long each task will take;
4) How tasks overlap and link with each other;
5) The start and finish date of the project.

Today, Gantt Chart is mainly used to track project schedules and make project management less stressful. Gantt chart helps to understand the relationship between tasks more clearly, keeping all the team members on the same page, and successfully complete project.
Gantt Chart has a lot of benefits, like giving a clear visible layout and a set of realistic time frame of the project. However, if it concerns about an ambitious and demanding project with hundreds of tasks, charts might become too complex. For example, as things change, the Gantt chart needs to be updated. Also, the size of the bar does not necessarily indicate the amount of work needed to successfully complete the project as activity may require more resources than initially expected.

5.4 Project management triangle

There are many project constraints and the three most frequent ones are time, cost, and scope. They are a part of every projects and together they make up the project management triangle (Figure 23)Figure 23 Project management triangle (elaboration of the author).

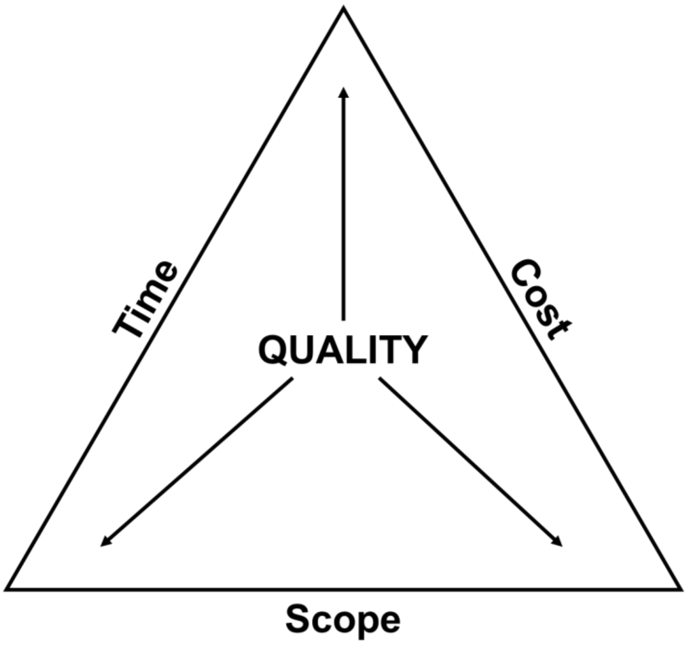

Figure 23 Project management triangle (elaboration of the author)

1) Scope

In the initiation phase, it is important to specify all the steps of the project development including what WILL be done and what WILL NOT be done. To keep the project under control, it must be allocated some time and carefully plan and define the scope.

2) Time

Time is an invaluable resource. While processes can be controlled and managed with necessary changes to improve them, time cannot be controlled. One of the biggest challenges each project manager has to face is to use time efficiently, keep the project on schedule, and reach the desired objectives.

3) Cost

The budget should be defined in the early stage of the project and then compared with the figure that the customer initially offered. If the client decides to spend a certain amount of money that does not match the requirements of the project, a business proposal has to be prepared, and it will include the estimates of the total cost of the project. This proposal helps the customer base his decision on more accurate estimates.

All three constraint are interconnected and depend heavily on one another. If the time allocated for the project is reduced, the cost increases. Also, the scope of the project dictates the pace and a number of resources necessary to realize and successfully complete the project.
The area inside the triangle represents the quality and it is the ultimate objective of every project delivery. The real challenge of the traditional project management is to control all three constraints of the triangle and produce the best quality. Project manager's ultimate goal is to meet their customers' requirements and live up to the quality standards.

5.5 Critical Path Method (CPM)

CPM (Critical Path Method) is a mathematical algorithm that helps the project teams to analyze, plan, and schedule complex projects. By determining the critical path, it will be defined which activities are critical in completing the project, and which ones will not have any serious impact on the project development and can be delayed.

It was created in the late 50's, when EI DuPont de Nemours Company, an American chemical company, was seriously falling behind its schedule, and they needed something that would get them back on track. They came up with a solution to divide their project into thousands of tasks, measure the time each task will take, and how asses critical they are to the entire process. They called this technique Critical Path Method or CPM. CPM was first tested in 1958 in a project to construct a new chemical plant, and has ever since, been one of the most frequently used techniques of project management.

Each project consists of a number of tasks and activities that are interconnected and essential for project's success. The more complex the project gets, the more demanding the project management is. At its core, CPM is a powerful tool that allows to identify the longest path of planned tasks necessary to meet the deadlines and identify the early start and finish dates (Figure 24).

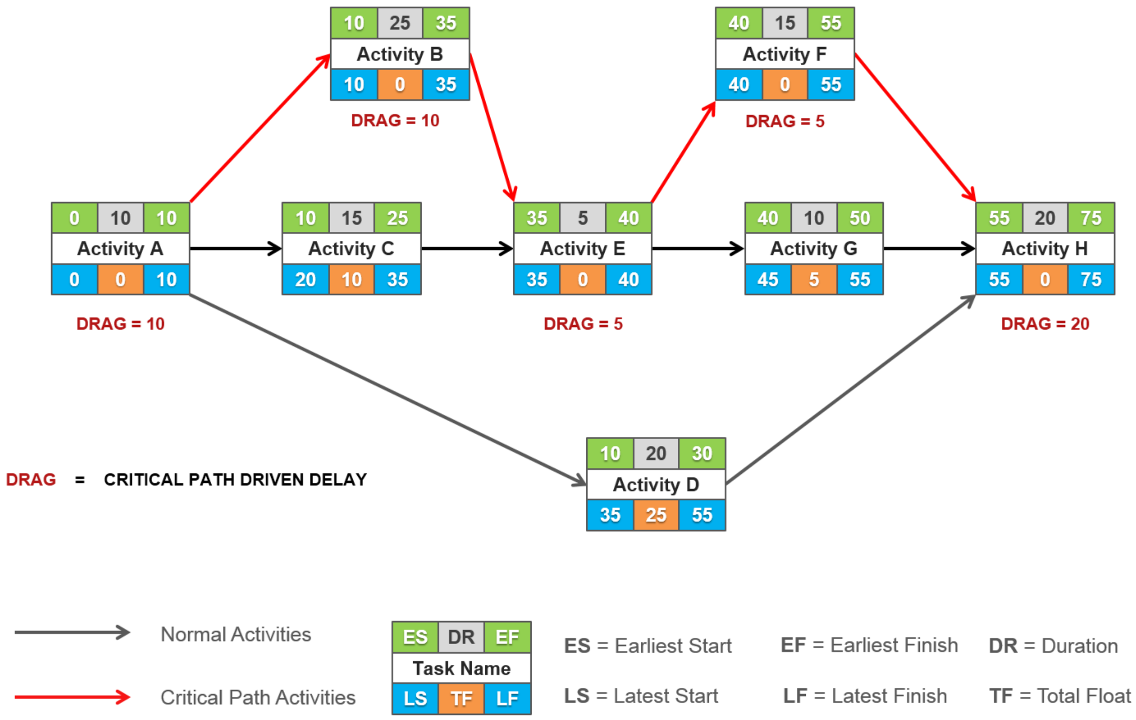

Figure 24 Example of Critical Path Method representation (source: www.project-risk-manager.com)

5.5.1 Main steps of Critical Path Method

A critical path method includes the following steps:

1) **Identifying activities**

   By using the project scope, you can break the work structure into a list of activities and identify them by name and coding; all activities must have duration and target date.

2) **Determining sequence of activities**

   This is the most important step as it gives a clear view of the connection between the activities and helps you establish dependencies as some activities will depend on the completion of others.

3) **Creating a network of activities**

   Once you determined how activities depend on each other you can create the network diagram, or critical path analysis chart; it allows you to use arrows to connect the activities based on their dependence

4) **Determining completion time for each activity**

By estimating how much time each activity will take will help you determine the time needed to complete the entire project. (While with smaller projects you can make estimates in days, more complex ones require making estimates in weeks)

5) **Finding the critical path**

A network of activities will help you create the longest sequence of activities on the path or the critical path using these parameters:

a. *Early Start ES* - earliest time to start a certain activity providing that the preceding one is completed.
b. *Early Finish EF* - earliest time necessary to finish activity
c. *Late Finish LF* - latest time necessary to finish the project without delays
d. *Late Start LS* - latest start date when the project can start without project delays

If there is a delay in any task on the critical path, the whole project will have to be delayed. The critical path is the path where there can be no delays.

Naturally, not all the project activities are equally important. While some have a huge impact on the critical path and are therefore critical, others don't make much difference to the project if they are delayed.

The critical path method helps us determine which activities are "critical and which have "total float". However, if any of the floating activities get seriously delayed, they can become critical and delay the entire project.

5.5.2 How resource limitations affect the CPM

In every execution of a project, there are still certain limitations that affect our projects and create new dependencies.

For example, if the number of team members suddenly drops from 10 to 7, it is easy to run into resource limitations (ie. resource constraint).

In such scenario, the critical path changes into "resource critical path" where resources related to each activity become an integral part of the process.

This means that some of the tasks will have to be performed in a different order which may cause delays, and, consequently, make the project longer than expected.

5.5.3 Benefits of Critical Path Method

The critical path method allows to stay focused on the big picture by giving a clear view of all project activities and its potential outcome. The best thing about CPM is that less important tasks can be rescheduled and focus the efforts on optimizing the work in order to avoid delays.

Although critical method path may have become an outdated technique due to fast-paced technological advances, it still offers a number of advantages:

a. Prioritized tasks
b. Clear insight into project's timeline so the time necessary for project completion can reduced
c. Comparison between planned vs actual progress
d. Easy risk assessment
e. Easy to make an efficient redistribution of team members
f. Helps teams to stay focused

5.6 Program Evaluation and Review Technique (PERT)

The Program Evaluation Review Technique, commonly known as PERT, is a visual tool in project planning that helps organizations analyze and represent the activity, and evaluate and estimate the time required to complete the project within deadlines (Figure 25). PERT allows planners to identify start and end dates, and ultimately reduce costs and time needed to complete the project.

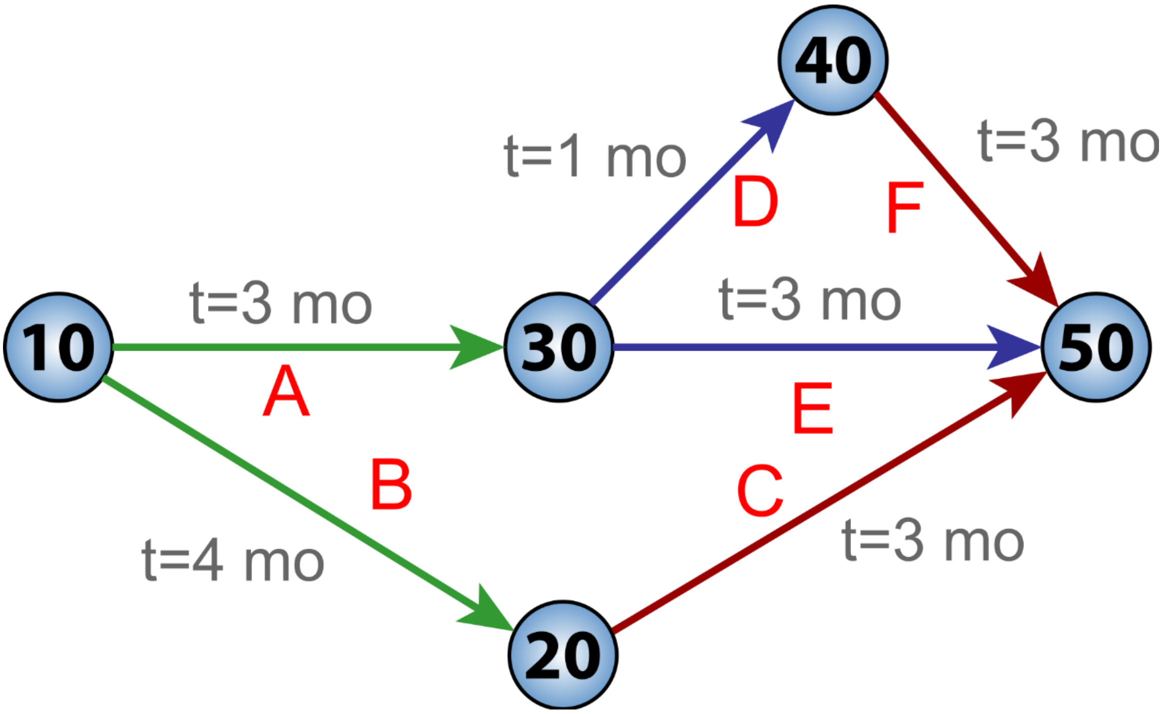

Figure 25 Example of PERT reticular diagram type AOA (Activities on the arrow) for a seven-month project with five stages (10 to 50) and six activities (A to F) (source: Wikipedia)

PERT was developed in 1958 by the US Navy as part of the Polaris project. Their aim was to manage the Polaris submarine missile program.

Unlike CPM, which determines the longest path needed to complete a project, PERT gives three different time estimates. While CPM focuses on time, PERT focuses on time-cost trade-off.

5.6.1 Main steps of PERT

1) Identifying specific activities and milestones

By listing all the tasks in the table, the result is a clear overview of all the steps which can be subsequently expanded by adding information on sequence and the time necessary to complete each activity.

2) Determining the sequence of activities

While it easy to predict the order of some activities, other tasks may require more in-depth analysis which will help to determine their order more easily.

3) Constructing a network diagram

Once established the sequence of activities, both serial and parallel activities can be represented in the diagram. Each activity should represent a node in the network, and arrows show relationships between activities.

4) Estimating the time necessary for each activity

What distinguishes PERT from other techniques is its ability to deal with uncertainty in activity completion time. There are three-time estimates this model typically uses for each activity:

a. *Optimistic time* - the shortest time in which the activity can be completed
b. *The most likely time* - the completion time that has the highest probability
c. *Pessimistic time* - the longest time in which the activity can be completed

Once identified the time estimates, the expected time for each activity can be calculated by using the following weighted average:

Expected time = (Optimistic + 4 x Most likely + Pessimistic) / 6

5) Identifying the critical path

By adding the times for the activities and determining the longest path, a critical path is created. The critical path involves the total amount of time necessary to complete the project. The total project time does nt change if activities outside the critical path speed up or slow down.

5.6.2 PERT advantages

At its core, PERT gives the ability to control complex and ambitious projects whose objectives can be highly critical in nature. It also helps to determine the fastest possible route to complete the projects.

PERT gives benefits such as:

1) *In-depth* analysis of project activities by viewing the activities both independently and in connection with each other, giving a clear view of the time and the budget required to finish the entire projects.

2) *What-if* analysis helps to identify all the possibilities and uncertainties related to the project. By trying different combinations and choosing the most useful possibility, it eliminates the risk of having project surprises. Also, it helps to highlight the activities that require careful monitoring.

PERT helps project managers identify responsible departments and delegate roles to their team workers. By gathering information from multiple sources, you can easily coordinate project activities and leverage communication between departments. Through efficient planning and decision-making, you encourage your team to truly invest their time and energy into delivering the best results.

5.6.3 PERT disadvantages

Even though PERT has proven to be effective in terms of reducing the expected project completion time, there are still some limitations to be aware of:

1) Although PERT clearly defines all the activities on a project, it is sometimes impossible to predict every step. Changes happen during the project and they can seriously affect the initial PERT. While it is possible to make modifications, it takes a lot of time and energy without contributing much to the project.
2) Project managers make time estimates and since they heavily depend on judgment, the numbers are only guesses, especially if the project manager has little experience with the activities at hand.

Overall, PERT allows to have an idea of possible time variation and helps you assess the importance of problems to face along the way. Unlike most methods, PERT gives the flexibility to identify the best-case and the worst-case scenarios and develop a strategy on how to best coordinate large-scale projects.

CHAPTER SIX: LAST PLANNER SYSTEM

6.1 Overview

The Last Planner System was developed by Glenn Ballard and Greg Howell as a production planning and control system to assist projects in smoothing variability in construction work flow, developing planning foresight, and reducing uncertainty in construction operations. While the system started as a production planning tool to manage workflow at the weekly work plan level, it soon expanded to become a production planning and control system combining four main planning processes (Figure 26):

1) Master scheduling;
2) Phase scheduling;
3) Lookahead planning;
4) Weekly work planning.

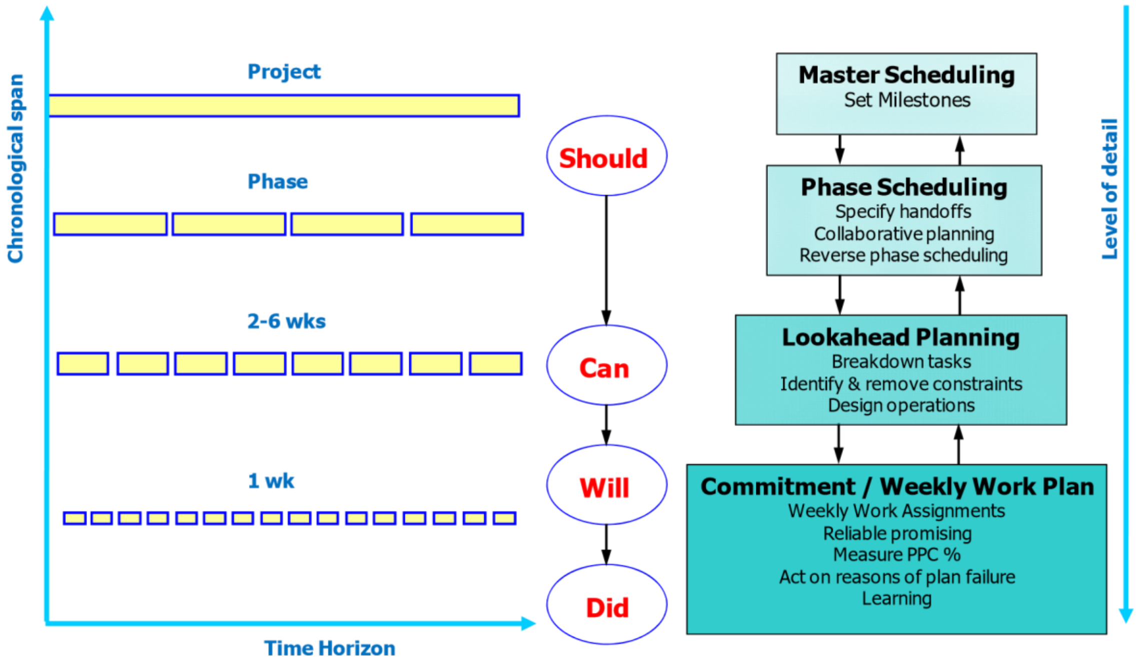

Figure 26 Planning stages/levels in the Last Planner TM system for production planning and control (Ballard 2000).

6.2 Work Structuring and Schedule Development

While variability and uncertainty are inherent to project processes, production systems can be designed to manage uncertainty and reduce the negative impacts of variability. A production system can be defined as a collection of people and resources (e.g. machinery, equipment, information) dedicated for designing/making goods or services to meet customers' value expectations (Ballard et al. 2007).

A component of production system design is *work structuring*, which can be defined as "*developing product design in alignment with process design, structuring supply chains, allocating resources, and designing offsite preassemblies to realize a reliable workflow and maximize customer value*" (Ballard 2000).

Work structuring covers an entire production system from major milestones down to operations performed on materials or information within the system. Work structuring differs from work breakdown structure (WBS) which was traditionally used by planners to decompose a project into work packages, build it into a project schedules, and use it for project control.

Work structuring answers the following questions:

1) In what units will work be assigned to work groups?
2) How will work units be sequenced?
3) How will work be released from one work group to the next?
4) Will consecutive work groups execute work in a continuous flow process, or will their work be decoupled?
5) Where will decoupling buffers be needed, where should they be located, and how should they be sized?
6) When will different units of work be executed?

Work structuring involves the development of various project planning and control processes including:

1) build work execution strategies (e.g. start with tower structure and build parking structure later);
2) develop project organizational structure (divide project into areas);
3) configure supply chains (e.g. supply chain for curtain wall glass/aluminum units);
4) design rough-cut operations (e.g. cast-in-place versus precast concrete panels);
5) design detailed operations (e.g. formwork for concrete core walls);
6) develop milestone schedules.

A practical method for the development of a work structuring can be also found within the Lean Project Delivery Method (Figure 11), already presented in Chapter 4.3.2.

Work structuring works hand in hand with s*chedule development* which can be defined as the planning process that translates owner's value proposition into operational work plans. Schedule development is strictly carried on with work structuring:

1) develops phase schedules based on master schedule;
2) designs lookahead plans grounded in pull and phase schedules;
3) produces weekly work plans of task made ready during lookahead planning.

6.3 Master Scheduling

Master scheduling is the first process in front-end planning, and it translates the owner's value proposition into a master schedule describing work over the entire duration of a project. It involves project-level activities mostly in relation to contract documents. These high-level activities describe milestones, which in turn define project phases.

Master scheduling starts by translating the owner's values and purposes (value preposition) into work plans and execution strategies which are expressed in project level activities. The dialogue between the owner's values and work strategies produces the foundation for setting project milestones. After identifying major milestone dates, Critical Path Method (CPM) logic is used to determine overall project duration. CPM logic can be represented in different forms including Gantt, PERT (Program Evaluation Review Technique), and line of balance diagrams.

The calculated project duration and the timing of milestones are checked against the owner's expectations. If found unsatisfactory, alternatives or adjustments to the original schedule in terms of duration, sequence, or scope are introduced and re-planning performed until a satisfactory schedule is developed.

When project stakeholders are engaged early in the project, as when employing integrated project delivery, it the master schedule can be developed collaboratively incorporating feedback from project parties who have already been engaged in the project at that stage. Figure 27 shows an example of master scheduling organization.

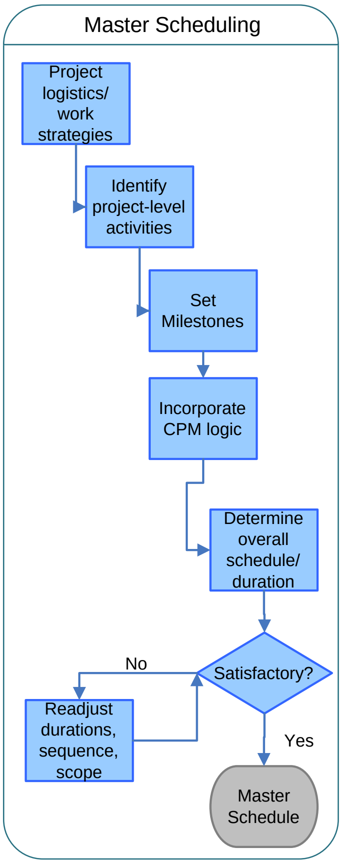

Figure 27 The master scheduling process in the LPS (Hamzel et. al *2009)*

6.4 Phase Scheduling

The purpose of phase scheduling (also called pull scheduling) is to produce a plan for meeting a milestone or completing a phase while maximizing value generation and establishing support from project stakeholders. Scheduled activities are then drawn from the phase schedule into the lookahead process, broken down into operations, and made ready for execution in weekly work plans.

Linking work structuring to production control, phase scheduling produces a phase schedule communicating handoffs and goals to which to steer production. In a collaborative planning setup, the phase schedule identifies handoffs between project parties and employs reverse phase scheduling to find the best way to meet milestones shown on the master schedule. Phase scheduling often results in introducing adjustments to original CPM logic as needed to meet project goals.

On large and complex projects, the master schedule includes many milestones and high-level tasks that express project phases. Figure 28 shows that the first step in master scheduling is identifying milestones delimiting phases that must undergo collaborative pull scheduling. Phase or pull scheduling is a collaborative process that a team can use to plan the delivery of a phase of work (to plan the accomplishment of a schedule milestone) according to customer pull or value expectations.

Pull scheduling works backwards from a target completion date. Tasks are defined and sequenced to release work to downstream tasks when they are requested/pulled, thus achieving a handoff. Pull scheduling works backwards from a target completion date to eliminate work that may not add value and reducing the waste of overproduction.

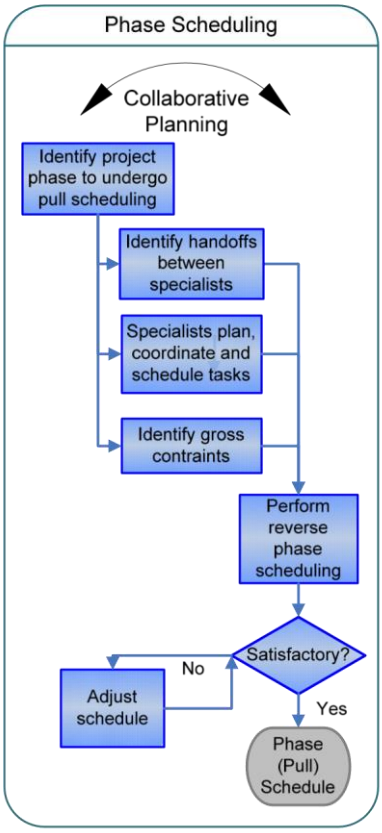

Figure 28 The phase scheduling process in the LPS (Hamzel et. al *2009)*

When identifying phases to undergo phase scheduling, it is essential to align the perspectives of various project partners unifying the team's expectations to what value needs to be delivered when executing this milestone. This step, called *milestone alignment*, starts by identifying deliverables or outcomes of value to downstream customers, followed by expressing and communicating the conditions of satisfaction for the outcome to be delivered by a partner upstream to another project partner downstream. Conditions of satisfaction result from negotiations/discussions between the parties. Setting tough time-targets often encourages such negotiations/discussions. Milestone alignment results in a better understanding of the milestone to be pulled, a date to pull to, and a set of handoffs between various specialists.

Collaborative or team planning engages representatives of all project stakeholders involved in a project phase. With handoffs or deliverables identified, team members begin team planning by writing on sheets of paper:

1) a brief description of work they must perform,
2) expected duration,
3) resources employed,
4) previous work to be completed by others to release work to them.

It is recommended that the meeting participants prepare for the meeting by reviewing their work scopes and developing a preliminary work plan. The team then arranges the sheets on a wall in their expected sequence of execution. This exercise encourages team coordination as planning breaks out in the room and team members start developing new network paths, devising new methods, negotiating sequence, and considering different batch sizes.

The next step is *reverse phase scheduling*, starting from the milestone and moving backwards towards the start. Backward scheduling is helpful in uncovering constraints when team members have to think of prerequisites required to start an activity (Ballard 2000). It is crucial at this stage to start uncovering gross constraints that impact a phase or a process within a phase.

While the phase schedule is developing, network logic is often readjusted, and task durations altered to find the best way to meet the milestone or phase undergoing phase scheduling. A phase may be decomposed into interim milestones that can be used in pull scheduling (e.g. structure as a phase can be broken down into many interim milestones such as ‘first floor’, ‘second floor’, etc.).

The resulting reverse phase schedule may take one of three possible forms:

1) a schedule that does not meet the allotted time frame,
2) a schedule that fits the time frame tight,
3) a schedule that contains some float.

The schedule that results from backward pass process is satisfactory only when the scheduled tasks fit within the available time, with sufficient float to buffer critical and variable tasks. First attempts often do not meet time limits, as in the example shown in Figure 29; much less provide a schedule buffer; so, re-planning is required.

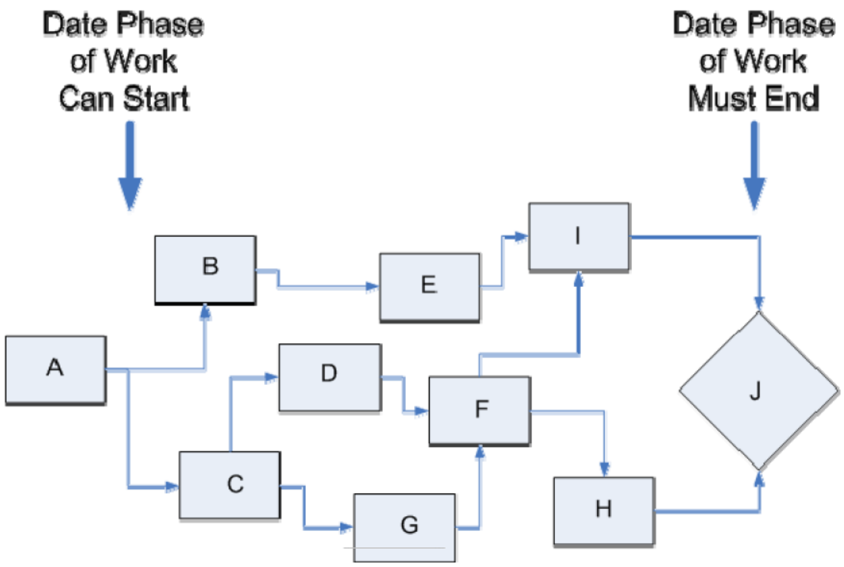

Figure 29 Reverse phase schedule exceeding limit limits (Ballard 2008)

To create an acceptable buffered schedule, the project team analyzes the network for possible changes in logic or task duration. The team may generate several ways to shorten time including:

1) starting more tasks in parallel (a matter of reducing the handoff batch size),

2) allocating resources differently,

3) applying new methods or technologies.

Figure 30 shows an example of an adjusted reverse phase schedule creating a schedule buffer.

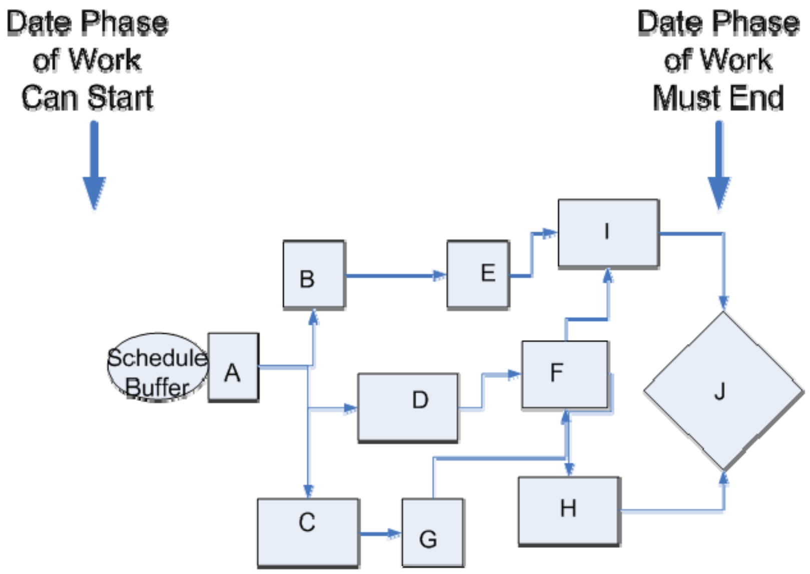

Figure 30 Reverse phase schedule adjusted to create a schedule buffer (Ballard 2008)

Once an acceptable schedule is created, the team then has to decide how to allocate this time.

Many options are available for the team to explore including:

1) allocating buffer to certain activities, usually activities with high uncertainty (as shown in Figure 31),
2) using the buffer in the beginning (delaying the start),
3) bringing the phase completion date forward.

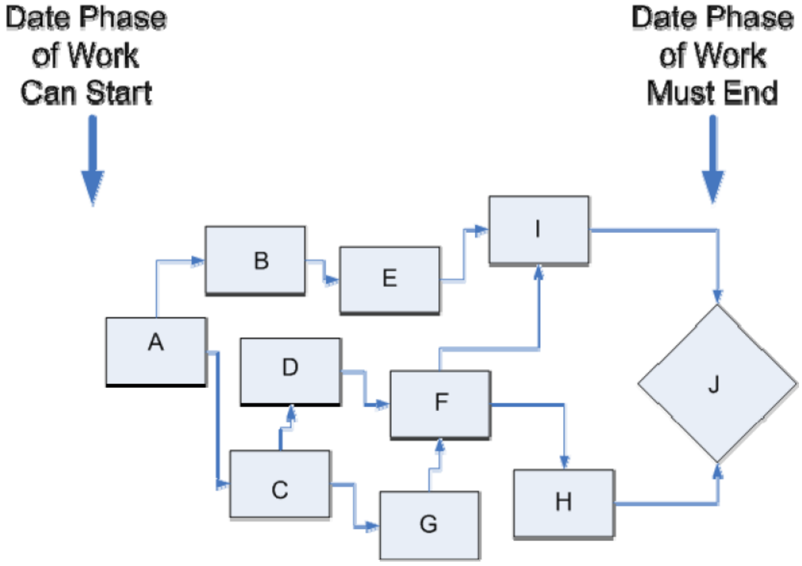

Figure 31 Reverse phase schedule after schedule buffer has been distributed (Ballard 2008)

Although the goal of phase scheduling is to find the best way to meet a milestone or accomplish a phase, sometimes this is not possible and in this case the phase completion date can slip out.

The goal of phase scheduling is to generate a schedule that all project stakeholders buy into, define handoffs between specialists for control without going into too much detail, introduce required adjustments to CPM logic, and produce an executable schedule agreed on before the start of phase.

6.5 Lookahead Planning

Lookahead planning is the first step in production planning and provides a link between the project schedule and short-term commitments. It starts with generating a lookahead view from phase schedule and continues to weekly work planning. However as Figure 32 shows, lookahead planning means not just viewing near-term tasks from the master or phase schedule and possibly detailing them; rather, it is a process that involves:

1) breaking down tasks into the level of processes/operations,
2) identifying and removing constraints to make tasks ready for execution,
3) and designing operations through first run studies (Ballard 1997).

Lookahead planning is an essential process in production planning and control. It:

1) shapes the sequence and rate of workflow,
2) links master and phase schedules to weekly work plans,
3) shields downstream tasks from uncertainty in upstream tasks,
4) sizes workflow to match capacity and constraints,
5) produces a backlog of workable activities by screening and pulling (Ballard 2000).

Screening submits tasks to constraint analysis to identify actions needed now to make scheduled tasks ready, so that they can be performed when scheduled, and to prevent commitment to tasks that cannot be made ready. Typical constraints are contracts, change orders, requests for information, design instructions, materials, predecessor tasks, labor, equipment, and space.

Pulling dictates which tasks to make ready by removing constraints and ensuring the availability of prerequisites as per actual site demand. While pulling is built into the schedule that lookahead planning should start with, it is also present in the LPS rule that no tasks are to be imposed on work groups unless they are ready to perform them (Ballard 2000).

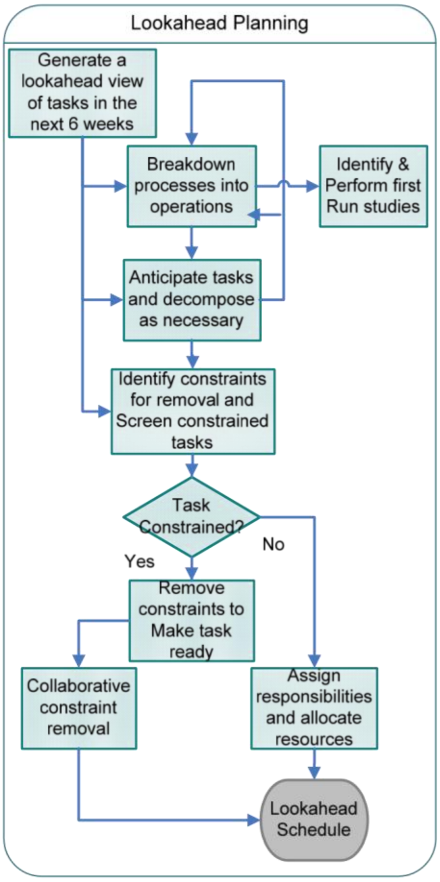

Figure 32 The lookahead planning process in the LPS (*Hamzel* et. al *2009)*

Lookahead planning starts by filtering a schedule that looks several weeks, most commonly six, into the future.

1) *Six weeks ahead of execution*. Tasks enter the six week lookahead plan from the phase schedule. At this stage, gross constraints are evaluated and a plan for removal is devised. Gross constraints are those that impact all instances of phase-level tasks and processes, i.e. to every operation that belongs to that type of process.
An example is the production of fabricated items such as precast concrete panels. This process involves several operations: detailing, fabrication, and delivery. Fabrication is one operation in this process and will recur many times. For construction, typical gross constraints are materials and design information. Phase scheduling can act as a catalyst for identifying handoffs and gross constraints early

on. Although removing constraints can take place anywhere within the six weeks on the lookahead plan, it is desirable to remove constraints two to three weeks prior to executing a task.

2) *Between five weeks and four weeks ahead of execution*. Activity break down starts by decomposing tasks into their elements, moving from processes to operations (projects consist of phases, phases of processes, processes of operations, operations of steps, and steps of elemental motions). Elemental motions are not represented in current forms of the LPS, although they may be appropriate analytical units for design of highly repetitive tasks executed under controlled conditions. Steps are defined in the design of operations and assigned to individuals or sub-teams within work groups.

   Activity breakdown goes in parallel with defining operations, sequencing work in the most optimal way, coordinating tasks among project stakeholders, loading operations with resources, sizing load to match capacity, and analyzing tasks for soundness so that prerequisite inputs are ready such as previous work, information, material, labor, and space (Hamzeh et al. 2008).

3) *Three weeks ahead of execution.* By this time the team should have designed operations through first run studies, developed detailed plans for work execution, and screened out those tasks they are not confident can be made ready in time. A first run study is an actual performance of an operation for the first time in order to try out, study, learn, and improve the method to execute an operation. It involves understanding the work involved, the skills and resources needed, and the interactions with other operations. The process involves evaluating the devised plan, launching refinements, and establishing standardized work. Potential operations requiring first run studies are those that are new, critical, or repetitive.

4) *Two weeks ahead of execution.* Lookahead plan activities are broken down and detailed as they move closer to execution. Accordingly, when activities are two weeks away from execution, they will match the detail required for production at the weekly work plan level. The level of detail in planning is time driven. It may be planning to the day, to the shift, or to the hour (e.g. planning of shutdown operations). Tasks that are constraint-free join the workable backlog (backlog of

workable or ready tasks). Tasks on the workable backlog may be selected to join the weekly work plan if they meet the quality criteria as discussed next.

5) *One week ahead of execution.* At this stage, a provisional weekly work plan is prepared according to quality criteria of definition, soundness, sequence, size, and learning. Tasks that are critical, made ready, or can be made ready in the upcoming week are incorporated in the weekly work plan within available capacity. Made ready and non-critical tasks are placed on the fall back / follow on work list to be performed in case of extra capacity, either from completing critical tasks sooner than expected.

6.6 Weekly Work Planning

Weekly work planning is an extension of lookahead planning into the execution week. It represents the most detailed plan in the LPS and directly drives production. It is the level at which promises and commitments are made. In phase scheduling, team members are committing to do their best. In lookahead planning, team members are doing all they can to remove constraints. In weekly work planning, team members are committing to doing their tasks. Plan reliability at the weekly work planning level is promoted by making quality assignments and reliable promises to shield production units from uncertainty in upstream tasks. At the end of each week, reliability is assessed by measuring the number of assignments completed relative to the number of assignments planned. For tasks that are not accomplished, analyzing the reasons for plan failure and acting on these reasons is used as a basis for learning and continuous improvement (Ballard 2000).

Weekly work planning involves:

1) advancing tasks that are well defined, constraint-free, in proper sequence, well sized (in terms of load and capacity),
2) performing collaborative weekly work planning to remove constraints for constrained tasks,
3) exercising reliable promising,
4) learning from plan failures.

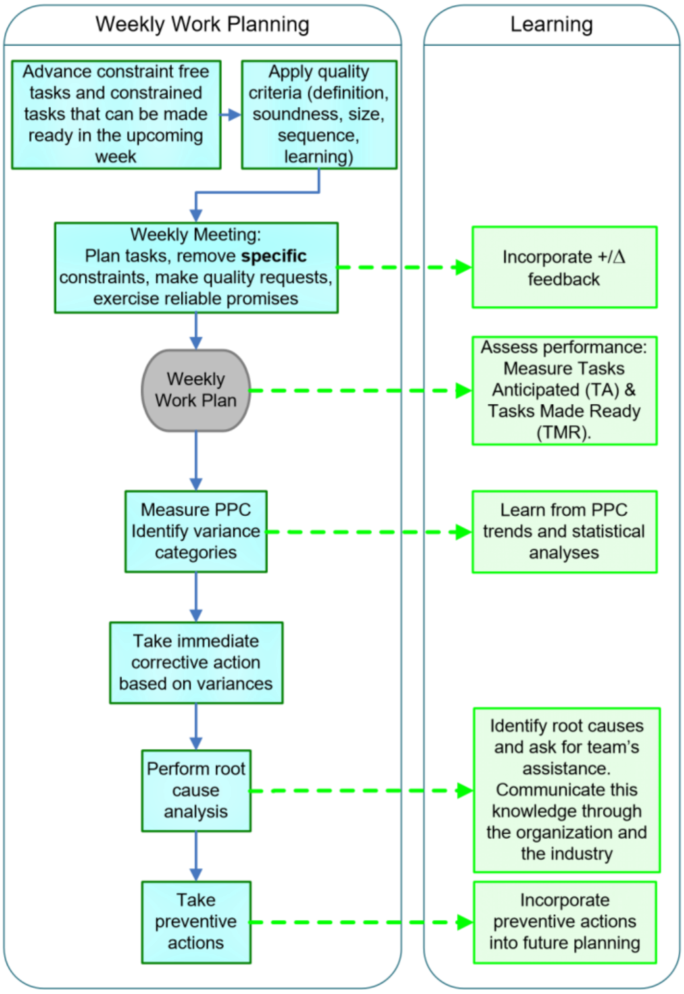

Figure 33 The weekly work planning process in the LPS (Hamzel et. al *2009)*

As Figure 33 shows, weekly work planning starts by advancing both tasks that are ready (constraint-free) and tasks that can be made ready during the course of the week. Capacity permitting, constraint-free critical tasks are given the first priority followed by critical tasks that are constrained but can be made ready during the week. Critical tasks that cannot be made ready are screened out of weekly work plans to shield production from executing tasks that are not ready. These tasks will be evaluated in the upcoming weeks and are given priority in removing their constraints. At this stage noncritical tasks that are not ready are also screened out while constraint-free critical tasks are incorporated on the fallback / follow-on list to be executed when having extra capacity.

It is desirable to advance to the weekly work plan only tasks that make quality assignments. Quality assignments are measured against five main quality criteria (Ballard 2000):

1) *definition*: a task should have a clear scope and desired outcomes,
2) *soundness*: planned tasks should be constraint-free or can be made constraint-free during the plan period,
3) *sequence*: arrange tasks in the proper sequence and avoid out-of-sequence work,
4) *size*: match load and capacity (e.g. match the workload placed on individuals, sub-teams, or work groups with their actual capacity),
5) *learning*: use root cause analysis to continuously improve the quality of assignments (make use of the plan-do-check-act (PDCA) cycle).

Then, next week's work plan is discussed, coordinated and finalized during a collaborative weekly work plan meeting involving project stakeholders. This meeting enables last planners (i.e. team leaders responsible for production teams) to discuss constrained tasks, make requests to remove constraints, and make activities ready by removing constraints. Last planners make quality requests to remove constraints and quality commitments to next week's work tasks.

6.7 The overall process

As explained so far, the process starts with front end planning when a master schedule is developed to translate the owner's value proposition into milestones. Phase scheduling utilizes pull techniques to define handoffs for delivering milestones. Production planning starts with lookahead planning which employs screening and pulling to make tasks ready for execution. Weekly work plans, which directly drive the production process, are produced from a backlog of constraint-free tasks and also tasks that can be made ready during the week. Applying quality criteria when developing a weekly work plan, exercising reliable promises, and learning from plan failures all combine to shape plan reliability.

The system works best when all these processes are developed in sync (i.e. schedules are compatible), involve project stakeholders, account for dynamic changes/updates, and utilize learning from planning failures for continuous improvement.
Figure 34 The Last Planner System (adopted from Ballard and Hamzeh 2007)Figure 34 represents the merged phases of the Last Planner System including also the communication arrows (dashed lines) between the phases.

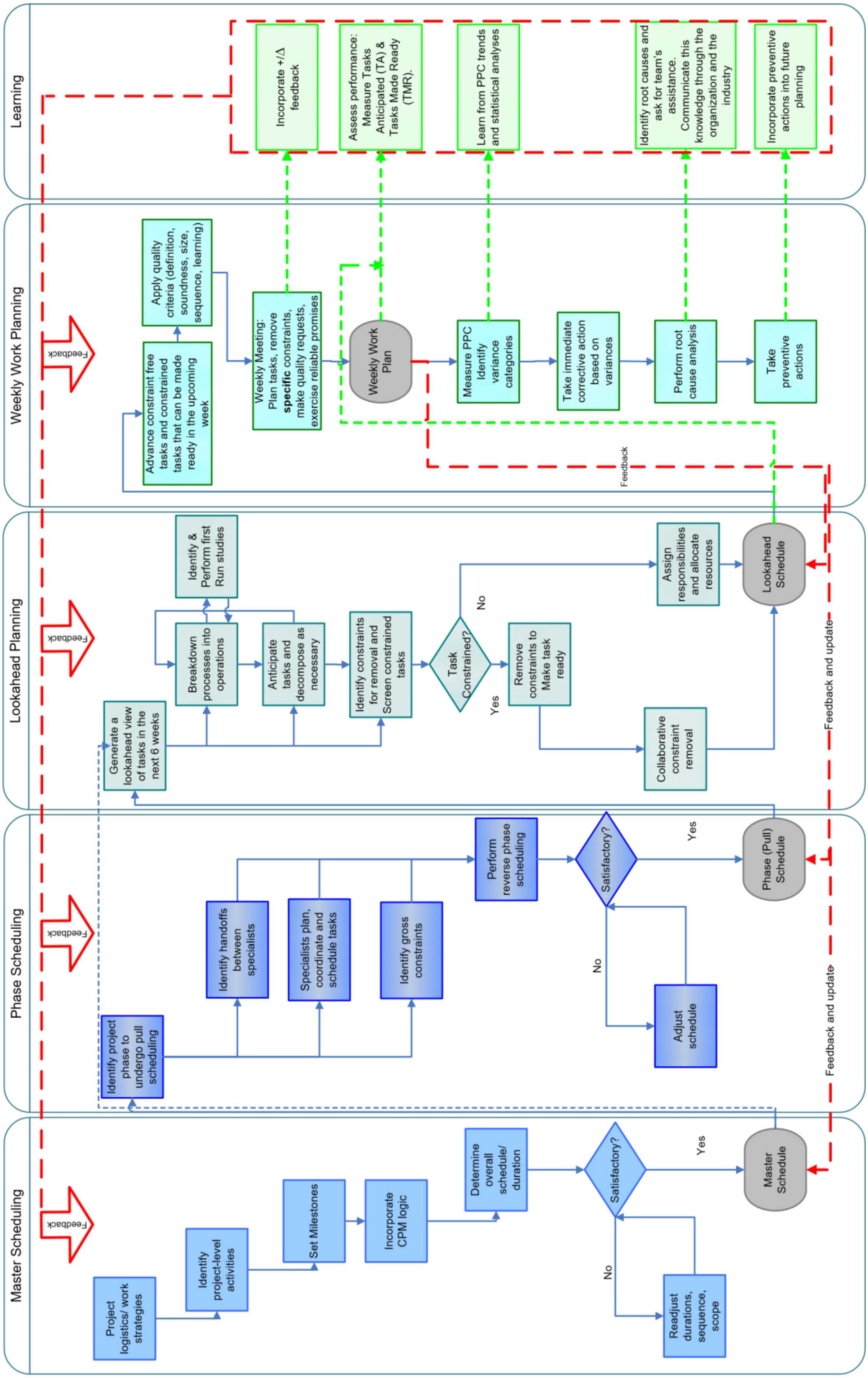

Figure 34 The Last Planner System (adopted from Ballard and Hamzeh 2007)

CHAPTER SEVEN: FINAL COMPARATIVE ANALYSIS

7.1 Comparative analysis of techniques and tools used in the traditional construction project with lean construction techniques

The growing context of globalization permanently increases pressure on companies to improve their performances. More recently, the lean philosophy begins to integrate into the construction sector. In order to improve the efficiency of the production system, Lean Construction philosophy was introduced as a new method of construction projects management.

The following comparative analysis focuses on three main criteria:

1) Creating value and eliminating waste;
2) Planning and mutual coordination;
3) Site organization.

7.1.1 Traditional construction

1) **Creating value and eliminating waste**. The analyses carried out by Koskela (1994) show that the conceptual engineering of traditional construction industry focuses only on the steps of conversion or processing activities and neglects the non-value-added activities, which leads to an uncontrolled variability of production. The most important parts of production in the construction sites are wastes. Leaders of traditional Construction project search in most cases to solve the production variability by incorporating more resources in order to increase the reliability of operations that create added value, which increases spending of companies that take the risk of investing in the introduction of new technologies often uncontrolled instead of trying to identify the real sources of wastes. Most of traditional construction sites are based on management modes "push" instead of "pull". This generates additional costs of storage and materials (or equipment) management. In addition to that, the site of construction become condensed by materials without adding value for the customer, which leads to negative impacts on quality, especially under weather conditions. Several studies have analyzed the different kinds of waste that are observed in traditional construction projects, but the survey

carried out by Patrick Dupin (2014) shows that value-added activities (direct work) do not exceed in most of the time 32% of time spent on site and the rest of the work is divided between waiting (29%), displacement of employees, instructions, transport actions and so on, as shown in Figure 35.

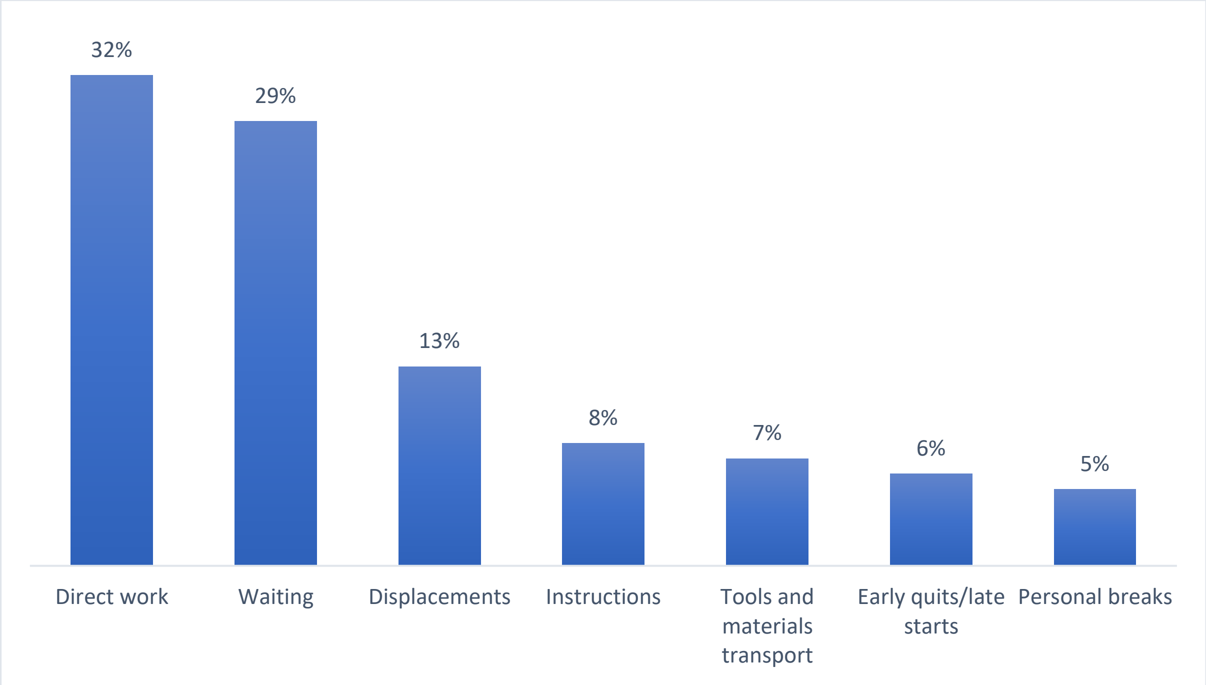

Figure 35 Proportions of the sources of waste in the construction industry (Dupin 2014)

2) **Planning and mutual coordination**. Several studies have shown that in the traditional planning model more than 50% of scheduled tasks are not carried out on time. In most of the time, a single entity (project manager) dictates 'what to do' and 'when' to the rest of the stakeholders in the project. Indeed, the project manager realizes the general planning “Master Schedule” based on the project information and the targeted objectives, leading to a temporal state of what “Should” be done without taking into account of neither the intrinsic reality of the site of construction nor the ability of companies to fulfill their missions. “Traditional,” push planning system is illustrated in Figure 36Figure 2 Traditional design approach.

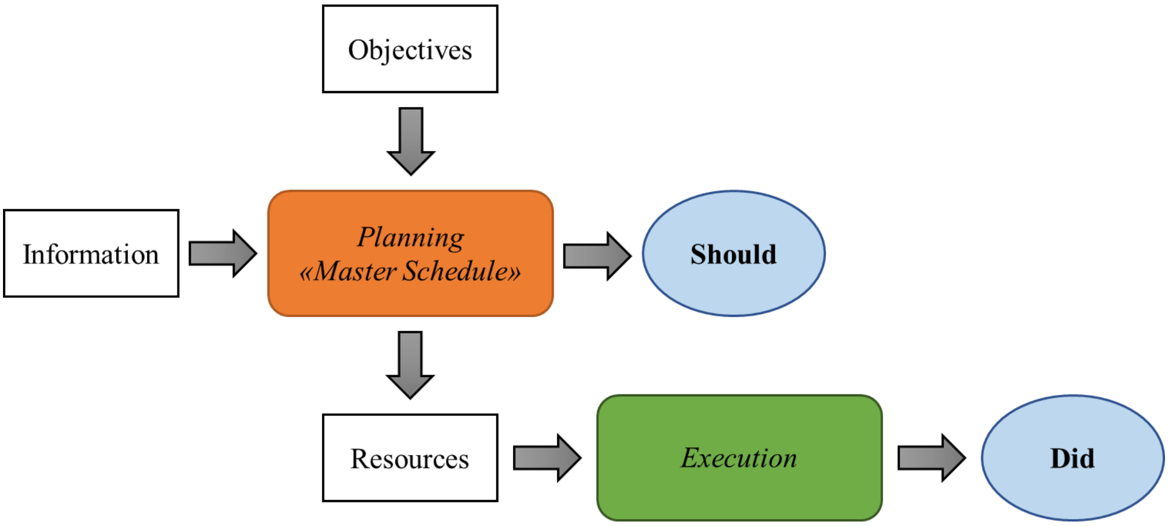

Figure 36 A push planning system (elaboration of the author)

Traditional project management is generally based on the principle of 'pushing' work to the companies and their subcontractors in objective to perform the tasks planned in the master schedule, whether or not these stakeholders have all the necessary resources to carry out their missions. The signature of the planning "Master Schedule" by the different contractors makes it contractual. Penalties are provided for each timeout. During the execution of the project, companies are more likely to perform their work as soon as possible, leading to risks at the level of the quality of construction and the safety of personnel, especially in the absence of real communication between companies and subcontractors operating on site. In the traditional model of planning, there is almost no incentive to work together and to collaborate with each other. A significant part of the time and energy is consumed to avoid penalties rather than seeking optimization and reducing of wastes. According to Dupin (2014), operational and relational effectiveness cannot be achieved in a model based on contractual relationships in the absence of a mutual collaboration between the different project collaborators (architect, engineering, companies, subcontractors, and suppliers).

3) **Site organization**. In a competitive market with increasingly shorter deadlines and several contractors working in the same place, the management of organizational level becomes more and more complex. Indeed, most of the traditional construction sites are poorly organized places. Poor visualization and organization are considered among the main causes of accidents on the site of construction. Most of

construction projects, that have an unorganized site of construction, are characterized by cost overruns and delays. In the traditional management, the construction sites present a very high level of risk for the staff, especially in the absence of visual management, and the presence of several stakeholders on site, performing varied activities simultaneously.

7.1.2 Lean Construction and LPS

1) **Creating value and eliminating waste**. Research, identification and elimination of activities with no added value are primordial in Lean Construction philosophy. Indeed, the removal of no value-added activities helps to get closer to customer expectations. According to Dupin (2014): "If an activity does not bring any value neither my client nor my company nor myself, so would I do it?".

   Value Stream Mapping (VSM), presented in Chapter 4.3.1, is considered among the most used Lean Construction tools for the identification of the sources of wastes. VSM consists in creating a visual map of the flow of materials and information from suppliers to consumer. The main objective is to identify the different tasks of the process analyzed and to distinguish between them into two categories: those that create value-added (VA) and those with no value added (NVA), which allows identifying the sources of wastes that must be eliminated for objective to transform the current process into a future process more optimized (Abdulmalek *et al*. 2007).

   Figure 10 Example of a Value Stream Mapping scheme (Yu et al. 2009)

   The concept of a pull system is a fundamental pillar in a lean approach. "Just in Time" philosophy is classified between the most developed Lean Construction tools designed to eliminate non-value-added activities and to reduce process variability, and is based on the concepts that stocks which do not bring added value to the customer (internal or external) should be considered as sources of wastes. So, the materials or equipment must be available only when it is necessary.

   Supply management using "kanban" cards is a very effective technique to ensure the minimum amount of materials, depending on the real needs of the site construction.

Dupin proposes another solution to the storage problem by tracing the working areas, so each one of them will have his own storage. In addition to that, we can use mobile storage blocks, equipped with wheels to facilitate the movement. Indeed, this solution will actually allow following physically the flow of production which helps to effectively reduce many sources of waste (operators' displacements, waiting, stocks).

2) **Planning and mutual coordination**. The Last Planner System (LPS), the main tool of Lean Construction, is a collaborative planning tool facilitating communication, participation and which take into consideration the constraints of each stakeholder. The scheme of planning with the LPS tool is shown in Figure 37.

"*Master Schedule*" is used to determine crudely the main actors, the sequences of building as well as the milestones which should be accomplished during the step "*Phase planning*"; each company, represented by a foreman, will try to regulate the schedule according to the activities for which it may engage. The objective is to identify possible constraints related to each task. At the end of this phase, the planning becomes not only more faithful to the reality of the work, but the most important are that it contains sequences and durations of tasks not imposed, which they have been planned in collaboration with all participants; those who are directly responsible for the supervision of the work on the site of construction.

"*Look-Ahead Planning*", schedule of two to eight weeks, which help to identify the constraints to be taken into account to avoid overruns of deadlines. Indeed, all companies and subcontractors must check the availability of all the necessary resources and conditions for the proper conduct of scheduled tasks. According to Ballard, the seven points to check are prerequisites Work, Surface ready, Labors available, Equipment available, Materials available, Plans available, and favorable external Conditions.

"*Weekly Work Plan*" is a weekly schedule containing only the tasks without constraints; so, all stakeholders become responsible and engaged on the activities that will be executed the next week (plans). PPC (percentage of plan completed) is an indicator that allows tracking the production by measuring the percentage of completed activities amongst those that have been scheduled (rate of implementation of the commitments). From this measurement, the difference between what was planned and what was achieved, can be evaluated by conducting PDCA approach.

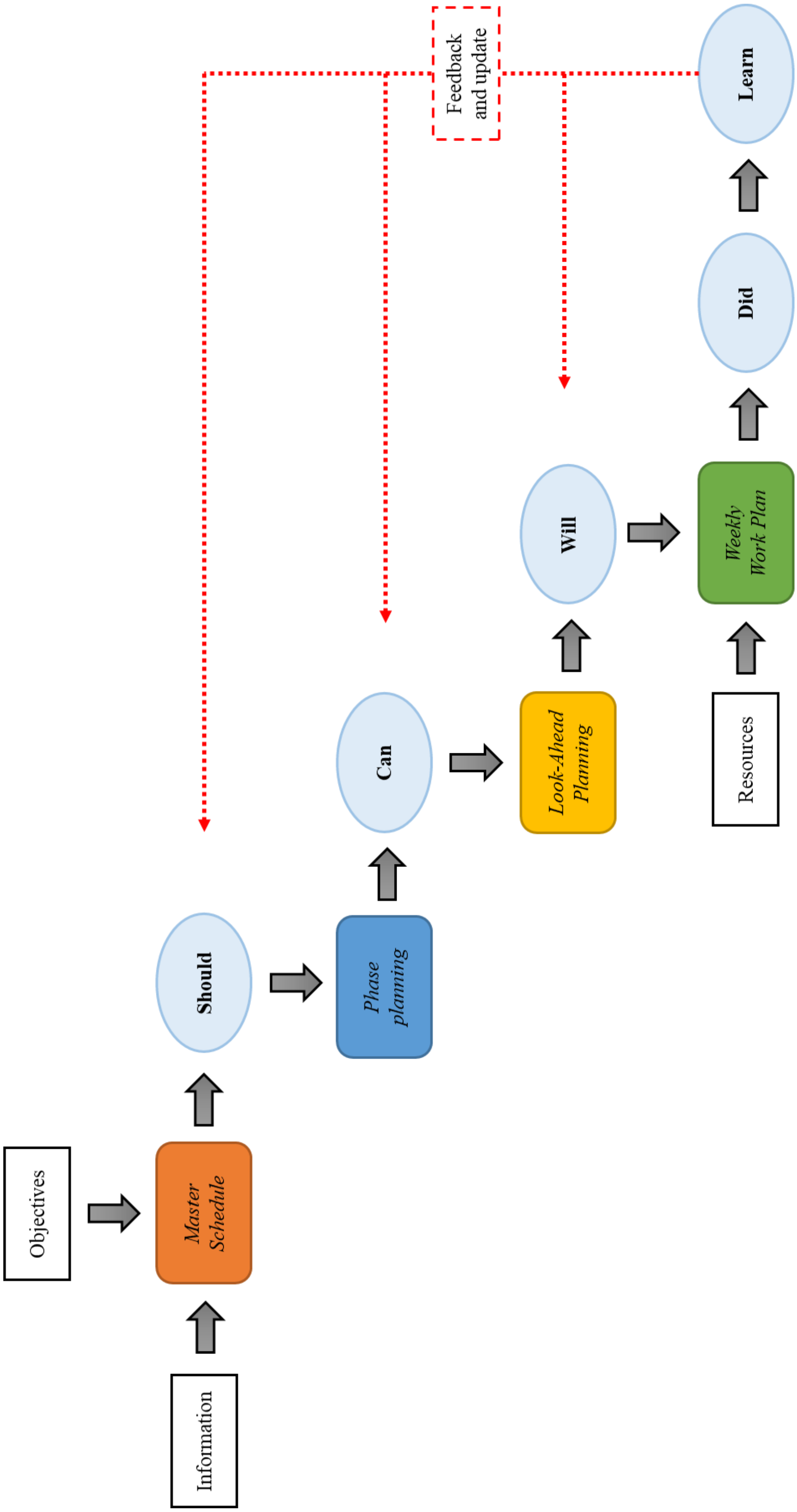

Figure 37 Scheme of planning with the LPS integrated (elaboration of the author)

3) **Site organization**. The 5S process is considered among the first steps that an organization should take into consideration during the implementation of the lean construction philosophy. Recent research shows that construction companies with an efficient organizational level are those who have started the deployment of Lean Construction by the implementation of 5S management (Desale *et al*. 2014). The application of the 5S approach allows keeping the construction site more organized than before, reducing damage to equipment/materials by improper storage, and increasing the safety of personnel.

   The term 5s refers to five Japanese words:

   a. Seiri "*Sort*": separate the needed materials and tools, which are essential for production steps, from the superfluous (trash);
   b. Seiton "*Set in order* or *Straighten*": dispose each tool and material in his position for ease of use;
   c. Seiso "*Shine*": maintain clean and liberated zone from bulky items;
   d. Seiketsu "*Standardize*": standardize the rules and keep the first 3Ss;
   e. Shitsuke "*Sustain*": progress and ensure continuous improvement.

   Visual management helps to make the construction process transparent, simple and secure for all stakeholders on site (Tezel *et al*. 2015). Digital billboards, signs of security and graphical dashboards of PPC facilitate the construction process and increase the performance of communication between the coordinators of the project, which make the site of construction safer and more transparent. So, each material/equipment can be identified using visual signs easy to understand by labor which helps to minimize unnecessary displacements/movements and increase the transparency of the flow.

7.1.3 Comparative summary

Table 7 shows a synthesis gathering the specificities of two methods of building (Traditional Construction and Lean Construction & LPS) according to three criteria: creating value and eliminating waste, planning and mutual coordination, and site organization.

	Traditional Construction	Lean Construction and LPS
Creating value and eliminating waste	Focuses only on the activities of conversion or transformation; neglects the non-value-added activities	Mastery of the entire construction process (flows, steps of conversion); takes into consideration the value-added activities and activities with non-value-added
	Lack of a waste elimination culture	Identification and elimination of all forms of waste throughout the project life cycle (design, construction, and demolition)
	Push strategy	Pull strategy
Planning and mutual coordination	Rigidly hierarchical organizational structure; the mission of scheduling, piloting and coordination is centralized on a single entity: project manager	Scheduling, piloting, and coordination with all the stakeholders of the project; a schematic of discussion open, clear and iterative
	Unilateral work, lack of mutual collaboration in problem-solving phase	Collaboration and sharing of multilateral issues
	Absence of performance indicators	Controlling of the variance of the construction process by measuring the PPC (percentage of plans completed)
	Contractual relationships between the stakeholders of the project based on a system of following orders; Penalties are provided for each timeout	Seeking to solve problems and find effective solutions, instead of searching responsible and penalize him; process optimization in a continuous improvement path
	Knowing	Learning
Site organization	Poorly organized site of construction	The organizational level of the site of construction is optimized through the 5S approach
	Lack of visual management	Visual management increases transparency, facilitates communication between stakeholders on site and ensures the safety of personnel

Table 7 Comparative synthesis between traditional construction and Lean Construction (elaboration of the author)

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