

UNIVERSITY OF LJUBLJANA
FACULTY OF ECONOMICS

MASTER'S THESIS
PROJECT PLANNING AND SOFTWARE APPLICATION IN CONSTRUCTION
INDUSTRY – A SELECTED CASE ANALYSIS

Ljubljana, July 2015

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INTRODUCTION

Project management started to develop as a discipline at the beginning of the 20th century – two important figures who are considered the forefathers are Henry Gantt and Henry Fayol (Witzel, 2003); they set the basic principles and afterwards, others started to research project management and expand the discipline further. It is said that one of the key points in the history of project management was development of the atomic bomb in 1946 during the Manhattan project. It involved a great number of people, had a budget and a schedule lead by an American general; the technical part was led by a man known today as the father of the atomic bomb, Dr. Robert Oppenheimer (Schwalbe, 2010). Between 1950 and 1980, a number of methodologies appeared on the market – CPM/PERT technique, material requirements planning systems, which later led to creation of enterprise resource system, and many others. In 1960s, NASA created the Apollo project and sent six missions to the Moon – implementing CPM/PERT technique to maintain and schedule the missions (Kwak, 2003). Over the years science evolved even further, different software became available first to the selected few and then to all public organizations, which made sure that project management became a discipline that was applied in many different organizations.

There are many industries where project management can be applied. Whether it is a human resource department, an IT company or a supply chain firm, all that matters is that projects exist and only the methods used are different, but the philosophy is the same. As the world's population grows bigger every year, one of logical consequences is that people need a place to live. Based on that assumption, it can be said that civil engineering and construction represent people's need – a discipline that already thrives and will continue to do so in the future. As construction projects are considered highly complex, project management methods are an inevitable tool that every stakeholder in such a project uses – whether it is a construction company planning and executing the project or a bank monitoring their investment.

Late 20th century brought infinite possibilities in application of information technologies, and civil engineering was one of the sciences affected by this; as a result, a number of web, regular and cloud-based software emerged and influenced the way the construction projects are planned and realized today. According to a research (Liberatore, Pollack-Johnson & Smith, 2001), 97% of participants use project management software and around 83% use it for both planning and controlling the project.

Main goal of this thesis is to examine construction industry through the viewpoint of project management and to analyze possible algorithms for optimization of time-cost variable from different branches of science and later, apply them to actual project data.

This thesis represents a connection between different sciences – civil engineering and management science. Project management, though an independent science is applicable in many different areas and construction industry is undoubtedly one of them.

I will research available literature connected to both disciplines and focus mostly on the optimization problem, namely how time and cost in a construction project can be optimized. After I finish the theoretical analysis, I will focus on a practical example and apply an optimization algorithm to actual project data.

This type of research has already been conducted many times, however not so often from the economics/management point of view, especially in Serbia. I hope it will bring a new perspective of the problem and raise interest of colleagues from my branch.

1 PROJECT MANAGEMENT IN CONSTRUCTION

In this chapter, an overview of existing project management methods used in today's construction industry for project planning will be presented. Though the methodology is the same in all fields using project management, it still needs to be adapted for the purposes of application in construction management.

1.1 Problems of applying project management in construction

There are two main factors that influence realization of a construction project:

1. Funding issues
2. Large number of participants in the chain

The first factor is also present in projects in other industries. Cash flow needs to be planned properly without huge differences in weekly needs for material and workers. However, to understand this from the perspective of a construction project, certain roles need to be defined.

For starters, a construction project has many different stakeholders. A short overview of all main participants is presented in the section below.

- **Customer** – a person who is requesting a project - to build a house, block of flats or any other kind of large object (bridge, large hall, dam, road, highway etc.).
- **Civil engineer** – a person responsible for designing, construction and maintenance of a project in the form of calculations.
- **Investor** – a person funding a project. In some cases, a customer is also the investor; however it is not always like that. For example, a municipality can be a customer when a city needs a new bridge and the investor can be a Chinese company interested in investing in that market. In many cases, banks are investing in projects and also take part in monitoring projects until completion.
- **Supervisor** – a person (or a company) who has background in civil engineering, but more from the perspective of executing the work, rather than designing the project. This is actually the most profitable branch of civil engineering and most engineers try to find jobs connected to supervising projects. If the supervisor is doing business in another country, he or she needs to learn all the procedures and laws related to construction industry in that country or else the project will not go forward.
- **Contractors** – they are the work force actually building an object. Depending on the size of the project, it can be just a few people or sometimes even a few thousand. One contractor can hire another contractor that is specialized in doing a part of the job – e.g.

introducing electricity in newly constructed block of flats. The work can be later divided to sub-contractors, depending on the project size.

- **Municipalities** – for any object, one needs to obtain a permit from local government before actually doing any work. This is usually a very tiresome and an expensive process that can last even up to a few years. In countries undergoing a transition period sometimes objects are constructed without permits as the law enforcement is more lenient. When the laws are applied as they should be, this can cause whole buildings being torn down, due to not having the necessary permits, even when they are close to being completed. The construction lobby is very powerful in the countries that are in this phase.
- **Community** – construction projects also involve the community. In some cases, projects can be stopped by groups of people who would be jeopardized by the project realization. For example, environmental protection agencies have the power to collect signatures and protest to the government if they feel the project would have a bad influence on natural resources of the planned location. This needs to be taken into consideration in the first phase when a project is planned.

Continuing with the funding issues, since construction project realization phase can last even for a few years, solvency issues are highly relevant. For example, building a metro network in a city can last 10 years and during this period the government can change more than two times. Different natural disasters such as tsunamis or earthquakes can deal a fatal blow to a project. Also, the person funding the project (investor) needs to be liquid for a long period of time – solvency is a pre-requisite for long term projects. Cash flow needs to be planned carefully. The biggest amount of money is usually spent on materials and equipment at the beginning and additional material can always be sourced at a later date. A company should strive to have balanced costs throughout the project, which will be shown later in the example. External influences can also have an impact on the project. For example, if the country is hit with inflation, it can have a negative influence on the realization of the project. All in all, there are a lot of factors that influence the funding issues and the project manager should think about the ways to get through them (or at the very least, expect that they might happen).

As mentioned before, a large number of stakeholders are present in any construction project. The relationships between them are very complex and can have an impact on the project itself. Conflicts often arise and these problems need to be solved as quickly as possible so the project will not be delayed.

The main causes of the above mentioned problems are as follows:

1. Project objectives are not clearly defined
2. Error in cost estimation
3. Lack of project approach

These problems are present mostly in developing countries and transition countries, also in some developed communities. Even if the methodology is implemented, some problems may still arise during the realization phase. A technique called risk management might be a solution. During the planning phase, after the project team has identified the activities, prepared the schedule and finished estimating the costs, three fundamental parts of the planning process have been completed. It would be wise to also identify “high-threat” problems that might arise during the project. A counter-action for each problem that might arise during realization needs to be found in order to react faster if it actually happens. This process should be done on a time to time basis in order to take into account new factors that become a part of the equation.

1.2 Supply chain management in construction projects

Council of Supply Chain Management Professionals defines supply chain management as a process that encompasses planning and management of all activities in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers and customers. Basically, supply chain management integrates supply and demand management within and across companies (CSCMP, Supply Chain Glossary, 2006).

Many problems that are present in construction projects originate from the supply chain side, so it is quite important to manage it properly. As the construction industry itself is split between groups of small, medium and large enterprises of different types (investors, contractors, sub-contractors etc.), the supply chain needed to support this operation is very complex in its nature and needs to be managed very carefully - especially with public projects, where delays can have legal consequences and can be very costly. For instance, a city decides to build a bridge that will decrease the amount of traffic during rush hours and is considered to be a public good; these types of projects are usually followed by media and have a tight deadline to be completed. In case of delay, the contractor might not lose just potential profit, but also credibility in the construction industry.

There are some risks involved in the supply chain network (Benton & McHenry, 2010):

- funding problems,
- working capital,
- delay in payment from the investor,
- work method and quality problems,
- inadequate use of information technology, and
- communication problems between supply chain stakeholders.

Any of these events may cause the whole supply chain to become insolvent and consequentially, for the project to be put on hold indefinitely. It is not uncommon for a construction project to be stopped for one reason or another. Sometimes there are construction sites that are seemingly standing still for many years. Supply chain management means identifying and assessing alternative strategies for eliminating and reducing potential risks in construction projects. All of the participants need to be monitored carefully; communication is an important tool between them, as well as safety and technology. Profitability is challenged from a strategic way and a construction company has to be solvent and have a high EBIDTA in order to keep doing business on the market. Decrease in the company's profitability has an impact on their ability to buy equipment, materials, hire new employees and follow ever changing trends in the construction business. One way of ensuring higher profitability is careful implementation of the supply chain concepts, so delays in services, work force, equipment and materials are reduced to a minimum.

Total cost of construction materials can be decreased, so profitability will naturally be higher. Buying cheaper materials will ensure that total cost is lower; however, the safety component also needs to be respected. If the amount of material used is less than proposed by norm, it violates the safety procedures put in place for a reason, so this needs to be done extremely carefully. There were cases where entire blocks of buildings were destroyed only months after being constructed, after determining that the wrong material was used in the construction process.

There are numerous authors in the area of construction projects as well as definitions of project phases. In this part, a division that allows insight in a construction project from the supply chain perspective will be explained, also involving different IT systems used in each phase.

According to some authors, a construction project can be separated into five different phases (Benton & McHenry, 2010) as stated below. Supply chain should be incorporated in planning already from the second phase of the project.

1. **Conceptualization** – a phase where the construction project is created as a concept. This is usually done by the project owner, individual or organization who wants to build something. This phase can last between a few weeks and even up to a few years, depending on the project size.
2. **Engineering and design** – usually the first proposal is prepared by an architect together with the client. It covers the preliminary design of the object, without going into details or complex calculations. When it is approved, the project then goes to a civil engineer who prepares all the detailed calculations, models, schemes and plans needed for actual construction. Different IT systems are used at this point – mostly AutoCad software for designing the project itself; Microsoft Project or Primavera Systems for project management, for planning and scheduling a project.

3. **Supply sourcing** – before the main phase of the project begins, all the resources need to be sourced first. This process differs depending on the size of the company that is implementing the project. In small companies, all functions are usually divided between employees, a system where everybody does everything. In bigger construction companies, a larger supply chain might be needed for higher quantities of resources in order to reduce labor and material costs. The person in charge of suppliers needs to take care of inventory management, to keep as low stock possible to cover all the demands from the clients. A Just-In-Time concept can be applied here, where the person can place orders for smaller quantities of materials scattered across different time periods, ensuring that the transport cost pays off for this quantity, so the stock levels of materials will not burden the warehouse according to the outbound plan. To make this process easier, many companies that have a strongly developed supply chain mostly use Enterprise Resource planning (ERP) systems. According to the APICS dictionary, ERP systems can be defined as a framework for organizing, defining and standardizing business processes necessary to effectively plan and control an organization so the organization can use its internal knowledge to seek external advantage. These systems evolved from Material resource planning and later Manufacturing Resource Planning systems. During the 90s they developed rapidly when they started covering all processes in a company. Today, the giants in this industry are SAP, Oracle e-Business suite, Microsoft Dynamics NAV etc.
4. **Construction** – a phase of the project where an object is being constructed – for example, a new business center in urban area of the city, a museum reconstruction or a house being torn down. Project management software is used heavily in this phase.
5. **Utilization** – at the very end the object should be prepared according to the client's requirements. In this phase, its main purpose is being fulfilled – use by the clients themselves.

1.3 IT projects vs. construction projects

In this part, a short overview of IT projects versus construction projects will be presented. Due to issue of measuring how much time is needed for a task in the IT industry, it is quite difficult to create and maintain a CPM schedule. A number of lines of code can take unpredictable amount of time to be developed – if it was done in a week, it could solve a month of development challenges. Scheduling in the construction industry is much easier as duration can be calculated more easily for activities of workers on the construction site. However, even here some unforeseen site conditions may occur and the project could be delayed.– After all, the project plan is not set in stone, no matter the industry. There is always of course the human factor.. Liquidated damage method of charging the delay to the construction firm is applied, and this is why the CPM is a key driver in construction projects and project management methodology is used more and more..

1.4 Project structure in construction industry

One of the specifics of construction industry projects is that the projects are realized only once. Since the two exactly the same bridges or houses do not exist in the world, the projects also differ. Sometimes only a few people take part in the project, whereas sometimes even a few companies can participate in one project. Mostly, it depends on the size of the object being built or reconstructed.

According to some authors, there are three main systems that present the management part of the construction project (Hauc, 1982).

1. **Main project system** – a part of the organization that actually initiates the project for their own or someone else's needs. Investor can also be in the main project system. Goal of this particular system is to meet objectives, monitor costs, obtain funds etc.
2. **Project management system** – this particular system represents the connection between the contractors and the main project system. Ones who are actually managing the realization phase – these people are actually of project management profile and are organized into a project management team with clearly defined roles for each member and a team leader – project manager. Their job description includes setting project's tactical objectives according to strategic goals, monitor time, resources, costs and quality during the realization phase, delegate tasks to contractors etc.
3. **Contractors system** – people who are doing the actual work. This system can be within the company or outsourced, as mentioned before. Their objectives are to do the job on a daily basis, communicate with the project management system and give performance reports on a daily or weekly basis.

As for the organization of the project management function, there are differences between authors. In this part, only one will be presented (Dinsmore, 1993).

- **Functional structure** – one of the more traditional ones. The form is similar to a pyramid and one employee can have only one superior officer – so there are not any mixed commands. The responsibility is divided to a horizontal and vertical basis. One person has only one responsibility and this type of organization is quite uncommon in construction projects nowadays.
- **Full project structure** – in this type of organization, the project department is completely separated from the rest of the organization. For example, when one company is responsible for both investment and realization, they can separate the whole project department and do the actual work themselves.
- **Matrix structure** – the goal of developers of this structure is to create a combination of the above mentioned organizations, where an individual is responsible to his or her

functional leader, acting at the same time as a member of the project team. It is not rare for construction companies to have such an organization – when they are doing a lot of projects at the same time and do not have enough people, some engineers can work on more than one project at the time.

- **Organic structure** – this structure can be found in small research and development companies or other highly professional organizations. In this case, there is a problem and finding a way to solve that problem actually gives birth to a project and creates a team.. This can work for smaller projects, however when constructing a complex object it is necessary to have a tighter control than the organic structure actually provides.

1.4.1 Concept with one contractor

There are two main concepts within the concept of organizing a construction project with one contractor – a turn-key classical approach and the “engineering” approach.

Turn-key solution is a classical approach where the investor subcontracts the realization phase of the project to another organization. The single contractor is one-hundred percent responsible and accountable for all things that happen during this phase – procurement of the materials, building the object and monitoring the construction process. The price is negotiated at the beginning of the project and if there are additional costs during construction, the contractor has to take care of this. The investor does not have a big role here – only being informed of the construction progress. This solution is actually the cheapest and least complicated one – however, for the same reason it is flawed for turbulent environments. For example, in more complex projects unforeseen circumstances can happen and both the investor’s and contractor’s position would be jeopardized in this type of organization.

On the other hand, the “engineering” solution is actually a further-developed turn-key approach. The responsibilities for all phases of the work are still on the contractor’s side; the price is negotiated as a “slide price” that can be changed during the realization phase if market conditions change for some reason.

1.4.2 Concept with multiple contractors

In this concept, the investor hires a main contractor that, in most cases, has a project organization structure and this organization is responsible for the whole realization phase. The difference from only one contractor is that the main contractor actually hires sub-contractors to do certain phases of the work. Prices are also calculated based on market conditions on the date of the contract.

1.5 Planning phase of a construction project

A paradigm can be defined as a pattern or a model by which we think about things or perform tasks. A planning paradigm, then, is a pattern or method for defining a project in terms of tasks, duration, resources and costs (Dinsmore, 1993).

Planning represents a future model of a project. At this stage, various simulations are conducted so most important variables influencing the project are foreseen. It is an activity where organizational systems do not act as chaotic group of human, material and money resources, but as a goal-driven organizational structure. In modern construction project management, a “just in time” approach taken from Japanese companies has numerous applications. It means that the object being built is constructed neither before nor after the deadline, with the planned quality and a pre-defined budget. The result of the planning phase is a document called the plan and in civil engineering, there are two types of plans – static and dynamic plans that will be explained in more details in this part of the paper (Hauc, 1982).

1.6 Static plans

Static plan in construction is a detailed list of resources necessary for project realization – excluding the time variable. Some basic terms used in construction industry are listed in this section (Hauc, 1982).

- **Bill of work** – a part of technical documentation containing the quantity of work necessary for partial and whole construction. Based on this, the calculation between the investor and the contractor is done, also the resources and necessary duration of the construction is planned here.
- **Work estimate** – it should contain the number of positions with details (same as in the bill of work), unit measures, quantities, unit prices and total price, which is calculated by multiplying the unit price with quantities. Various software is used at this point – such as Primavera, one of the most commonly used packages for construction projects.
- **Normative** – in order to create the most realistic quantity estimate of different resources (materials, workers, machines, funds, space and time) some things need to be defined. Normative is the time needed for an experienced worker to do necessary operations in certain order, using certain materials, tools and machines within normal environment and with a reasonable amount of effort to accomplish a clearly defined task (Hauc, 1982). There are different normative in construction engineering terminology – referring to human normative and machine normative. Whenever people are concerned, different factors such as working conditions can influence their work (e.g. if it is too cold, a worker cannot be expected to perform with the same normative as when the temperature is twenty degrees Celsius). As for the machines, they are limited by their manufacture with times

needed to start them or to clean them after the work has been done. Some machines have higher normative than others, for example some cranes can carry more material than others and consequentially, people using them can be more productive.

- **Standards** in civil engineering – Standards represent the exact kind, quality and quantity of the material necessary to create a unit of product in certain processes, including the material waste in the same work process (Hauc, 1982). For example, to construct one cubic meter of wall that is 0.5 meters thick with standard sized brick (6.5 x 12 x 25 centimeters), one needs to use 385 bricks and 0.32 cubic meters of mortar. In this process, around 10-15 bricks are extra for potential material waste that is inevitable in the process. Depending on the type of the material, different standards exist and can be found in construction management books and written materials.
- **Resources database** – includes all resources that are present in every position of normative and standards. These databases are very detailed and long, also they need to be updated frequently and this can be a difficult task.
- **Final work estimate** – based on the work breakdown structure and defining the above mentioned, final work estimate is created. Based on cost calculation, profit is calculated for the whole project. There are two types of costs in the construction project – direct costs and indirect costs. Direct costs of the construction are contract positions, e.g. the cost analyzed through normative and resources. Indirect costs include salaries of the project team, maintenance, electrical usage, protection at the workplace etc.

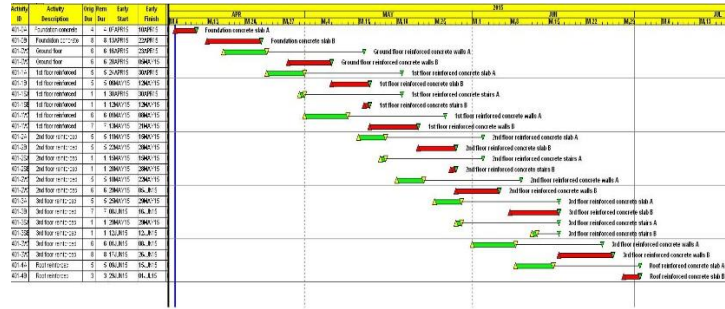
1.7 Dynamic plans

Dynamic plans are visual representation of the planning process – a time schedule of resources defined in static plans and logical schedule of activities that those resources belong to (Hauc, 1982). Two main types of diagrams are used – Activity on Arrow network and Activity on Node network. The first level of details within a dynamic plan is a Gantt chart – includes basic phases of the project and milestones. The second level is further developed specific phases in the Gantt chart and the third level is based on the work breakdown structure, mostly for a week time-frame (construction projects can last up to a few years and sometimes it is complicated to prepare the third level breakdown, even on a weekly basis).

1.7.1 Gantt charts

Gantt chart used in construction project is not much different from the one used in projects in other industries. However, it would be wise not to use the Gantt chart for projects containing over 80 activities since it does not present organizational and technical dependence between some of the planned activities (Hauc, 1982).

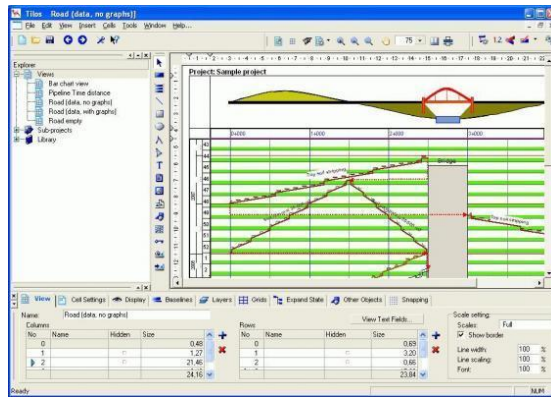
Figure 1. Example of a Gantt chart in a construction project from practical example



1.7.2 Time-distance plans

Orthogonal plans are a build-up of Gantt charts and can be used for objects such as bridges, railroads, highways, regular roads etc. The X-axis represents the distance and the Y-axis contains the time dimension (Hauc, 1982).

Figure 1. Print screen of a time-distance plan for road construction

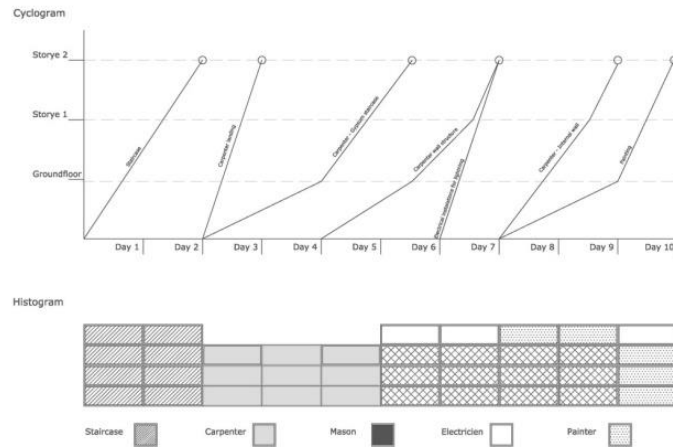


Source: ProjectLink training documentation, 2015.

1.7.3 Cyclogram

Cyclogram is a special kind of a time-distance plan for activities that are done cyclically – repeatedly (Hauc, 1982). They are used if the object has one dimension, can be divided into a number of same parts (e.g. floors in a building) or when work processes are done in a cyclical manner. They also allow for inputs of non-working days and can present the work that needs to be done clearly in a graphical manner.

Figure 2. Cyclogram



Source: *ProjectLink training documentation*

1.7.4 Resource planning

After cost and time planning, resources need to be taken into consideration. In construction projects, there are a lot of fixed assets used in all phases and they need to be used as efficiently and effectively as possible in order to minimize the total resource use of the project.

The whole construction industry is very demanding when capital input is concerned and fixed assets are a large part of this capital. Things like land, facilities or equipment are a very important part of any project and represent critical assets that need to be managed. IT is always used in this process since owners need to manage indicators like amortization, average cost of use, availability, start-up time, preventive and corrective maintenance etc.

Figure 3. Type of dredgers used in construction projects



Source: *Proizvodi Gradimo, 2015*

Materials also need to be planned. At different phases of the project, there is a need for different material – concrete, bricks, timber, different types of metal and other raw materials. Waste management also needs to be in place – since many materials can be re-used or recycled (AIA Houston, 1994).

The goal of material planning is to deliver the necessary materials at exact times they are needed on the construction site, with pre-defined quantities and quality.

Workers also need to be managed and the project manager needs to find the optimal schedule of the work force needed for each phase of the project.

2 IT IN CONSTRUCTION PROJECTS

In this section, importance of IT in construction projects will be presented starting with its role, following historical and modern application, with different types of IT used in construction industry and software used for project planning and monitoring projects, with advantages and disadvantages.

2.1 The role of information technology

Continuous changes in markets of the 21st century is driving companies towards lean production and finding the most efficient way of doing business in order to stay competitive. The role of IT in this industry has greatly shifted in the last few decades. According to some authors (Choi & Ibbs, 1990), A/C/E (architecture/construction/engineering) industry uses information technology for administration, accounting, design, analysis, marketing and project management and it allows companies to increase productivity. As reliable and timely information is one of the key resources today, companies have made it their prerogative to have what they need at the exact right time – IT is greatly used to automate key processes in companies. Starting with calculating salaries, through using IT as a support system for decision making process (second generation) and finally reaching a more strategic level – systems that are instrumental to the company’s survival (Gaith, Ismail & Khalim, 2012).

According to some authors (Millar & Porter, 1985), a concept that is very significant in showing the importance of IT is the “value chain”. This principle is applicable especially for A/C/E industry as it connects quite a large number of companies, freelancers, contractors, subcontractors and even large multinational companies; however, it can be applied to any other industry as well. It separates different activities that are economically and technologically distinct in all of the company’s activities and names each one “value activity”. It could, for example, be

inbound/outbound logistics, sales, service, finance etc. Profit is generated on total level when created value is higher than the cost of value activities. When compared to competitors – the company needs to either have a higher price or lower cost to be better than other companies in the same branch of industry – information technology is a key factor in this process.

2.2 Types of IT software in construction projects

Throughout the 80s and the 90s, computers were rarely used in construction and most of the work was done by hand. After a couple of years when personal computers became commercialized, construction industry had some benefits from this. Many companies began introducing IT and the advantages of new technology in the area of project planning and designing. Development of LAN and WAN enabled users to connect and improve their communication and rapid development in the last 20 years has been very fruitful for the construction industry as well.

According to some authors, different information technologies are used today (Howard & Sun, 2004):

- Computer Aided Facilities Management (hereinafter: CAFM) – The International Facility Management Association defines CAFM as the practice of coordinating the physical workplace with the people and work of the organization. It integrates the principles of business administration, architecture and behavioral and engineering sciences. CAFM encompasses Computer-Aided Design and database management systems and allows project managers working in construction industry to do space management, strategic planning, asset management, lease administration etc.
- Planning, Scheduling, Site Management – the IT software used here is mostly project management software with the capacity to plan, schedule, allocate resource and manage changes in a project. It allows project managers to control costs, budget and take care of quality management as well as managing documents and administration within a project. It can also be used as a communication tool between stakeholders in a project. Most commonly used software in the construction industry are Microsoft Project, Primavera and Power project. Nowadays, the use of open source software is more and more common – there are numerous solutions available on the market for both companies and individuals. Some of them are ProjectLibre, LibrePlan, OpenProject,]project-open[, Redmine etc. This part will be described in more details in chapter 3.4.
- Computer Aided Design and Visualization – it allows users to prepare project design to the detailed level. AutoCAD is the most-widely used 2D design software in the world today. As any other program, it allows the user to save the project at different periods of

time in different versions, making it easy to share files between people and collaborate on the same project at the same time. This program is mostly used by construction engineers and architects.

- Business and Information Management – construction process is one where a lot of documents are used, from the design phase until the project finishes. Even though some things still have to be paper-based – for example, contracts between stakeholders – the biggest part of the documentation nowadays is stored and managed electronically. There is a wide range of Electronic Document Management Systems used today, where people make use of functionalities such as working on the same files at the same time, managing project documentation on a cloud platform, exchanging plans and administrative papers via this system etc. Document management encompasses the processes and procedures one organization uses as it pertains to capturing, storing, securing and retrieving information every day. Sharepoint is the most commonly used software in this area.

Figure 4. Sharepoint



Source: *Microsoft Office for Home and Enterprises, 2015.*

- Integration – since one construction project includes many stakeholders, different IT systems and tools and quite a lot of documentation, in most cases different data formats are used, which are not always compatible with one another. One country is using different systems when compared to another country and there is not an integrated process that could cover all the necessary things from start to finish, thus a need emerged to have an integrated project database to encompass all this. International Organization for Standardization (ISO) has three standards that are applied in the construction industry globally, which could help the integration process – ISO 9001, a Quality Management System that gives organizations a systematic approach for meeting customer objectives; ISO 14001 – an Environmental Management system that provides a system for measuring and improving an organization’s environmental impact; OHSAS 18001, an Occupational Health and Safety Management System that provides a system for measuring and improving organizational health and safety impact. These are the most important standards applicable in the construction industry – environment is definitely something that needs to be considered during a construction project – for instance, a sustainable

waste management operation from huge construction sites. Quality of the materials also needs to be according to standards, so the building is safe for use. Different countries also have different standards, depending also on the climate or nature of the environment – for example, buildings are reinforced more heavily in Japan compared to the rest of the world, due to the presence of earthquakes on almost daily basis. Safety of construction workers on building sites needs to be managed as well, since it includes operating different machinery, bad weather conditions, possible hazards etc.

- Computer Aided Cost Estimation – in the preliminary phases of the construction project greater part of the cost is actually an estimation based on current market conditions. When a client who wants to build something asks an architect or a civil engineer for a preliminary plan, usually a cost analysis is prepared based on current data. Work is divided into positions and to each position a certain cost is allocated. This is used in the decision-making process – choosing between alternatives, possible contractors and subcontractors, managing costs during realization process, budgeting etc. Supply chain is very important here, as the greatest costs actually come from purchasing materials and equipment. According to MTI research, one of the more popular trends today in cost estimation process is to determine the “real cost” of materials and equipment purchased from the suppliers, as they are most often using market prices at a certain period of time, regardless of the actual production cost of making the parts. The result is more efficient cost management process, and there are many systems that allow the user to do this – Esti-Mate, Manifest, FBS-Estimator, PRESTO, GO, ITEC etc.

2.3 IT systems used in construction

The design phase of the construction project is crucial, as the project design presents a base for all future phases. If the design is done incorrectly, the project cannot go forward as it can cause consequences such as instability of the building, failures of basic systems (e.g. pipes, electricity, heating etc.), even the whole buildings collapsing. A person preparing a project design usually has civil engineering background and, for numerous advantages already stated in the sections above, they mostly use some sort of software to create a project design plan. Here the most commonly used computer program AutoCAD software and some open-source alternatives will be presented.

2.3.1 AutoCAD solution

AutoCAD is one of the programs from Autodesk Inc., a leader in today’s market in 2D and 3D design and engineering software. Many designers, surveyors and drafters in architecture, construction, media and entertainment use programs offered by this company to visualize and present their ideas before they are realized. AutoCAD came out on the market in 1982. Since then many different versions of this software have been published and used by millions of people across the globe. Autodesk Inc. also offers a mobile application for the growing market of tablets

and smart phones since 2010, as well as a cloud-based solution called AutoCAD 360. It is available on most of the platforms used today – Windows, Mac OS and Linux platform.

Figure 5. An example of a preliminary project plan done in AutoCAD



Source: *AutoCAD overview at AutoDesk, 2015.*

According to the software creator, there are many benefits to using AutoCAD software, some of them are listed below.

- Taking advantage of data compatibility – since there are only a few niche markets where there is no competition, naturally in the area of 3D and 2D design there is more than one company offering solutions and software for design. AutoCAD enables the user to work in most of the formats available on the market – read and write DWG, DGN, LandXML and GIS data formats. Data can be exported in graphic multi-dimensional models, as well as metadata. It also includes a strong API (application programming interface) inside, so it can be tailor-made to every customer’s needs. Print control is also included in the software, and as it always uses full scale this option can be quite useful.
- Similar environment in every version – with every new variation to the AutoCAD software there are some additions and improvements compared to the previous version. The designers, however, try very hard to keep every new version of the program fundamentally the same, so the experienced users will get used to the new one easily, at the same time taking advantage of the new features.
- Dynamic engineering model – part of the software that improves efficiency and helps reducing errors. For example, the program allows the user to make one change to the design – for example changing the vertical design alignment – and the software will

update all parts of the project to which this is connected to – update the road model, recalculate volume, styles, profiles, corridors and repose proposed contours. This way, the user can do the work faster, checking the effect of one change on multiple areas, which basically allows him or her to do what-if analysis and check different scenarios.

- One model with multiple representations – the layout itself allows the user to draw only one model and show it from different perspectives and different scales. The drawing scale is quite easy to use and the drawing is always made in full scale, which is quite advantageous for beginners.

As there is no perfect software on the market, AutoCAD also has some disadvantages for users, listed in the section below.

- Very high cost – even though there are trial and student versions that are free in most countries, the software for professionals is quite costly, for companies even more so.
- Unrealistic models – due to the software advantages, even inexperienced users with very little training can build models that actually cannot function properly in practice, as it is quite easy to ignore laws of physics on a screen.
- Limiting from the idea developing perspective – some architects state that the software can be restrictive as it requires a lot of data to be inserted at the beginning, whereas they would like to do it in the middle of the process, as this is how most of them do their work. Due to continuous changes in the construction industry (and in the mind of the client requesting the project) or lack of funds, one can use quite a lot of time in the design phase to simplify the work of contractors, even though this does not benefit the designers at all since they are not connected to the realization part, only makes them use up more work hours without extra money.
- Difficult to grasp the conceptual form and long and demanding training for first time users.
- Processing power limitations – the software allows the users to do difficult calculations, render and work on 3D models, however under the assumption of strong and, in most cases, expensive hardware behind it.

2.3.2 Open-source CAD software

Internet has opened up more possibilities for growth and many companies have used that to their advantage. NIST defines cloud computing as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction (Grance & Mell, 2011, p.2). It is no wonder that large companies that deal with thousands of projects per year with multiple vendors,

contractors and sub-contractors have decided to move to an internet-based platform for planning and controlling construction projects. Software-as-Service (SaS) has been growing recently and according to Construction.About, top SaS companies in construction industry are:

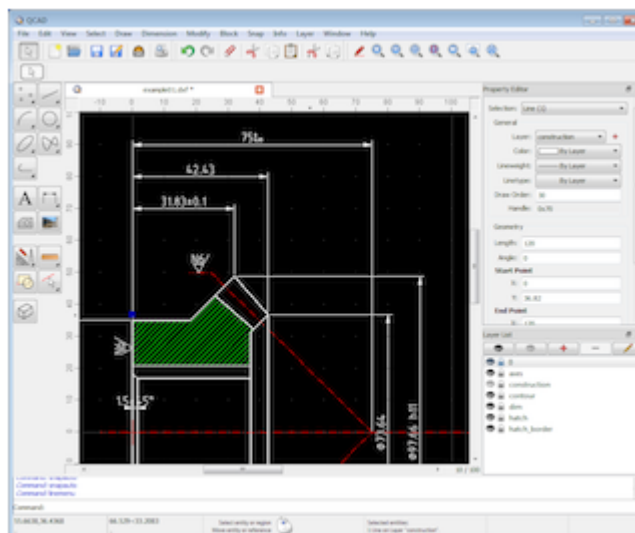
- Fusion Live (USA, Europe and Middle-East)
- Pivotal CRM
- eBid systems
- e-Builder
- Microsoft Dynamics CRM
- etc.

According to Opensource.com, open source software is software that can be freely used, changed, and shared (in modified or unmodified form) by basically anyone. It is designed by many people and distribution is done under certain licenses that are aligned with Open Source Definition (ten conditions all software must comply with to be presented and used as open-sourced software). Ever since 1998, open-source market has grown exponentially and it will probably continue to skyrocket in the decades to come.

There is numerous software available on the market right now. In this part only a few of them that appear on almost every list of top free alternative to AutoCAD with some basic features will be presented.

1. QCAD – software that deals mostly with 2D modeling, available for Windows, Mac OS and Linux. It enables the user to create technical drawings like interior plans, mechanical schematics and diagrams and plans for buildings. According to user reviews, its main advantage is that it is quite intuitive to user needs.

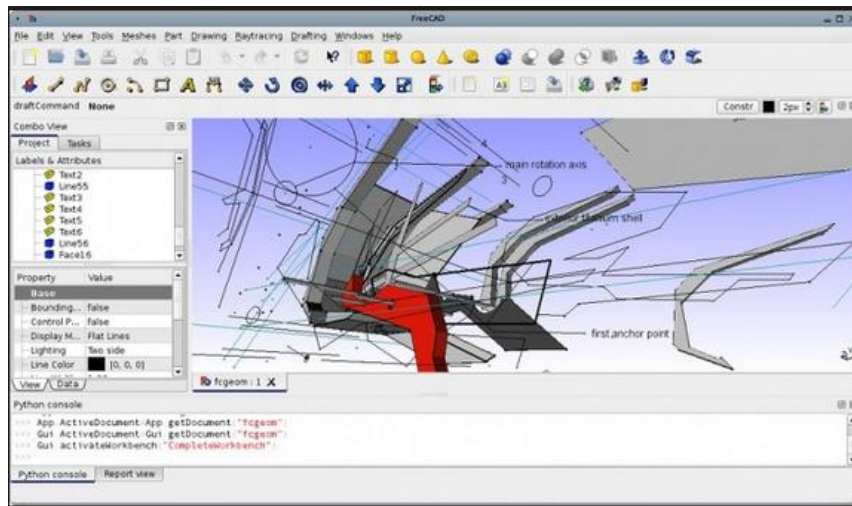
Figure 6. The QCAD Application Window



Source: *About Qcad software, 2015.*

- FreeCAD – this program is actually a parametric 3D modeler that allows the user to easily modify their design by accessing model history and changing the parameters, checking the results in the future models. Supposedly good for first time users due to its rich support forums as well as for experienced CAD users, also allows programmers that are adept in Python programming language to include it in their applications.

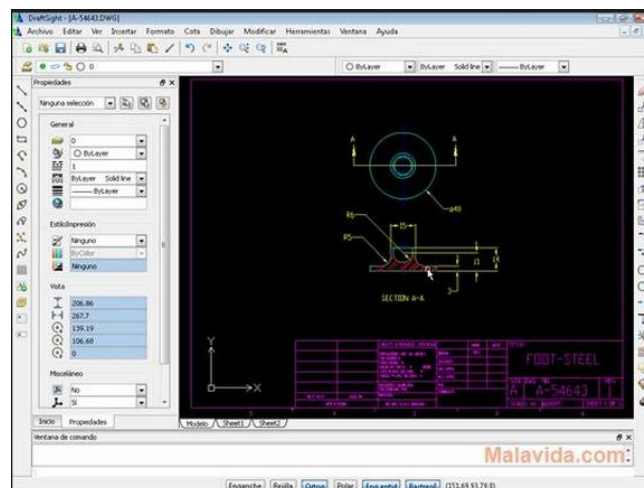
Figure 7. The FreeCAD Application Window



Source: *Getting started with Freecad software, 2015.*

- DraftSight – another very popular program among students, professionals and enterprises (as they offer three versions of the program), 2D modeling CAD software. It can be used to create, modify and view all types of .dwg files. A free curriculum for teachers is available on the web page of the company that developed it.

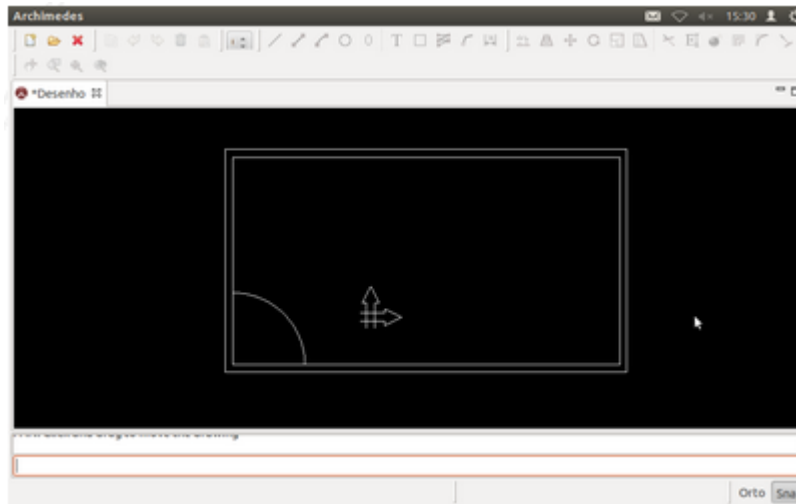
Figure 8. The DraftSight Application Window



Source: *About Draftsight software, 2015*

4. Archimedes – a 3D modeling application that allows the user to create 3D shapes that can be very complex in nature. Many reviews state that it is the best AutoCAD alternative on the market. Even though it is easily extensible, it also offers a thin core that gives the user options to select only the features they require and leave out the ones they do not need to simplify their work process.

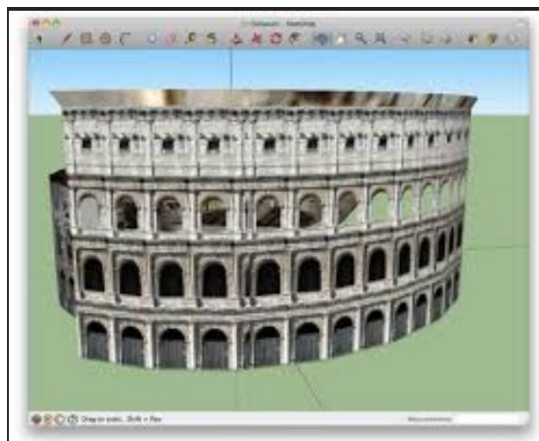
Figure 9. The Archimedes Application Window



Source: *Support page for Archimedes software, 2015.*

5. Google SketchUp – as Google usually makes an open source alternative for every branch of software industry, SketchUp is actually a great replacement for 3D modeling software such as 3DSMax, which is quite expensive and complicated to use. SketchUp offers an intuitive and easy system for 3D modeling, with a lot of user-support forums and even things such as posting the solutions on Google Earth for everybody to see. In the latest version, SketchUp has been integrated with Google Maps, so actually realized projects can be tagged on the internet much easier than before.

Figure 10. The SketchUp Application Window



Source: *Learn Center SketchUp, 2015.*

2.4 IT systems used in planning, scheduling and site management

In this section, an overview of top three project management programs used in the construction industry will be presented. Granted, some of these programs are used in many different industries, however as stated in this thesis already, a construction project is in many ways similar to any other project from, let's say, area of event management planning. It has all the same phases, activities and scheduling like any other project and using project management software enables stakeholder's visibility and a tool to make their work easier and more efficient. Support of communication across organizational boundaries is sometimes necessary in huge construction projects so information will be shared where necessary. All managers within a project should have insight into the project's process and progress, one of the features offered by programs in IT project management. It should encompass resource management and provide a portfolio-based view for a company that is dealing with a lot of projects at the same time, allowing them to prioritize and have insight into phases of each specific project. In cases of changing resources across multiple construction projects, as resources are most often limited, software can help project managers decide where to cut which resource and for what period of time, to avoid delays in other construction projects and reach deadlines.

According to some authors Liberatore et.al. (2001), 97% of participants use project management software and around 83% use it for both planning and controlling the project. Other authors did research on different software used in the construction industry for project planning - most widely used and best suitable software for planning and controlling construction projects is Primavera, different versions and modules (Bell, Blain, Sulbaran & Williams, 2008). Microsoft Project ranks second; however, it cannot support all aspects of a construction project as efficiently as Primavera is able to. In this part, both software packages will be presented.

2.4.1 Primavera

Primavera is the brand name of a variety of software packages for students, professionals and enterprises that represent project portfolio management solutions. The program was first launched during the 80s and was bought in 2008 by Oracle Corporation, second largest software company in the world, third largest software company in both US and the world. For bigger construction companies, a module for central planning can be purchased, which allows user manipulation with a lot of project data, detailed cash flow forecasting, monitoring different linked or independent projects at the same time, as well as use built-in dashboards and reporting tools. Constantly changing environment in the construction business may require adjusting project activities – for example, due to sickness some workers need to be transferred to another construction site – these kind of decisions can be made only based on relevant data; if a project manager does not have proper insight into each of the project's needs, he or she cannot make a decision on how to spread the resources a bit more thin in cases like this. Primavera has time sheets for tracking progress and data about costs and resources used.

There are five main Primavera applications offered by Oracle Corporation:

- Primavera Contract Management – used mostly for managing documents, job costs and field control for construction projects
- Primavera P6 Enterprise Project Portfolio Management – allows users to plan, manage, prioritize and execute projects. Multi-disciplinary teams can communicate, allocate the needed resources and track project progress using just one system
- Primavera Portfolio Management – mostly used in program management, excellent tool for allowing different stakeholders' input in project progress
- Primavera Risk Analysis – enables users to analyze potential risks in projects and prepare plans on how to counter them
- Primavera Unifier – also referred to as Skire. A platform that facilitates management solutions to encompass program management

Oracle Corporation also offers a cloud-based solution called Oracle's Instantis EnterpriseTrack, one of the leading solutions in managing a project portfolio, all in a single system. It also offers users a variety of dashboards with excellent reporting capabilities.

Complex projects such as building a bridge or a dam can be managed at the same time and team members can view their schedules and planned activities for the future. This program envelops the whole project management lifecycle – from putting the first cornerstone of a house to wrapping up with blue walls in the kid's bedroom. Documentation flow can sometimes be very complex and this is one of the advantages of using Primavera, as all versions are saved and users can share files, work on them at the same time, without the need to go through paper folders. Document control is also included in the package and visibility can be tweaked based on each user's access level. E-mails notifications are also integrated, daily or weekly digests of the progress of current project phase. Communication is enabled between different stakeholders, sub-contractors and/or investors, interest groups can be notified about project progress, potential issues or scope changes. The environment of Primavera programs is quite dynamic, sustaining bottom-up as well as top-down staffing and resourcing for a project.

PERT and CPM are included in the package for professionals and enterprises. In order to get a realistic completion date using CPM requires great experience and knowledge to design the activity schedule in the logical sequence of events. On the other hand, user-interface is very friendly and it allows managers to plan and monitor activities in a construction project if they have the right knowledge in both construction industry and project management. Primavera allows the user to do analysis of different alternatives, substituting one resource for another or push deadlines with increasing or balancing the costs.

Scheduling options in Primavera can sometimes be advantageous as well as disadvantageous. Users can select between Retained Logic, Progress Override and Actual Dates to identify how Primavera will schedule progressed activities. When Retained Logic is used, the activity that starts within the sequence cannot actually finish until the preceding activity has finished and it follows the network logic. In some cases, the program provides the user with an unrealistic schedule when out of sequence progress happens and project looks like it is delayed, even though it actually is not.

If the user is using Progress Override to schedule activities the program actually disregards the connection between activities and schedules the duration left of the “out of sequence” activity from the date data.

2.4.2 Microsoft Project

Microsoft Project is one of the leading programs developed by Microsoft created for project managers for use in planning, assigning resources to tasks, managing budgets and tracking progress of a project. It is project management software and in the last few years, it became the leading software on the PC market. The program represents Microsoft’s foundation stone in the Microsoft Office Enterprise project management software. By combining Microsoft Project Professional and Microsoft Enterprise Project Management with Microsoft Project Server, users can actually work on program management and product portfolio management. The programs offer a variety of reporting methods, where users can track the progress of project(s) quite easily.

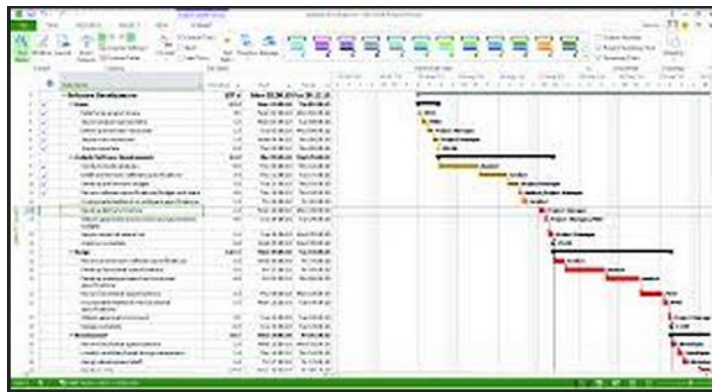
When starting a project, not all data needs to be filled at once in Microsoft Project. Users can insert as much data as they choose and then add more later – this is an advantage if a user wants to get only basic information about a planned project, before going further into details. The users first create a new plan, save it and can continue to work on the project. After building a task list, resources are defined, including their names, maximum capacity, pay rates, working time in resource calendar, costs and appropriate documentation. Afterwards, resources are assigned to tasks for which they will be utilized. Files are prepared in .mpp format and as it comes from the same company, users can import files easily from Microsoft Excel. The software works on Windows OS or Mac OS, however only the professional version can be integrated with SharePoint.

Most versions of the program allow professionals to work on resource management, schedule management, collaboration of the project team and share documents. Built-in reports in the software are not appropriate for all organizations, so users can prepare their own custom-made reports and dashboards. It supports powerful budgeting capabilities, allowing the users to compare forecast of budget to actual. Rates per resources are calculated hourly and one can check the adjustment of total project cost based on changes in individual resources, using this mostly in day-to-day decision making process. Microsoft Project allows the management to define different

classes of users, allowing access to different levels of the project. Users can create and forecast budgets, even to the level of setting an hourly rate, track project and staff hours.

Office 365, a cloud-based version of the software has been available since 2013 – Project Online, a very flexible solution for managing a portfolio of projects and accessible anywhere from the globe as long as there is an internet connection behind it. Many global teams have already started to make use of this feature, as construction companies today more and more often have subsidiaries thousands of kilometers away from one another, and this particular feature helps them to stay connected. From task management perspective, recurring tasks can be added, as well as group tasks by projects.

Figure 11. A sample Gantt's chart in Microsoft Project software



Source: Microsoft Office for Home and Enterprises, 2015.

In a traditional project management sense, Microsoft Project offers interactive Gantt Charts, lot of different project templates, scheduling and multiple project support. In the collaboration sense, different user groups can be created. Communication is done via messaging or instant messaging, RSS Feeds and social collaboration platform. E-mail notifications of project progress are also included in Microsoft Project features.

A vast majority of construction projects require periodic schedule updates. Due to different circumstances on the construction site, project status needs to be updated, work schedule and the prediction when the project will be completed. Most important steps for users are to set up a baseline, update the schedule and compare the schedule updates during the realization. Microsoft Project starts with Project Start Date and uses CPM rules in order to calculate the schedule. If one activity has an actual date, the calculated ones are overwritten.

2.4.3 Microsoft Project vs. Primavera in construction projects

The use of Microsoft Project in the construction industry has been limited when compared to Primavera software, even though it has been growing in recent years. Primavera has been the dominant software as a scheduling tool and Microsoft Project has been the prevailing software in

other industries. First, a few operational differences will be presented, with a few core differences following.

Overall impression upon opening both programs is that Primavera environment is a bit more robust than the Microsoft Project one. As Microsoft Project is part of Windows Inc., the work is performed in the computer memory, so save file option is actually done when a button to save is clicked by the user. In Primavera, change is saved by pressing the Enter key. In Microsoft Project, only one user can actually check the schedule at one time, due to the computer memory-centric scheme. In Primavera software, if the “Exclusive” option is not checked, multiple users can open the schedule at the same time. Office 365 Project pro offers up to five users to work on one project simultaneously. Opening a project schedule in Primavera Enterprise version (in case the project has less than 10,000 activities, a category where most of the projects fall under) is enabled within ten seconds, Microsoft Project Enterprise version takes a minute. Granted, not a key difference, however today’s users want to get what they need as quickly as possible. Microsoft Project is also portrayed by some as the program with slower response rate between the two. Customer support for Primavera users is characterized as reliably responsive in a great majority of cases, whereas Microsoft sometimes is not as responsive as their competitors.

In Microsoft Project, user can choose only one relationship between two activities, whereas in Primavera, Finish-to-Finish and Start-to-Start can be assigned, for example. Primavera includes changes in the critical path in all activities, including those that have a status “completed”, overriding the dates in the previous calculations with actual dates. In Microsoft Project, if an activity has an actual date, calculated dates are not taken into consideration – Primavera uses the Actual dates method for this. Overall, scheduling capabilities of Primavera are better than Microsoft Project (enterprise edition), with an easiness of checking statuses of a great number of projects, resources and participants, with reporting options and fast-response rate to the user requirements.

To conclude this part with the human factor, namely what are the users already used to. Habits are quite difficult to change for existing users (for example, when a PC user buys a Mac OS machine), so people are prone to continue working in the software in which they are used to working – in this case, the most available software on the market for construction project – Primavera. Knowledge of the user is more important here – actual experience on the construction site, how long an activity lasts, what is the potential problem that might occur in the project - it is simply not possible to do this sort of work just by learning to use a program. In this segment, Primavera being the less available software in terms of not coming in a Microsoft Office package – blocks out more amateurs in the industry. On the other side, if a user is knowledgeable in planning and scheduling construction projects, it will be only a matter of getting used to whatever software that will allow him or her to do exactly that.

3 OPTIMIZATION PROCESS

Optimization problems are very common in different sciences and industries. Basically, it is a process of trying to find a solution to a problem – it should be either optimal or sub-optimal within certain constraints. According to the Princeton university dictionary, optimization (the act of rendering optimal) can be defined as “the simultaneous optimization of growth and profitability; while solving an optimization problem, we seek values of the variables that lead to an optimal value of the function that is to be optimized”.

In the construction industry in the past two decades, there have been some leaps in the construction schedule optimization problem (hereinafter: CSO). Number of methods and algorithms have been established, and basically they can be classified in three groups of methods – metaheuristic, heuristic and mathematical (Love, Irani, Zhou, Wang & Theo, 2013). In this section, an overview of optimization process that can be used for optimization of time and cost in a construction project will be presented. From many different sciences that offer optimization algorithms, I have chosen operations research to analyze and present critical path method and dual graphs as possible method of optimization of construction project’s time and cost variable (belonging to the mathematical method of CSO).

3.1 Operations research

Many branches of science today were established during difficult periods for the mankind – during war times. Even ancient Greeks used the word *logistics* when they moved their necessities from one place to another. When operations research is concerned, it actually emerged during the World War II, when military tried to find the shortest path for goods to reach their destination.

There are two main factors that influenced the development of operations research – firstly, after the World War II, scientists were motivated to explore this newly-found discipline and as a result George Dantzing set grounds for the *simplex method*, one of today’s most commonly used methods. The other factor was technical progress – namely, the development of computers. Since operations research involves doing a lot of complex calculations, with the appearance of computers this was made possible. During the 80s when personal computers appeared on the market, operations research techniques were accessible to a larger number of people.

A number of modern definitions of operations research exist in literature, however only a few will be mentioned here (Taha, 2007).

According to Balasubraman, Natarajan & Tamilarasi (2006, p. 2) operation research is a scientific approach to problems solving for executive management.

According to Balasubraman et al (2006, p. 2), operations research can be defined also as the application of scientific methods, techniques and tools to problems involving operations of a system so as to provide those in control of the system with optimum solution to the problem.

Another definition of Balasubraman et al (2006, p. 2) refers to operation research as a scientific methodology – analytical, experimental and quantitative – which by assessing the overall implication of various alternative courses of action in a management system provides an improved basis for management decisions.

Today, doing any kind of calculations when different alternatives are concerned is unimaginable without operations research. This branch of science has application in all parts of a company – identifying a problem in production, logistics, sales or marketing; organizing information from different sources; use of different techniques to formulate a problem and others to find a solution etc. There is also a lot of available software for operations research analysis, allowing humans to make complicated calculations with just a few clicks.

3.2 Available software for simulation

There are a few main players among software developers that provide users with environments for doing different kinds of simulations.

First one is undoubtedly Microsoft Excel – or better yet, Frontline Systems who have created the Solver Add-In that is widely used. Though many people use this add-in, they do not realize that the mathematical formulas behind it actually come from operations research theory.

Then there is a large company Oracle, famous for its enterprise resource planning systems used by many companies across the globe. Aside from their business process management tool, their applications have made operations research models available to public and made it into mainstream business.

SAP also must be mentioned – this company has also incorporated operations research into their applications.

One of the less known– Rockwell – with their software Arena, is actually one of the widely used applications for doing simulation on the market.

3.3 Optimization process

In this part, the main algorithm needed for the optimization of the network diagram will be presented, including most popular techniques – CPM and PERT technique, as well as rarely applied method originating from the operations research theory.

Optimization process of the construction of complex objects represents finding the optimal time for construction with minimal cost – a solution based on the criteria of operations research, to find a maximum or a minimum value of the target variable. In this step, a dynamic schedule is defined where the actual need for resources is minimized.

3.3.1 Critical path method

In this part, only fundamentals of CPM will be presented. Critical path method is a mathematical algorithm for scheduling project activities. It was developed in the 1950s by the US navy and originally it considered only logical dependencies between elements and later was expanded to encompass also the resources that are designated to each of the activities. These processes are called activity-based resource assignments and leveling resources. John Fondahl, a US Marine Corps Sergeant in his paper from 1961 set the fundamentals for using critical path method in the construction industry. Today this method is used in other industries as well (software development, research projects, engineering, plant maintenance etc.). Basically, it can be used in any project that has activities that are mutually dependent. However it can only deal with single-objective problems so it is usually used with Program Evaluation and Review Technique (PERT) (Love et al, 2013).

Basic CPM process:

- creating the Work Breakdown Structure, a list of all activities necessary to complete the project
- adding time variable to each activity
- designate dependencies between activities

The longest path is calculated first, earliest and latest start and finish without delaying the project. A “critical” path is identified at this point and the project manager can do activity prioritization by shortening the critical path, either by pruning critical path activities, by performing more activities in parallel (this is called “fast tracking”), or by “crashing” the critical path. This means that additional resources need to be added to selected activities on the critical path, moving up the

time in the schedule, but on the other hand using additional resources. A project can also have multiple critical paths. Float (slack) is also identified, and it presents the amount of time a task can be delayed without causing a delay to the tasks that follow (free float) or to project completion date (total float). PERT chart is still used today, however diagram called activity-on-node is being used more commonly. In this diagram, each activity is shown as a node (box) and it contains arrows that represent the logical relationship of all activities in the project.

3.3.2 Classification of project costs

Usually, before the construction begins and after the project has been designed, certain things need to be negotiated. Cost is calculated in a different manner according to the contract and here an overview of different types of contracts will be presented.

- **Lump Sum Contract** - in this type of contract, the person in charge of all the work (contractor) takes over the whole risk. If some circumstances have not been forecasted in the preliminary analysis, the contractor can ask for more money only at the beginning. If something happens and the budget is underestimated, he or she has to cover the additional expenses and vice-versa. Also, a monitoring system or a quality control system is established and the contractor commits to honor this by signing the contract.
- **Unit Price Contract** - when prices are calculated via unit price contract, different quantities are estimated for a different price. Uncertain quantities are removed from the estimation and the contractor can negotiate on the estimate made by the owner of the contract. This can be a double-edged sword since the contractor can make a mistake and lose profit if a bad estimate has been made
- **Cost Plus Fixed Percentage Contract** - this type is used for urgent constructions or when a new technology is involved. The risk is on the owner's side and the contractor gets a fixed percentage plus a little incentive to reduce the job cost. The owner has the responsibility to cover overtime or double-shifts cost, if needed.
- **Cost Plus Fixed Fee Contract** - the risk is still on the owner's side and the contractor is rewarded with a fixed fee, added to the actual direct job cost. If the project is delayed, the contractor will take on the risk of losing his profit in this case.
- **Cost Plus Variable Percentage Contract** - the contractor is rewarded if the actual cost is lower than the planned cost and in turn, receives a penalty if the project is over the budget. The deadline is fixed and the contractor needs to fulfill it according to this type of contract.

- **Target Estimate Contract** - this type is almost the same as the previous one, including bonus and penalties. However, the project deadline can be moved up or down and the rewards (or penalties) will be modified accordingly.
- **Guaranteed Maximum Cost Contract** - if the project scope is well defined, this type of contract is applicable. The contractor takes on all the risk and the maximum cost is specified at the beginning. In cases where the project has been completed within the budget, all the money that has been saved can be divided among the contractor and the owner, however it needs to be defined clearly in the contract.

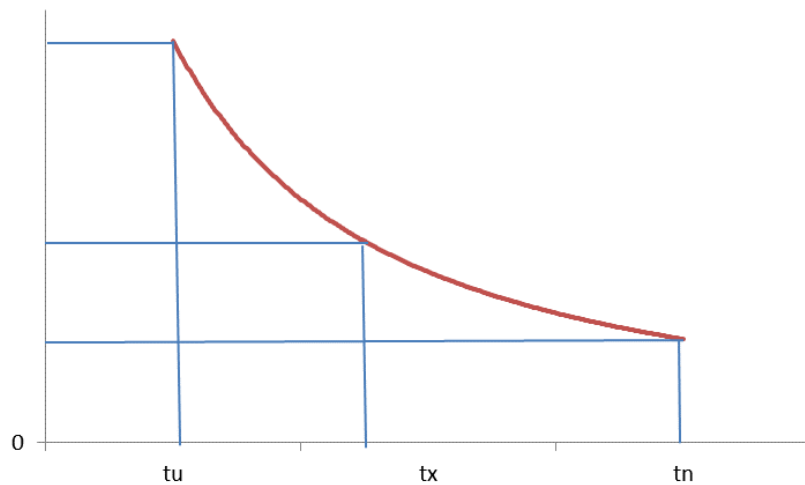
3.3.3 Time-cost optimization

In this phase, it is important to find the optimal duration of each activity in which the cost is relatively minimal. In Figure 14, growth of cost can be monitored with the following variables (Vuleta, 1987)::

Table 1. Time and cost variables

Normal duration	Tensed duration	Normal cost	Tensed cost	Total cost for duration tx	Average cost growth
t_n	t_u	c_n	c_u	c_x	ΔC

Figure 12. Activities cost growth



According to this data, the average cost growth can be calculated using the following formula:

$$\Delta C = \frac{C_u - C_n}{T_n - T_u} \quad (1)$$

The sum of all normal costs for normal duration of each activity is normal duration, whereas the sum of tensed cost of each activity for tensed duration is tensed cost. Since shortening time causes greater cost, it is necessary to find the optimal time frame for all activities in order to reach the minimal cost.

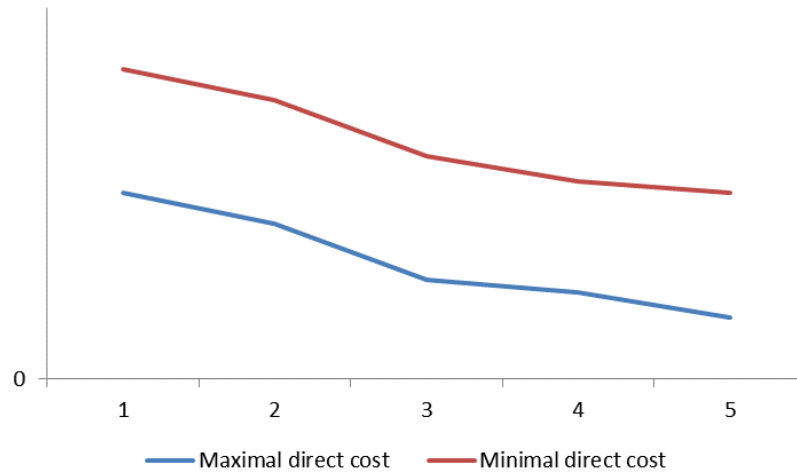
In order to shorten the schedule following steps can be taken on the construction site, each inducing more cost in the project:

- Working in more than one shift or overtime
- Use of more productive materials
- A greater number of fixed assets on the site

The average change direct cost in the project can be seen in Graph 2. It includes two lines – the first one represents maximum direct cost with tensed duration and the second one minimal direct cost with normal duration. Constraint values are as follows:

- Point A – tensed duration of all activities
- Point B – all activities aside from critical ones have tensed duration
- Point C – critical activities have tensed duration, others normal
- Point D – all activities have normal duration

Figure 13. Average change in direct cost

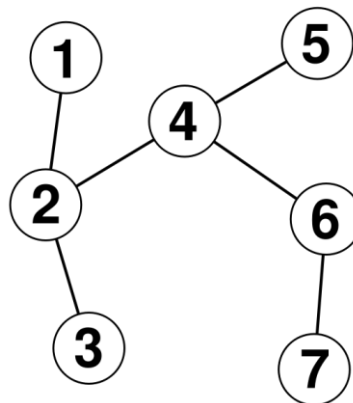


The optimal solution is between line one and line two and the process of finding it consists of searching for minimal cost when shortening the schedule.

3.3.4 Application of graph theory in solving the optimization problem

Graph theory has been used in many disciplines to solve problems of maximization or minimization in order to find an optimal solution. A "graph" in this context is a collection of "vertices" or "nodes" or "knots" and a collection of edges that connect pairs of vertices.

Figure 14. A representation of a graph



Source: *Applied Mathematics*, 2012.

Graph can be described in many different ways (Vuleta, 1985).

- Graph represents the collection of all points whose coordinates satisfy a given relation (as a function).

- A diagram (as a series of one or more points, lines, line segments, curves or areas) that represents the variation of one or more variables.
- A collection of vertices and edges that join pairs of vertices.
- A graph is a non-empty set of vertices V along with a set E of two-element subsets of V . The elements of V are called vertices and elements of E are called Edges.

The history of this particular theory mentions the term “graph” for the first time when J.J. Sylvester used it to describe diagrams of chemical bonds of molecules. However, the first person to ever actually apply the graph theory was Leonhard Euler in 1735 when he tried to find a way to pass all seven bridges on the Pregel River in Konigsburg, Russia and come back to the same starting point. He used a method for solving this problem and called it the graph method as it is known nowadays.

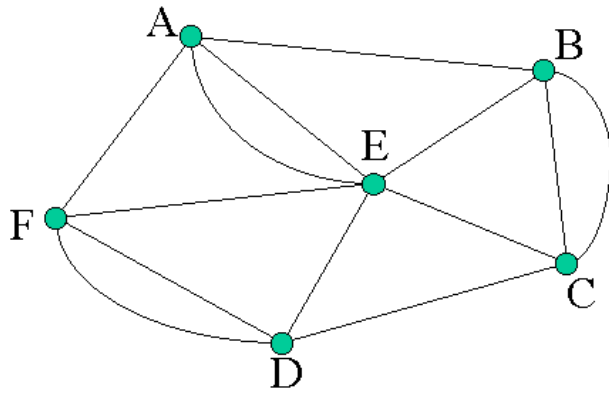
Today, the graph theory has practical application in many areas:

- Routing and logistics
- Electrical circuits
- Chemistry and biology
- Flowcharts
- Databases
- Probability theory
- Operations research
- etc.

In this paper, the application of the graph theory as an operations research method used to optimize the cost of a construction project will be presented. However, in order to understand it, first some basic terminology will be introduced.

Picture 17 gives the perfect model to do just that. If this particular graph is used to represent people on a party, where number is actually one person, we can define connections between knots (from this point onwards they will be named vertices). The edges of any graph are basically the lines that connect vertices. The type of graph in this example is called the tree graph since none of the vertices has a loop leading it back to itself, like in Picture 19 which is a circuit – graph that has loops.

Figure 15. A circuit graph



Source: *Applied Mathematics, 2012.*

Going back to the graph on Picture 16, if vertices represent people at a party in this example, this means that person 1 knows person 2. Following, person 2 knows persons 3 and 4, person 4 knows persons 2, 4 and 5 etc. Basically, people represent set V (as stated in the fourth definition) – a vertex. Cardinality is the actual number of pairs of vertices connected to one another.

$$\text{Set } V = [V1, V2, V3, V4, V5, V6, V7]$$

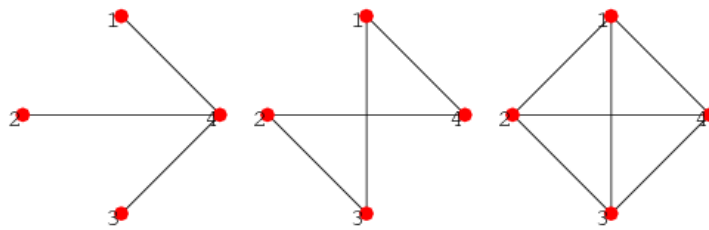
$$\text{Set } E = [(V1, V2), (V2, V3), (V2, V4), (V4, V5), (V4, V6), (V6, V7)] \quad (2)$$

Cardinality in this case is equal to 6. Degree is another term that needs to be introduced – it represents the number of edges on a particular vertices.

$$\text{Deg}(V1) = 1, \text{Deg}(V2) = 3, \text{Deg}(V3) = 1, \text{Deg}(V4) = 3, \text{Deg}(V5) = 1, \text{Deg}(V6) = 2, \text{Deg}(V7) = 1$$

Connections between vertices can be presented either as a list or as a matrix, as seen on Picture 18 (adjacency matrix).

Figure 16. An example of an adjacency matrix



$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 1 & 1 \end{pmatrix}$$

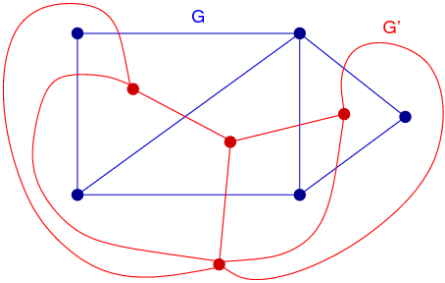
$$\begin{pmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{pmatrix}$$

$$\begin{pmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{pmatrix}$$

Source: *Applied Mathematics, 2012.*

In this part, a dual graph will be used and it can be seen on Picture 17. The dual graph of a planar graph is the one that has a vertex corresponding to each plane region of G and an edge joining two neighboring regions for each edge in G for certain embedding of G. It is explained with duality since it has a symmetric propriety – H is a dual of G, then G is also a dual of H if G is connected. The dual graph of a dual graph is the first graph, it has the same number of edges as the first graph and the number of planes in the first graph is same as the number of vertexes in the dual graph.

Figure 17. A representation of a dual graph



Source: *Applied Mathematics*, 2012.

Different experts have worked on the graph method and its application in project management. Among them – D. R. Fulkerson and L. R. Ford Jr. made a breakthrough and their methodology of an iterative procedure used to find the minimal/maximum flow in a network will be presented. Their idea is actually not so complex when basics of the graph theory have been explained – with an existing path from the source (start node) to the sink (end node) and with available capacity on all edges of the path; the flow is sent to one of these paths.

3.3.5 Algorithm for optimizing direct cost of the project

In order to do the analysis (Vuleta, 1985), first the duration of activities needs to be defined. It can be presented as an interval.

$$t_{u_{ij}} < t_{ij} < t_{n_{ij}} \tag{3}$$

In (3), $t_{u_{ij}}$ represents the minimal duration of the activity t_{ij} , and $t_{n_{ij}}$ represents the normal duration of the activity. After specifying the critical activities, critical path, total time reserves have been calculated, a dual network plan is generated. Then, average growth of cost is added to activities of the primary network plan and in such a way that the edges cutting the critical activities have the value of average cost growth, whereas the edges cutting the non-critical activities obtain the

value 0. After this, the shortest path in the dual graph is calculated via different methods – one that can be used is E. Dijkstra’s developed in the 1960s.

By doing this, the activities that can be shortened are the ones cutting the shortest paths in the dual graph. The difference between minimal and normal time, as well as the minimal time reserve of the non-critical activities in the primary graph, represent a limit to where the activities can actually be shortened. If the second condition was not met, non-critical activities would be shortened as well and cost would become greater in this case.

- For every step of the process, total direct cost needs to be calculated. In iteration K for example, the formula goes like bellow.

$$C_d^{(k)} = C_d^{(k-1)} + \sum_{ij}^{\infty} (\Delta C_{ij} \times \min R_{(k)}) \quad (4)$$

In (4), variables are defined as:

$C_d^{[k-1]}$ – direct project cost from the previous iteration

$\sum_{ij} \Delta C_{ij} \times \min R_{(k)}$ - sum of average cost growth of the critical activity being shortened in the K iteration multiplied by the amount of time shortening in the same iteration

- Total duration of the project is calculated as:

$$T_k = T_{(k-1)} - \min K \quad (5)$$

Where the variables are:

$T_{(k-1)}$ - Duration of the project in previous iteration

T_k - Duration of the project in K iteration

- Duration of the shortened activities:

$$t_{ij}^{(k)} = t_{ij}^{[k-1]} - \min R \quad (6)$$

$t_{ij}^{[k-1]}$ – Duration of the activity in previous iteration

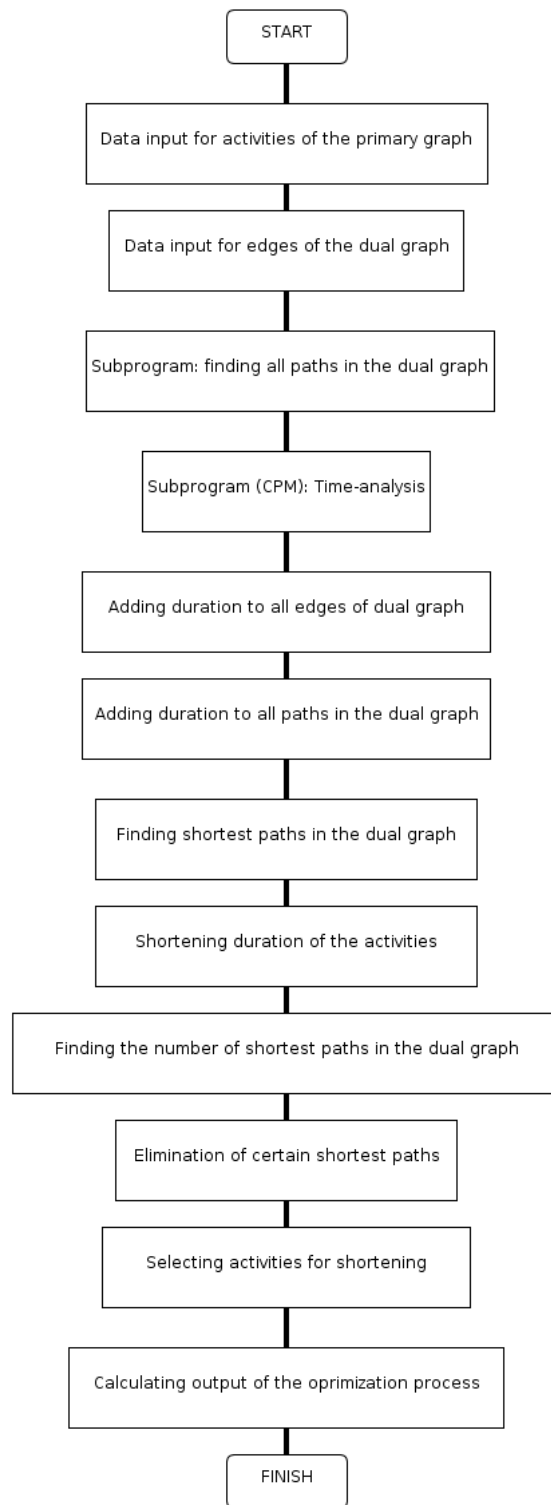
After calculation and input of these parameters, in the next iteration the process is repeated with certain changes.

- In case of shortening a certain activity $t_{uij} = t_{ij}$, the edge in the dual graph plan’s value becomes infinity – this edge cannot be on the shortest path, e.g. this activity cannot be shortened anymore
- If a certain activity has become critical, the average cost growth needs to be put on its edge in the dual graph

The steps are repeated iteratively until the duration of the shortest path is equal to infinity – at this point, the primary graph contains the minimal duration for each activity and the process is done.

3.3.6 The diagram of the algorithm

Figure 18. Optimization algorithm with 12 steps



1. Data input for activities of the primary graph

After data input, average cost growth is calculated. The required data input is the following:

- Starting event of the activity
- Ending event
- Normal duration
- Minimal duration
- Number of edge in the dual graph corresponding to the activity in the primary graph
- Normal cost
- Minimal cost

2. Data input for edges in the dual graph

Necessary data:

- Starting node
- Ending node
- Number of the activity in the primary graph corresponding to the activity in the dual graph

3. Subprogram: finding all paths in the dual graph

Previous input and the average cost growth represent columns; number of edges of the dual graph represents rows. A matrix containing all possible paths in the dual graph is created.

4. Subprogram (CPM): time analysis

Critical path method is used for time analysis for normal duration of activities, as well as the cost of the project. Output:

- Early start
- Late start
- Early finish
- Late finish
- Total time reserve
- Duration and cost of the project

5. Adding duration to all edges of the dual graph

This step is done according to critical activities – average cost growth is added to each and rest of the edges gets a value of zero.

6. Adding duration to all paths of the dual graph

The sum of each path in the dual graph is calculated by adding all average cost growth of the edges on a certain path.

7. Finding shortest path in the dual graph

Choosing the shortest paths in the project (ones with minimal sum of average cost growth).

8. Shortening duration of the activities

Finding the minimal time reserve as explained in the previous part.

9. Finding the number of shortest paths in the dual graph

The output of this step is the shortest paths found in the dual graph.

10. Elimination of certain shortest paths

Activities that have minimal and normal duration equal or paths on which there is at least one edge corresponding to a fictive activity in the primary graph are excluded since they cannot be shortened anymore.

11. Selecting activities for shortening

Choosing which activities will be shortened in the process.

12. Calculating output of the optimization process

The main outputs of the process are minimal duration after shortening and minimal cost of each activity and of the project.

4 CONCRETE WORKS STATIC AND DYNAMIC PLANS – OPTIMIZATION PRACTICAL EXAMPLE

Planning is a way of visualizing a project in the future. By making a model of the project, it is possible to simulate and analyze scenarios that can happen in order to predict possible mistakes in advance and deal with them in time.

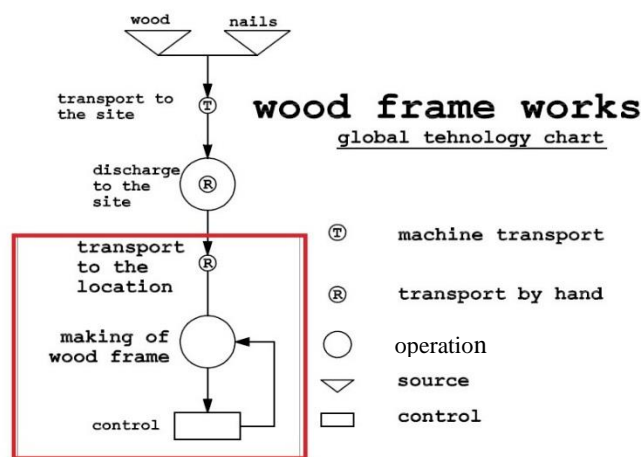
In this part, Static and Dynamic plans for reinforced concrete works for a building P+4 will be presented (ground floor + four additional floors). First thing to do is to list the activities, add duration and price of each one, insert the data in Primavera software and optimize the activities in order to minimize the costs and time needed for the project. This is the most common practice in most of the companies involved in project management in the area of construction.

Static planning is a list of positions needed to finish a certain project, or part of a project. Static plans in construction are made with the analysis of the Construction norms for labor and equipment, and with the quantity of the material needed.

For example, in order to make a reinforced concrete stairs, the following activities are necessary:

- Make wood frame
- Put steel inside the frame
- Pour the concrete - specifications on how to do this are in the construction project. To calculate the price for this position, knowledge of the technology of the process is needed.
- Making a wood frame for reinforced concrete stairs

Figure 19. Technological Chart of Making a wood frame for reinforced concrete stairs



Source: Inženjerska komora Srbije, 2008.

Table 2. Basic norm for making a wood frame for reinforced concrete STAIRS P=14.57m²

M2	14.57	Wood frame for reinforced concrete stairs				
code	Description	Unit	Norm	UnitxNorm	Price per hour/unit (€)	∑jm x nor x price
R2	worker	hours	0,10	1	4	5
T3	wood worker	hours	0,18	2	5	13
T5	wood worker	hours	0,73	10	5	53
T7	wood worker	hours	1,05	15	5	76
13260	wire	kg	0,13	1	0,5	0,94
23152	nails	kg	0,21	3	1	4
51005	wood board 4. kl. 24/80	m3	0,0072	0,1	180	18
51020	wood 24/48	m3	0,001	0,01	180	1
51030	wood 5/8	m3	0,0015	0,02	170	3
51070	staff	m1	0,25	3	0,5	1
						179

The highlighted part of the chart above and the red text in the table represent the manpower (machine and equipment) needed for the making of the wood frame for the stairs; the other part represents the material.

Four things are necessary for basic price calculation:

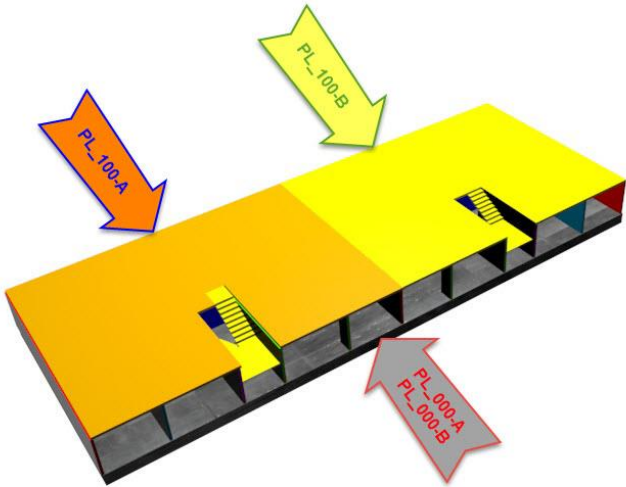
- Technology of the process
- Norms required
- Quantity of materials needed
- Price per unit

Technology of the process is defined by the standards and regulations in that field.

Norm represents the time needed for a qualified worker, working with normal intensity, under normal conditions, with pre-defined method of work, and with supervision, to finish an operation with required quality.

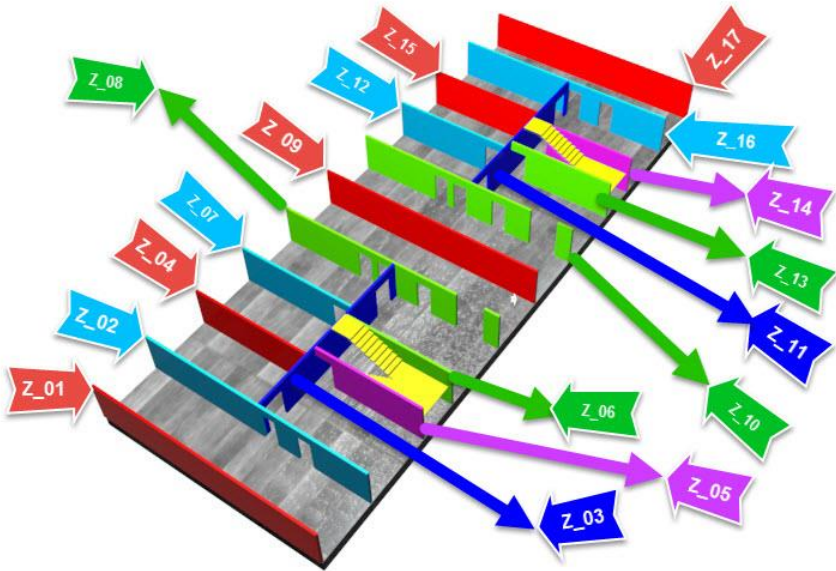
The basic price, resources and quantity are needed for the next step, to make a dynamic plan. The final price will differ from the basic price by a percentage determined by optimizing the dynamic plan. Tables used for calculating the quantity of the material are in the Appendix.

Figure 20. 3d representation of foundation and first floor concrete slabs



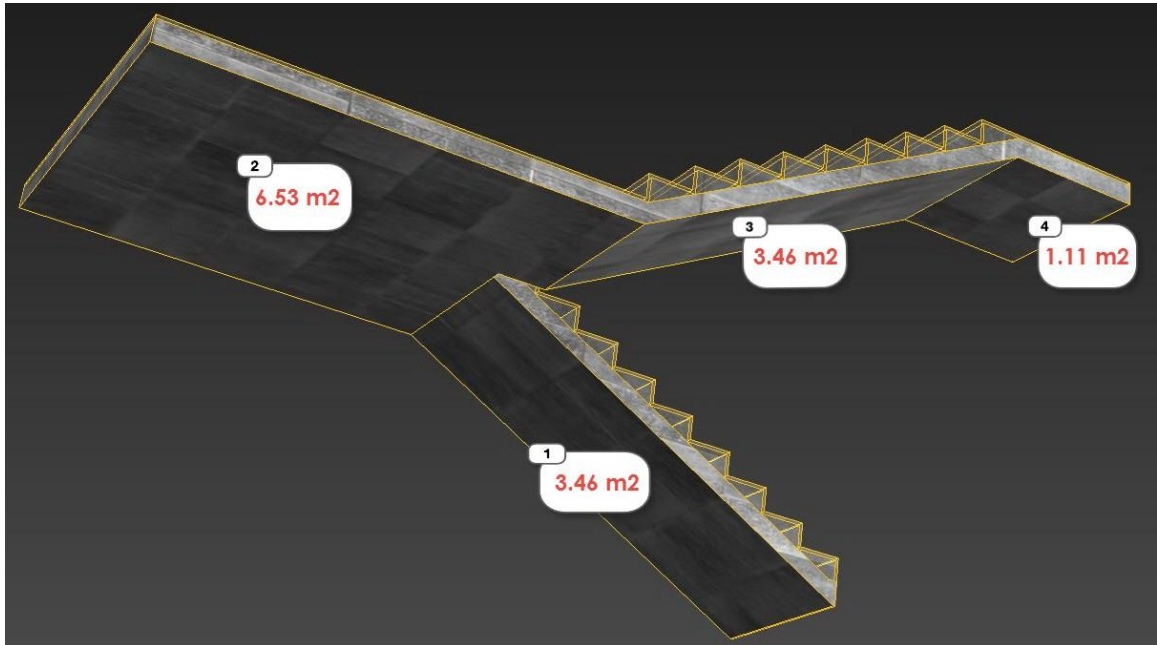
Source: 3D Max, 2015.

Figure 21. 3d representation of walls in the object



Source: 3D Max, 2015.

Figure 22. 3d representation of stairs in the object



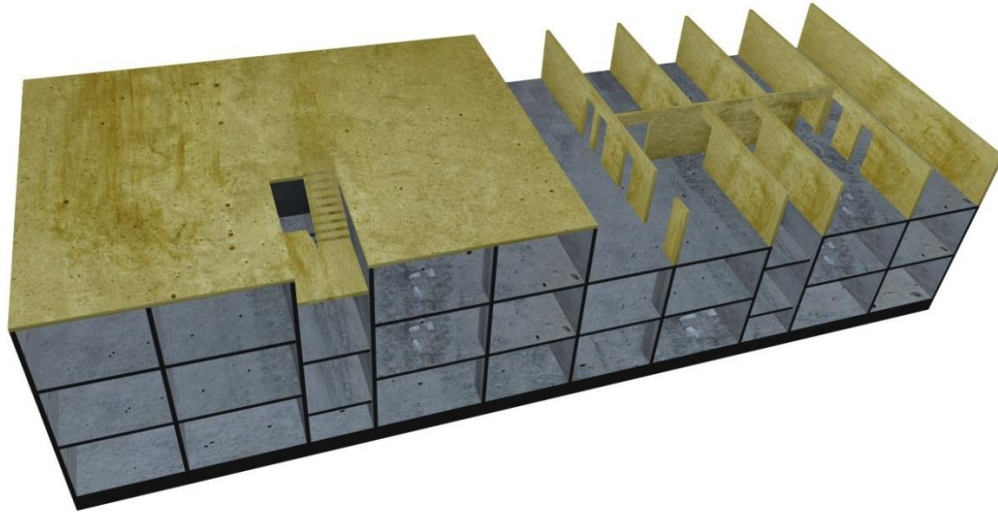
Source: 3D Max, 2015.

With information about quantity, prices, and norms gathered, the next step is dividing the project into activities. Usually activities are divided by type into different groups, for example (wood works, concrete works, glass works, etc.), but in this case, since only concrete works are done – the division to activities will be done according to the construction point of individual parts.

To explain the logic behind the activities in the pictures below the process of building is presented. The left side of the pictures is marked side A, and the right side of the building is marked side B. In the dynamic plan that will follow, this order will be used.

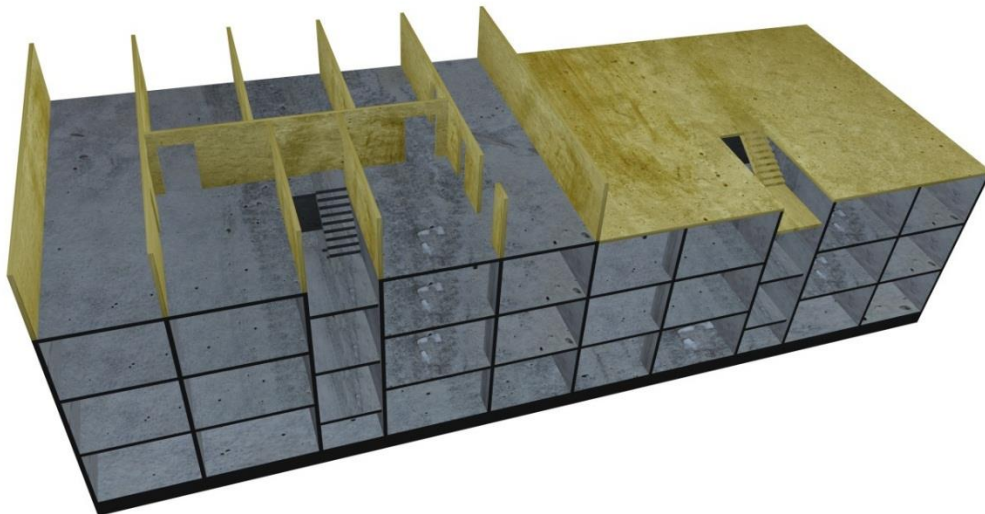
1. Foundation concrete slab A is made,
2. Foundation concrete slab B is made, and side A concrete walls
3. 1st floor reinforced concrete slab A, 1st floor reinforced stairs A, Ground floor reinforced concrete walls B

Figure 23. 3d representation of the building first phase



Source: *3D Max, 2015.*

Figure 24. 3d representation of the building second phase

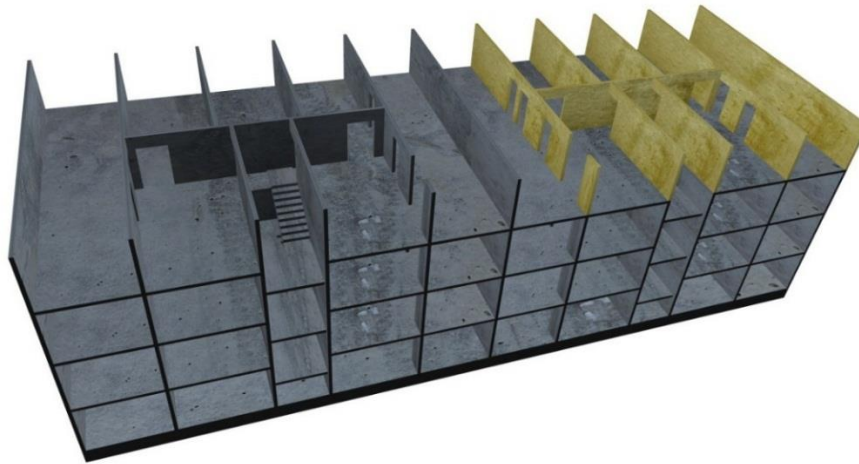


Source: *3D Max, 2015.*

The following activities are done as phases in between:

- 3rd floor reinforced concrete slab B, 3rd floor reinforced stairs B, 3rd floor reinforced concrete walls A

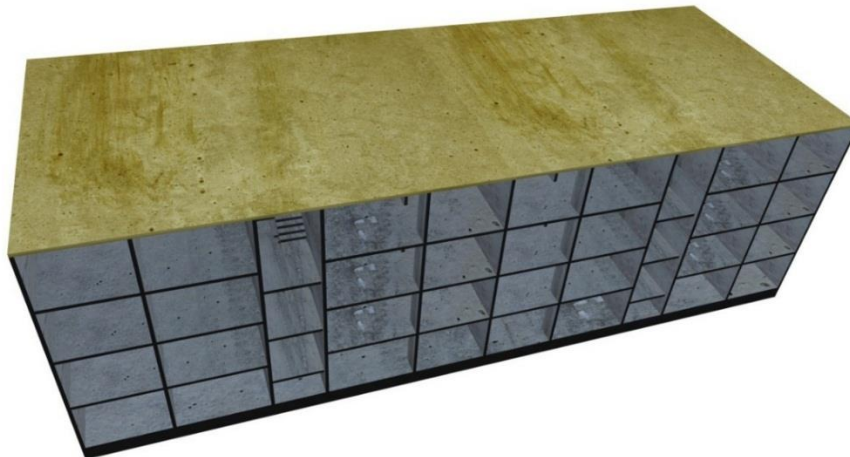
Figure 25. 3d representation of the building third phase



Source: *3D Max, 2015.*

Between figures 25 and 26, the following activity is done: 3rd floor reinforced concrete walls B.

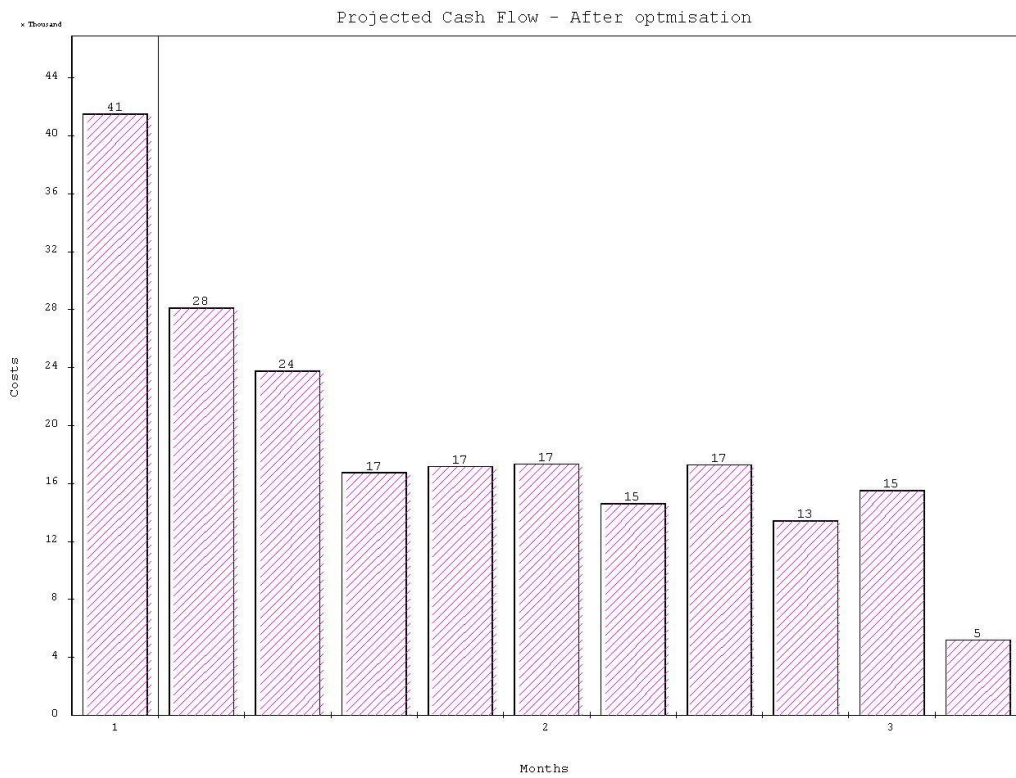
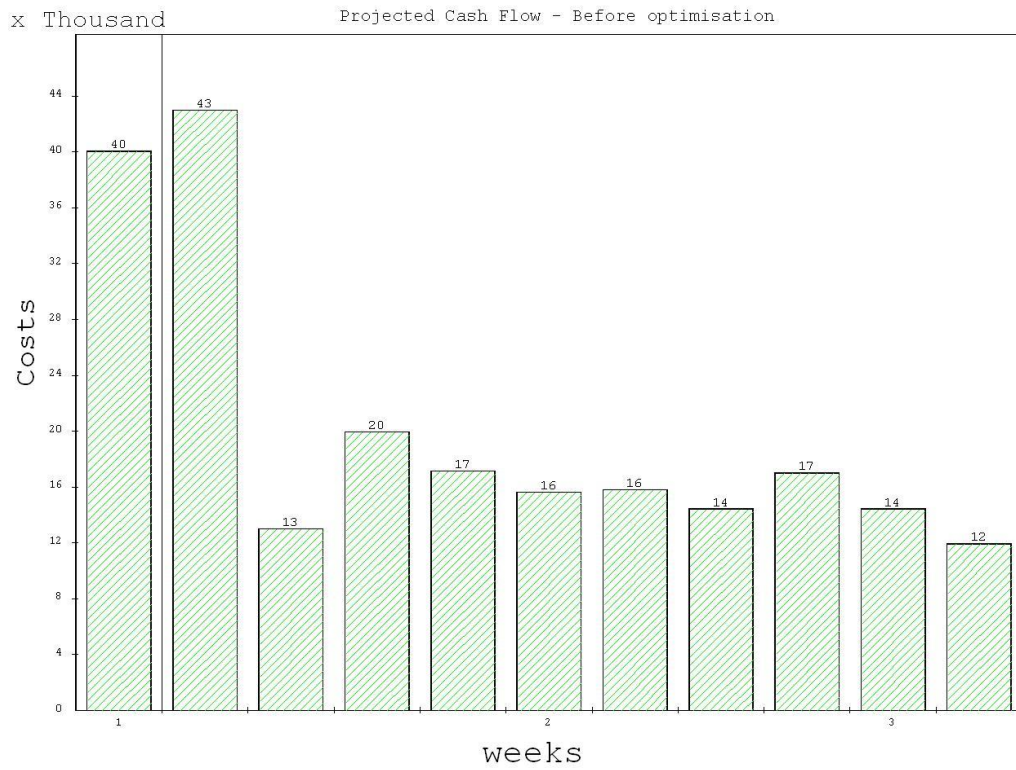
Figure 26. 3d representation of the building fourth phase



Source: *3D Max, 2015.*

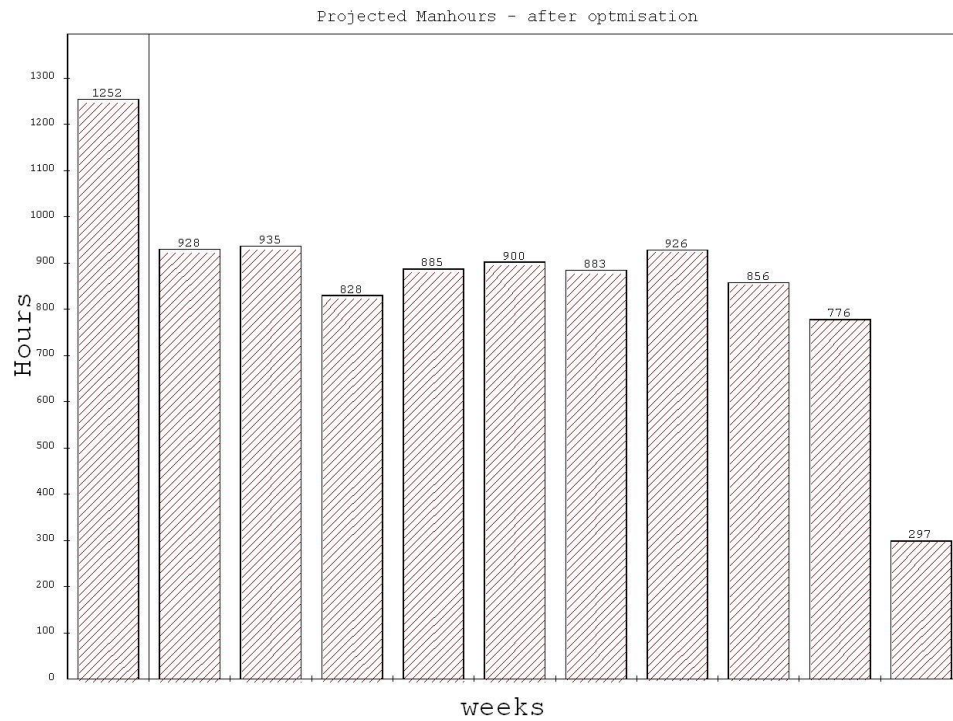
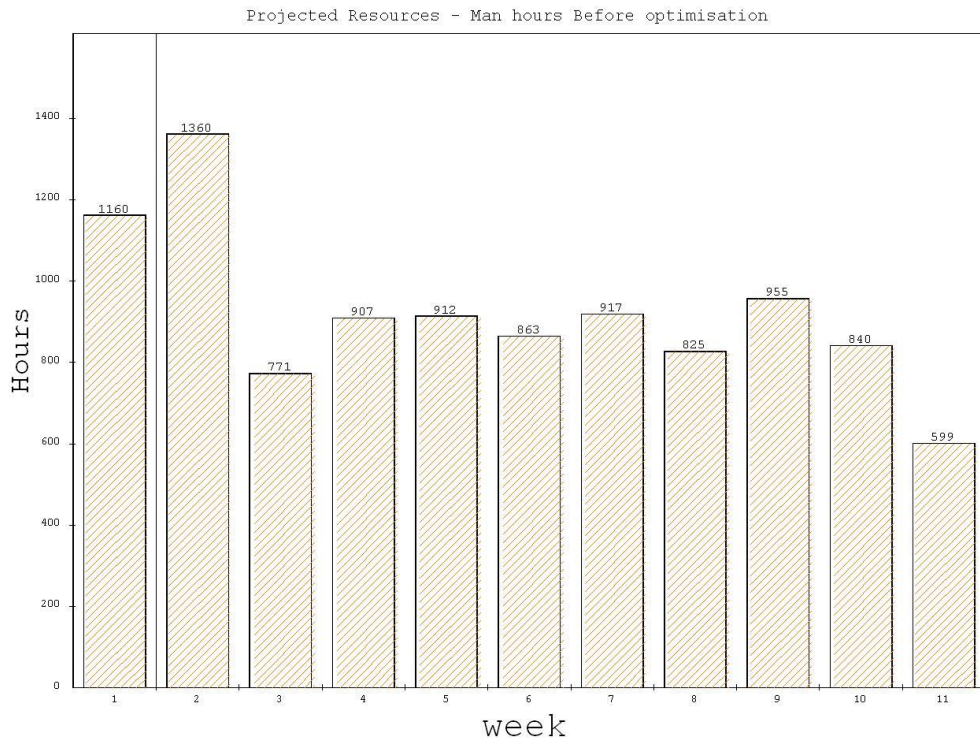
After dividing the project into activities, knowing the norms and price per unit, the price for each activity is calculated and summary of all costs is made. The costs are divided into Materials, Equipment, and Labor costs and detailed calculation, as well as the project activities before and after optimization, can be found in the Appendix section. According to the plan, it starts on 7th of April 2015, the first project finishes on 24th of June and after optimization, the date is moved to 1st of July.

Figure 27. Cash flow before and after optimization



Source: Primavera software, 2015.

Figure 28. Man hours before and after optimization



Source: Primavera software, 2015.

CONCLUSION

This thesis describes a converging point of three different branches of science – project management, construction and operations research. The connecting point is construction of complex objects in the area of civil engineering – one of the first crafts known to mankind and also one of the few ones that will never perish, only advance further with technology and IT systems application. The demand for construction projects is on the rise in the past few decades with the population growth and new approaches, equipment, tools and techniques are being constantly developed. The Norwegians have built highways over parts of the ocean, the Europeans built the Channel tunnel underneath the sea to connect different parts of land and the Chinese can build entire cities in just two years. Where there is a need, a way will be found and people will continue to develop new methods and technologies to construct even more remarkable things in times to come. Nevertheless, the project dimension will most probably never change and will still be used, only in a different improved form in the future as the disciplines develop further.

Nowadays, the specifics of the construction industry vary from country to country. Even in transitional countries, project management software is used more and more and the need to optimize time and money is the same everywhere. One of the methodologies of optimizing cost and time in a construction project was presented in the theoretical part known as the Graph theory. Operations research is most definitely an asset to those who know how to use it and many project managers would, undoubtedly, make their job easier if they applied this theory. This is applicable not only to construction projects, but for other types of projects as well. Whether a bridge needs to be built or a new IT system designed for a company, cost, time and resources are always an issue. With the application of the dual graph method, optimal schedule with minimal cost can be found. However, most project managers in the construction industry have civil engineering background and their academic studies do not offer multi-disciplinary knowledge of optimization algorithms from different sciences. Also, due to the nature of materials and resources used in the construction business, it is a bit difficult to apply this theory in practice.

In this thesis, a more simple method available in the Primavera software was used to optimize one part of constructing an object. In the practical example of wood works in building construction, a more common method of optimization was used – CPM technique. Only a small part of the construction project was taken, since the entire project would be too complicated to analyze without more knowledge of the processes in the construction industry. In the example, the project was optimized by changing duration of certain activities, but not by disrupting the critical path or the technology of work conditioned by the nature of construction. Cash flow was

also optimized, in order not to have jumps from one week to the next. In cases where the project realization is controlled by gigantic construction companies, with many different teams of workers who go from site to site, this would not be such a problem. For an individual contractor or a small company however, this could be problematic and that is why the cash flow optimization is very important. Usually at the beginning of the project, the cost is the greatest when the majority of material is bought – then it drops and should be on approximately the same level until the project is completed.

Some activities could also be shortened with the use of different material. For example, there are many kinds of concrete used in the construction industry. It is defined by the design how much time they need to dry completely– more expensive ones can dry in two-three days, but the ones used normally take even up to ten or fifteen days to dry completely. This is one of the constraints that cannot be avoided by the nature of the materials – for example, workers cannot start building the second floor until the first floor has dried completely. If concrete is not left to be dried completely, the building could collapse as it could not take the weight of the floors built on uncertain ground. What the workers can do however – to build the floor in different phases, as it was illustrated in the example – this way, while the concrete is drying, work force is used elsewhere. It is the job of the project manager who plans and oversees the construction site to optimize the project.

Most of the projects in the construction industry are planned as described in the practical example. Investors usually have their own project managers who are assigned tasks to estimate the cost of the project, either for the purpose of overseeing the project themselves or to make sure the sub-contractors are not ripping them off. Contractors on the other hand, are doing the same thing – they do the exactly same calculation and propose the price to potential investors, with certain amount of profit added. Project approach and optimization methods are one the tools they use in order to make sure the profit is maximized.

Finally, even if the project is planned nearly perfectly at its beginning, it is actually people that do the realization – unfortunately, scientists still have to invent an algorithm for human optimization. Until that time comes, we will continue to rely on the existing methods and try our best to cope with the complexity of the 21st century. To quote Alan Lakein, one of the most famous authors on the topic of time management – “Planning is bringing the future into the present so that you can do something about it now”. If every project manager adhered to this saying, the number of failed projects would probably be much smaller.

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APPENDIXES

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Appendix A: Calculations used in the practical example from Primavera software.

Table 1 – Reinforced concrete slabs

Reinforced concreet slabs									
	SEGMENT	x	y	z	P (m2)	P stairs (m2)	∑P	V[m³]	∑V
A	PL_000-A	18.96	14	0.80	272	0.00	542	217	433
B	PL_000-B	18.80	14	0.80	269	0.00		215	
A	PL_100-A	18.96	14	0.16	272	14.40	527	41	82
B	PL_100-B	18.80	14	0.16	269	14.40		40	
A	PL_200-A	18.96	14	0.16	272	14.40	527	41	82
B	PL_200-B	18.80	14	0.16	269	14.40		40	
A	PL_300-A	18.96	14	0.16	272	14.40	527	41	82
B	PL_300-B	18.80	14	0.16	269	14.40		40	
A	PL_400-A	18.96	14	0.16	272	0.00	542	43	86
B	PL_400-B	18.80	14	0.16	269	0.00		43	

Reinforced concrete WALLS

		SEGMENT	L [m']	d [m']	'H [m']	Pw [m ²]	Vw [m ³]	vo	V	V [m ³]
S1	A	Z_01	14	0.16	2.64	37	6.06		6.06	36.78
S1	A	Z_02	14	0.16	2.64	37	6.06	0.6	5.47	
S1	A	Z_03	11	0.16	2.64	29	4.70	0.8	3.85	
S1	A	Z_04	7.56	0.16	2.64	19	3.19		3.19	
S1	A	Z_05	6.64	0.16	2.64	17	2.80	0.3	2.47	
S1	A	Z_06	6.64	0.16	2.64	17	2.80	0.3	2.47	
S1	A	Z_07	7.56	0.16	2.64	19	3.19	0.4	2.76	
S1	A	Z_08	14	0.16	2.64	37	6.06	1.6	4.44	
S1	A	Z_09	14	0.16	2.64	37	6.06		6.06	
										36.78
S1	B	Z_10	14	0.16	2.64	37	6.06	1.6	4.44	30.72
S1	B	Z_11	11	0.16	2.64	29	4.70	0.8	3.85	
S1	B	Z_12	7.56	0.16	2.64	19	3.19	0.4	2.76	
S1	B	Z_13	6.64	0.16	2.64	17	2.80	0.3	2.47	
S1	B	Z_14	6.64	0.16	2.64	17	2.80	0.3		
		continue	.56	0.16	2.64	19	3.19		3.19	
S1	B	Z_16	14	0.16	2.64	37	6.06	0.6		30.72
S1	B	Z_17	14	0.16	2.64	37	6.06			
										30.72
S2	A	Z_01	14	0.16	2.64	37	6.06		6.06	30.72
S2	A	Z_02	14	0.16	2.64	37	6.06	0.6	5.47	
S2	A	Z_03	11	0.16	2.64	29	4.70	0.8	3.85	
S2	A	Z_04	7.56	0.16	2.64	19	3.19		3.19	

S2	A	Z_05	6.64	0.16	2.64	17	2.80	0.3	2.47	
S2	A	Z_06	6.64	0.16	2.64	17	2.80	0.3	2.47	
S2	A	Z_07	7.56	0.16	2.64	19	3.19	0.4	2.76	
S2	A	Z_08	14	0.16	2.64	37	6.06	1.6	4.44	
S2	A	Z_09	14	0.16	2.64	37	6.06		6.06	
										36.78
S2	B	Z_10	14.3	0.16	2.64	37	6.06	1.6	4.44	
S2	B	Z_11	11.1	0.16	2.64	29	4.70	0.85	3.85	
S2	B	Z_12	7.56	0.16	2.64	19	3.19	0.43	2.76	
S2	B	Z_13	6.64	0.16	2.64	17	2.80	0.33	2.47	
S2	B	Z_14	6.64	0.16	2.64	17	2.80	0.33	2.47	
S2	B	Z_15	7.56	0.16	2.64	19	3.19	0.33	3.19	
continue			14.3	0.16	2.64	37.9	6.06	0.60	5.47	
S2	B	Z_17	14.3	0.16	2.64	37.9	6.06		6.06	
										Table continues
S3	A	Z_01	14.3	0.16	2.64	37.9	6.06		6.06	
S3	A	Z_02	14.3	0.16	2.64	37.9	6.06	0.60	5.47	
S3	A	Z_03	11.1	0.16	2.64	29.3	4.70	0.85	3.85	
S3	A	Z_04	7.56	0.16	2.64	19.9	3.19		3.19	
S3	A	Z_05	6.64	0.16	2.64	17.5	2.80	0.33	2.47	
S3	A	Z_06	6.64	0.16	2.64	17.5	2.80	0.33	2.47	
S3	A	Z_07	7.56	0.16	2.64	19.9	3.19	0.43	2.76	
S3	A	Z_08	14.3	0.16	2.64	37.9	6.06	1.63	4.44	
S3	A	Z_09	14.3	0.16	2.64	37.9	6.06		6.06	
										36.78
S3	B	Z_10	14.3	0.16	2.64	37.9	6.06	1.63	4.44	
S3	B	Z_11	11.1	0.16	2.64	29.3	4.70	0.85	3.85	

	continue		56	0.16	2.64	19.9	3.19	0.43	2.76	
S3	B	Z_13	6.64	0.16	2.64	17.5	2.80	0.33	2.47	
S3	B	Z_14	6.64	0.16	2.64	17.5	2.80	0.33	2.47	
S3	B	Z_15	7.56	0.16	2.64	19.9	3.19		3.19	
S3	B	Z_16	14.3	0.16	2.64	37.9	6.06	0.60	5.47	
S3	B	Z_17	14.3	0.16	2.64	37.9	6.06		6.06	
30.72										
S4	A	Z_01	14.3	0.16	2.64	37.9	6.06			Table continues
S4	A	Z_02	14.3	0.16	2.64	37.9	6.06	0.60	5.47	
S4	A	Z_03	11.1	0.16	2.64	29.3	4.70	0.85	3.85	
S4	A	Z_04	7.56	0.16	2.64	19.9	3.19		3.19	
S4	A	Z_05	6.64	0.16	2.64	17.5	2.80	0.33	2.47	
S4	A	Z_06	6.64	0.16	2.64	17.5	2.80	0.33	2.47	
S4	A	Z_07	7.56	0.16	2.64	19.9	3.19	0.43	2.76	
S4	A	Z_08	14.3	0.16	2.64	37.9	6.06	1.63	4.44	
S4	A	Z_09	14.3	0.16	2.64	37.9	6.06		6.06	
36.78										
S4	B	Z_10	14.3	0.16	2.64	37.9	6.06	1.63	4.44	
S4	B	Z_11	11.1	0.16	2.64	29.3	4.70	0.85	3.85	
S4	B	Z_12	7.56	0.16	2.64	19.9	3.19	0.43	2.76	
S4	B	Z_13	6.64	0.16	2.64	17.5	2.80	0.33	2.47	
S4	B	Z_14	6.64	0.16	2.64	17.5	2.80	0.33	2.47	
S4	B	Z_15	7.56	0.16	2.64	19.9	3.19		3.19	
S4	B	Z_16	14.3	0.16	2.64	37.9	6.06	0.60	5.47	
S4	B	Z_17	14.3	0.16	2.64	37.9	6.06		6.06	

Reinforced concrete STAIRS

SEGMENT	S_KD	S_KS	D_PL	P[m ²]	V[m ³]
SP_01	2.96	1.17	0.12	3.46	0.42
SP_02	2.88	2.40	0.14	6.53	0.91
SP_03	2.96	1.17	0.12	3.46	0.42
SP_04	0.95	1.17	0.14	1.11	0.16
					1.90

Table 2. Activities before optimization

Activity ID	Activity description	Quantity	Unit	Price per unit €	Price €
0A	Foundation concrete slab A	217.81	m3	183.65	40,000
0B	Foundation concrete slab B	215.97	m3	183.65	39,662
0WA	Ground floor reinforced concrete walls A	36.78	m3	266.43	9,799.
0WB	Ground floor reinforced concrete walls B	30.72	m3	268.48	8,247
1A	1st floor reinforced concrete slab A	41.26	m3	279.39	11,527
1B	1st floor reinforced concrete slab B	40.89	m3	279.50	11,428
1SA	1st floor reinforced concrete stairs A	1.9	m3	275.44	523
1SB	1st floor reinforced concrete stairs B	1.9	m3	275.44	523
1WA	1st floor reinforced concrete walls A	36.78	m3	237.35	8,729
1WB	1st floor reinforced concrete walls B	30.72	m3	238.62	7,330

Table 3. Slabs and stairs before optimization

Activity ID	Activity description	Quantity	Unit	Price per unit €	Price €
2A	2nd floor reinforced concrete slab A	41.26	m3	206.38	8,515
2B	2nd floor reinforced concrete slab B	40.89	m3	206.40	8,439
2SA	2nd floor reinforced concrete stairs A	1.9	m3	262.77	499
2SB	2nd floor reinforced concrete stairs B	1.9	m3	263.23	500
2WA	2nd floor reinforced concrete walls A	36.78	m3	237.35	8,729
2WB	2nd floor reinforced concrete walls B	30.72	m3	238.62	7,330
3A	3rd floor reinforced concrete slab A	41.26	m3	206.38	8,515
3B	3rd floor reinforced concrete slab B	40.89	m3	206.40	8,439
3SA	3rd floor reinforced concrete stairs A	1.9	m3	263.23	500
3SB	3rd floor reinforced concrete stairs B	1.9	m3	263.23	500
3WA	3rd floor reinforced concrete walls A	36.78	m3	237.35	8,729
3WB	3rd floor reinforced concrete walls B	30.72	m3	238.62	7,330
4A	Roof reinforced concrete slab A	43.56	m3	205.09	8,933
4B	Roof reinforced concrete slab B	43.19	m3	205.09	8,857
total					€ 223,595.32

Table 4. Activities after optimization

Activity ID	Activity description	Duration of activities before optimization (days)	Duration of activities after optimization (days)
0A	Foundation concrete slab	4	4

	A		
0B	Foundation concrete slab B	4	8
0WA	Ground floor reinforced concrete walls A	6	6
Activity ID	Activity description	Duration of activities before optimization (days)	Duration of activities after optimization (days)
0WB	Ground floor reinforced concrete walls B	6	6
1A	1st floor reinforced concrete slab A	5	5
1B	1st floor reinforced concrete slab B	5	5
1SA	1st floor reinforced concrete stairs A	1	1
1SB	1st floor reinforced concrete stairs B	1	1
1WA	1st floor reinforced concrete walls A	6	5
1WB	1st floor reinforced concrete walls B	6	7
2A	2nd floor reinforced concrete slab A	5	5
2B	2nd floor reinforced concrete slab B	5	5
2SA	2nd floor reinforced concrete stairs A	1	1
2SB	2nd floor reinforced concrete stairs B	1	1
2WA	2nd floor reinforced concrete walls A	6	5
2WB	2nd floor reinforced concrete walls B	6	6
3A	3rd floor reinforced concrete slab A	5	5
3B	3rd floor reinforced concrete slab B	5	7
3SA	3rd floor reinforced concrete stairs A	1	1

3SB	3rd floor reinforced concrete stairs B	1	1
3WA	3rd floor reinforced concrete walls A	6	6
3WB	3rd floor reinforced concrete walls B	6	8
4A	Roof reinforced concrete slab A	5	5
4B	Roof reinforced concrete slab B	5	3

Table 5. Activities before optimization

Material	Description	Quantity	Unit	Price per unit	Total price
71601	Formwork oil	59.76	kg	2.00	119.52
130006	Steel 12mm	28175.20	kg	1.00	28,175.20
130075	Mesh reinforcement	77838.00	kg	1.00	77,838.00
132600	Wire	96.00	kg	0.50	48.00
231520	Nails	392.96	kg	1.50	589.44
250402	Formwork suspensor	542.24	A peace	10.00	5,422.40
510052	Board 4. kl. 24/80 3-6m	0.68	m3	180.00	122.40
510201	Wood 24/48 l=2-2.75m	0.02	m3	180.00	3.60
510300	Wood 5/8 3-6m	0.42	m3	170.00	71.40
510303	Wood 10/10 3-6m	1.73	m3	150.00	259.50
521406	Formwork 27mm 40	1.03	m3	1,500.00	1,545.00
910107	Concrete Mark 40	1048.38	m3	50.00	52,419.00
					166,613.46

Equipment	Description	Quantity	Norm hour	Price per unit	Total price
170200	Concrete mixer 5m3	1,530.62	ns	5.00	7,653.10
170205	Concrete Auto pump 50 m3	21.00	ns	40.00	840.00

170400	Lifter	169.79	ns	5.00	848.95
					9,342.05

Labor	Description	Quantity	Norm hour	Price per unit	Total price
A	Ironworker	3,914.58	ns	5.00	19,572.90
R	Worker	3328.03	ns	4.00	13,312.12
T	Carpenter	2951.07	ns	5.00	14,755.35
					47,640.37

TOTAL PRICE					223,595.32
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Appendix B: Gantt's chart

