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DEVELOPMENT OF LAYOUT ENGINEERING IN PLANT DESIGN PROJECTS

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TIIVISTELMÄ

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Layout-suunnittelun kehittäminen laitossuunnitteluprojekteissa

Diplomityö

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82 sivua, 33 kuvaa, 6 taulukkoa ja 2 liitettä

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Avainsanat: layout-suunnittelu, layout, prosessilaitos, laitossuunnittelu, modulointi, standardointi

Tässä diplomityössä selvitetään, mitkä ovat prosessiteollisuudessa toimivan laitostoimittajan suurimmat kehityskohteet layout-suunnittelussa, kun kyse on uusien projektien tarjousvaiheesta. Kohdeyritys tekee vuosittain useita eri tarjouksia, joissa layoutin vapausasteet ovat tapauskohtaisia. Työssä tutkitaan, millaisilla keinoilla nykyistä läpimenoaikaa voitaisiin lyhentää ja miten tarjottavaa hinta-arviota voidaan tarkentaa.

Layout-suunnittelussa käsillä olevien kriittisten kehityskohteiden selvittämiseksi tehtiin seitsemän puolistrukturoitua haastattelua. Haastateltavana oli kohdeyrityksen insinöörejä, joilla on kokemusta tarjousvaiheessa työskentelystä. Haastattelut analysoitiin käyttäen temaattista sisällönanalyysia, jolla saatiin selville kategorioittain eri kehityskohteet.

Haastattelujen pohjalta voitiin todeta, että kriittisiä kehityskohteita olivat layoutin ensimmäisen luonnoksen huolimattomuus, layoutin suuri muuttuvuus yhden tarjouksen aikana, puutteet alkutiedoissa, liian lyhyt varoitusaika layoutia pyydettäessä, mallinnusohjelmasta puuttuvat primitiivimallit, ostolaitteiden geometrian puute, standardiratkaisun osittainen puute layoutissa ja materiaalin arvioinnin epätarkkuudet. Näistä kehitykseen valikoitui layoutin muuttuvuuden vähentäminen, standardi-layoutin luominen ja materiaaliarvion tarkentaminen.

Täysin standardoitu detalji-layout olisi hyötyjen kannalta potentiaalisesti paras vaihtoehto, mutta myös eniten resursseja vaativa sekä vaikeasti toteutettava. Yksinkertaistettu standardi-layout vaatisi vähemmän resursseja ja toisi silti hyötyjä. Moduloinnin saralta esitettiin mahdollisuus moduloida laitoksen osaprosesseja PI-kaavion mukaan. Vähiten resursseja vaativana nähtiin putkisillan modulointi, joka on täten paras metodi aloittaa layout-suunnittelun kehittäminen.

ABSTRACT

LUT University
LUT School of Energy Systems
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Development of layout engineering in plant design projects

Master's thesis

2021

82 pages, 33 figures, 6 tables and 2 appendices

Examiners: Professor Jussi Sopanen
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Keywords: layout, layout design, process plant, plant design, modulation, standardization

In this master's thesis, process plant supplier's critical improvement areas during the quotation phase are identified. Target company makes several offers each year, where the layout's degrees of freedom depends by the case. The study examines the means by which the current lead time could be reduced and how the price estimate can be refined.

To find out the critical improvement areas at hand in the layout design, seven semi-structured interviews were conducted. The interviewees were engineers from the target company, who have experience of working in the quotation phase. The interviews were analyzed by using thematic content analysis, which identified different areas of development by category.

Based on the interviews, the critical development areas were mistakes in the first draft layout, layout variability during the quotation phase, insufficient initial design data, too short of a notice when requesting the layout, lack of primitive models in the design software, lack of geometry of the purchased equipment, partial lack of standard layout solutions and inaccuracies in material estimation. Of these development areas, reducing layout variability, creation of standard layout and refining the material estimate were selected for development.

A fully detailed standard layout would be potentially the best option in terms of benefits, but also the most resource intensive and difficult to implement. A simplified standard layout would require fewer resources and still bring benefits. In the field of modulation, the possibility of modulating plant's sub-processes according to the P&ID was presented. Modulation of a pipe bridge was seen the least resource intensive, which is thus the best method to start developing the layout design.

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Roope Ritala
Kotka, 2.6.2021

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LIST OF SYMBOLS AND ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
CAD	Computer aided design
ECC	Engineering & construction contracting
EPC	Engineering, procurement & construction
EPCC	Engineering, procurement, construction & commissioning
EPCM	Engineering, procurement and construction management
EPS	Engineering, procurement & supply
ETO	Engineering-to-order
FLP	Facility layout problem
HVAC	Heating, ventilation, and air conditioning
P&ID	A piping and instrumentation diagram
RFQ	Request for quotation
STEP	Standard for the exchange of product model data, typical 3D model file type
SWOT	Strengths, weaknesses, opportunities and threats

1 INTRODUCTION

This master's thesis studies what are the critical improvement areas in layout design during the quotation phase of new process plant projects. The study was conducted in collaboration with a process plant supplier.

1.1 Background and motivation of the research

Process plant industry is a competitive industry with multiple business operators involved within one process plant. Companies competing for new plant delivery projects will do a quotation to obtain a project deal. Since process plants are large and include lots of different equipment, piping and buildings, spatial layout plays a significant role. Customers often want to see the actual layout of the process plant, since especially 3D layout presents good view on how the plant would look.

Target company of this master's thesis makes several offers yearly. Depending on the customer and the project, layouts may have infinite number of degrees of freedom. If that is the case, it is wise to develop the layout design process in a way that optimal layouts can be created in a timely manner. Illustration of a commercial fully built plant layout can be seen in Figure 1.

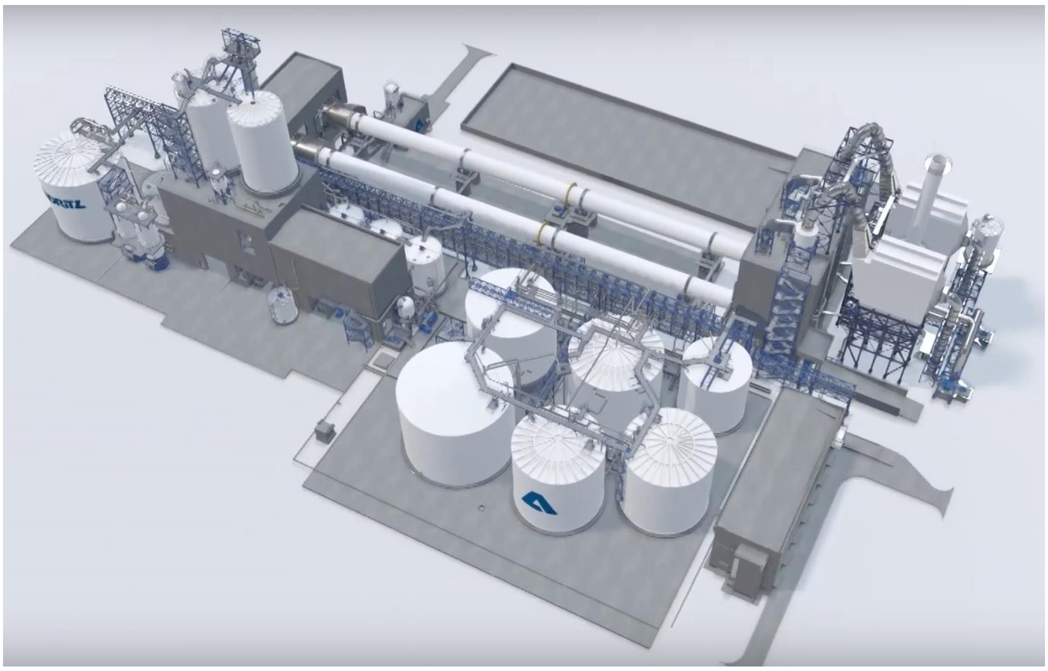

Figure 1. Layout illustration (ANDRITZ, 2021)

Plant layout presents the arrangement of the equipment and their interconnections, such as piping and cables. A good layout will cover the safety requirements, which include operational safety as well as environmental safety. Plant layout should be designed in a way that the plant is easy to construct, and that the equipment is easy to be maintained in terms of space. All this should be kept in mind, while keeping the layout economical.

Plant design needs an input from many different engineering viewpoints. In order to design a functional plant, it is necessary that all the important disciplines are taken into account. In layout design, three main approaches may be utilized. These approaches are chemical engineering, piping engineering and process architects' viewpoints. Chemical engineers have typically good knowledge on the process itself but may lack knowledge on creativity. Piping engineers are focused on pipe- and steelwork and they have good knowledge on traditional spatial layout but may lack process knowledge. Process architects main focus is on buildings and their strengths are in esthetics and spatial intelligence, however they may lack knowledge about the process and mathematics. (Moran, 2019, pp. 238-239).

1.2 Aim of the research

This master's thesis is a qualitative study to find out, what are the most critical areas of the plant delivery projects when developing the process for plant layout design at the quotation phase. Quotation phase means the time at which a product or service is offered to a customer. By examining the current methods used in the layout design process at the quotation phase of the project, it should be possible to pinpoint the most critical improvement areas in the layout design and to find solutions to those areas.

1.3 Research problem and questions

Layout design is an important part of the plant delivery projects. Layout presents the overall view of the plant, its' equipment, piping, buildings and so on, thus making it important for the customer. This means that the layout must be ready in early stages of the project. In order to examine the development possibilities in layout design process, the following research questions are presented:

- What are the most critical development areas in the layout design process?

- How the lead-time of the layout design process can be reduced?
- How the price-estimation can be refined?

1.4 Methods and limitations of the research

To find answers to the research questions, both literature study and interviews are used. Theoretical background will serve as basis for the interview process. Theoretical background presents the basis of the commonly known design and manufacturing developments, such as modularization and standardization. Interviews are semi-structured, in order to achieve the qualitative study to its' full potential. Knowledge about the target company's quotation phase actions are collected by interviewing personnel who have knowledge about the subject, who either currently work or have worked with the quotations. Process layout designers, sales personnel, estimation experts and engineering managers are interviewed.

2 THEORETICAL BACKGROUND AND METHODS

This theoretical background presents a general idea for the execution of the project, followed by theoretical aspects of the plant layout and its creation. Common design improvement methods: modularity and standardization are explained, followed by innovative plant design, which utilizes those traits. The literature review concludes with the science behind the interviews as part of qualitative research and how they should be analyzed.

2.1 Project Execution

Project usually has a clear objective that can be achieved by using predetermined amount of resources, both human and financial. In order to manage a project properly, a set of different variables needs to be taken into account. These variables are quality, time, costs and other human or technological resources. (Tonchia, 2018, p. 21).

Process plant design process starts with conceptual design. In this phase, the operating constraints are clarified, and rough designs are produced based on the possible solutions that can be achieved. Typical information used in the conceptual design is consisted of general plant description, location, standards, and seismic conditions and so on. Next step in the design process is the basic design, in which the process engineer will prepare a process mass and energy balance model. At this stage the produced drawings should present the real items that are proposed by subcontractors and other suppliers. Products, such piping and flanges should be in the drawings, due to pricing and manufacturing. Detailed design is the next step in the design process, in which more detailed drawings and documentation are produced. Detailed design allows the procurement of the items. Usually the plant needs redesigning, because something has been missed in previous design phases. Revision in drawings are more inexpensive to do, than physically do the changes in the site. Final design phase is called post-handover design, in which the plant capacity is tuned. In some cases, one unit's smaller capacity can act as a restrictor of the whole plant possible capacity. Upgrading the small capacity units will increase the whole plant's capacity and therefore make it more economical. (Moran, 2019, pp. 28-32).

Process plant projects are large, with many different suppliers. Project scope is therefore an important concept to understand. Scope defines what are project deliverables, meaning what is expected to be delivered when the project is done. Scope should also include the work that is needed to obtain those deliverables. (Tonchia, 2018, p. 74).

There are different types of projects, which indicate what type of work is included in the project. According to Tonchia (2018), there are two ways the conracting company can execute the project: receiving the specifications directly from the client or design and engineer the products in-house, which is called Engineering-To-Order (ETO). The first mentioned case happens typically with subcontractors or with companies who offer only specific services. In ETO projects the client requests design and engineering, or only engineering. Engineering and design are made case by case for the customer when contract is received. ETO industry is also known as ECC (Engineering and Construction Contracting) or EPC (Engineering, Procurement and Construction). In EPC projects, the contractor is responsible for all engineering, procurement and construction which is defined in the project scope. EPCM is similar to EPC, with the difference that in EPCM construction is only managed, not executed by the contractor. EPCM stands for engineering, procurement, and construction management. Figure 2 presents chart of firms operating by contract works.

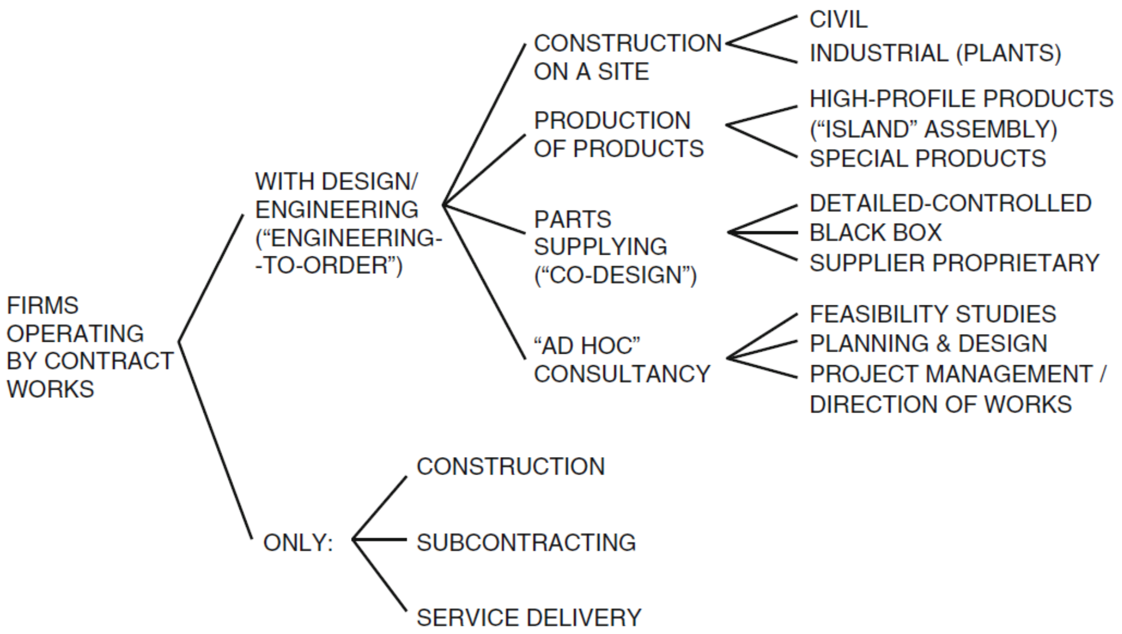

Figure 2. Contract work types (Tonchia, 2018, p. 37)

Project owner can also be self responsible for all project activities and manage them. This kind of project type is referred as owner-directed project. Project owner can utilize hybrid project delivery model as well. In hybrid project model the owner may take lead role in some area of the project and contract the remaining sectors. (Hickson & Owen, 2015, pp. 307-310).

2.2 Plant Layout

Layout depending of the project can be designed in a greenfield or a brownfield site. Greenfield sites are new sites, where layout designer concerns are on the known needs of the process plant and process units that are installed on the site. Brownfield sites are old sites, where number of plots already exist. These kinds of projects are often expansion projects, which means that the site already has old equipment, roads, buildings and so on. In brownfield situations, the designer must take into account the following aspects: site layout, plot layout and equipment layout. Site layout refers to plots relations between each other within the site. Plot layout means how the process units relate to each other within the plot. Equipment layout is the one that considers the general arrangement of the process equipment and units associated to them, this is explained further in the next paragraph. (Moran, 2016, p. 71).

Layouts indicate where the equipment and its’ sub equipment, buildings, piping and other civil constructions are located. In plant layout design, the aim is not only to make the general arrangement look pleasant to eye, but also to be functional and reasonable in every possible way. How the equipment is positioned within the layout, will have impact on the final costs of the plant. The most critical factors that have to be taken into account in the layout design are cost, safety and the process robustness. These factors interfere with each other, meaning that if safety for example was increased by moving the equipment further away from each other and making more space to maintenance platforms, it would increase the costs and could harm the process robustness. (Moran, 2019, p. 241). This equipment related challenge can be called as FLP, which means facility layout problem. FLP can be divided into two stages: block layout design and detailed layout design. (Barbosa-Póvoa, et al., 2002, p. 1669).

According to Moran (2019) the general rule in layout design process, is to start by inserting the most important object from the process viewpoint first in the layout and after that the second most important object, and so on. All the equipment and their sub equipment still must fit to the given space.

Physical layouts are not easily or budget friendly modified once they are built. Poorly designed layouts will cause reduced productivity, additional process work, increase in manufacturing lead time, disordered material handling etc. (Pillai, et al., 2011, p. 813).

Costs add up easily, since civil work is expensive. Plants have heavy equipment, so it is important to place them on places that are able to withstand the weight. If the soil in question has poor bearing capacity, more support structures are needed. Equipment and other structures must be placed in a way, that they will not cause delays in the construction stage. Additional costs come also from the actual process operation and process control, if the layout is designed poorly, the process might need more resources in the management, control and operation areas. Plants are maintained at regular intervals, so the equipment should be placed in a way that the maintenance can take place near the equipment without the need of excessive disassembly of the components around the equipment. (Moran, 2019, p. 243).

Process plants are exposed to many different hazards, which can be roughly divided into physical and chemical hazards. Physical hazards are presented when working at high altitudes or at tight spaces around moving machinery. Process plants often produce, or its' equipment is maintained by using chemically harming substances. These substances may be flammable, toxic or even explosible if handled without proper care. (Hauptmanns, 2020, p. 1). In layout design, it is therefore important to ensure that the operators and maintenance personnel have a safe access to equipment, with the possibility to exit easily the premises in case of an emergency. Operating the plant must be safely managed, meaning that manual valves or other manual instruments are placed so that they are easily accessed. Process plant also should not expose the surrounding environment and people to excessive noise, odors or visual harms. (Moran, 2019, p. 243).

Safety related aspects, such as stair towers and maintenance levels for the equipment are designed to the layout. In sales phase, the main stair towers are often included, but safety aspects are added to the model throughout the iteration rounds. 3D-model of the layout is useful when measuring the needed space for maintenance work in example. 3D-model presenting part of the plant equipment general arrangement, with stair towers and some maintenance levels is presented in Figure 3.

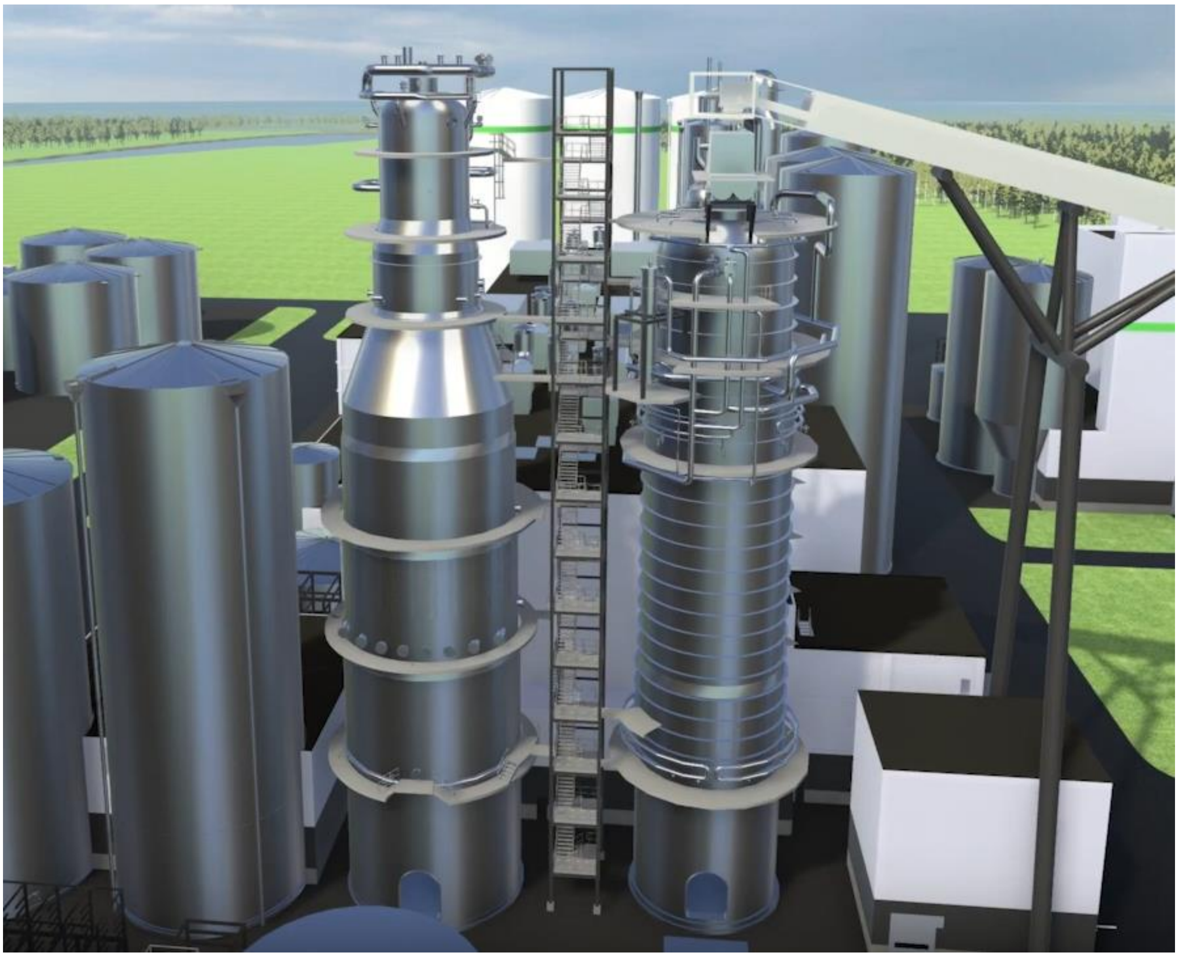

Figure 3. Part of the layout in 3D (Valmet, 2021)

Model presented in Figure 3 is from industrial operator's press release regarding a new project, which means that the model have not been designed in detail level yet, but it already includes main stair towers for example.

Figure 4 presents an example of 2D drawing of the process plants unit plot plan, which shows the location of site's equipment, buildings, tanks and other items. Drawing is used to present the general arrangement of everything that needs to be erected in the site, not the details of the above. (Parisher & Rhea, 2012, p. 176).

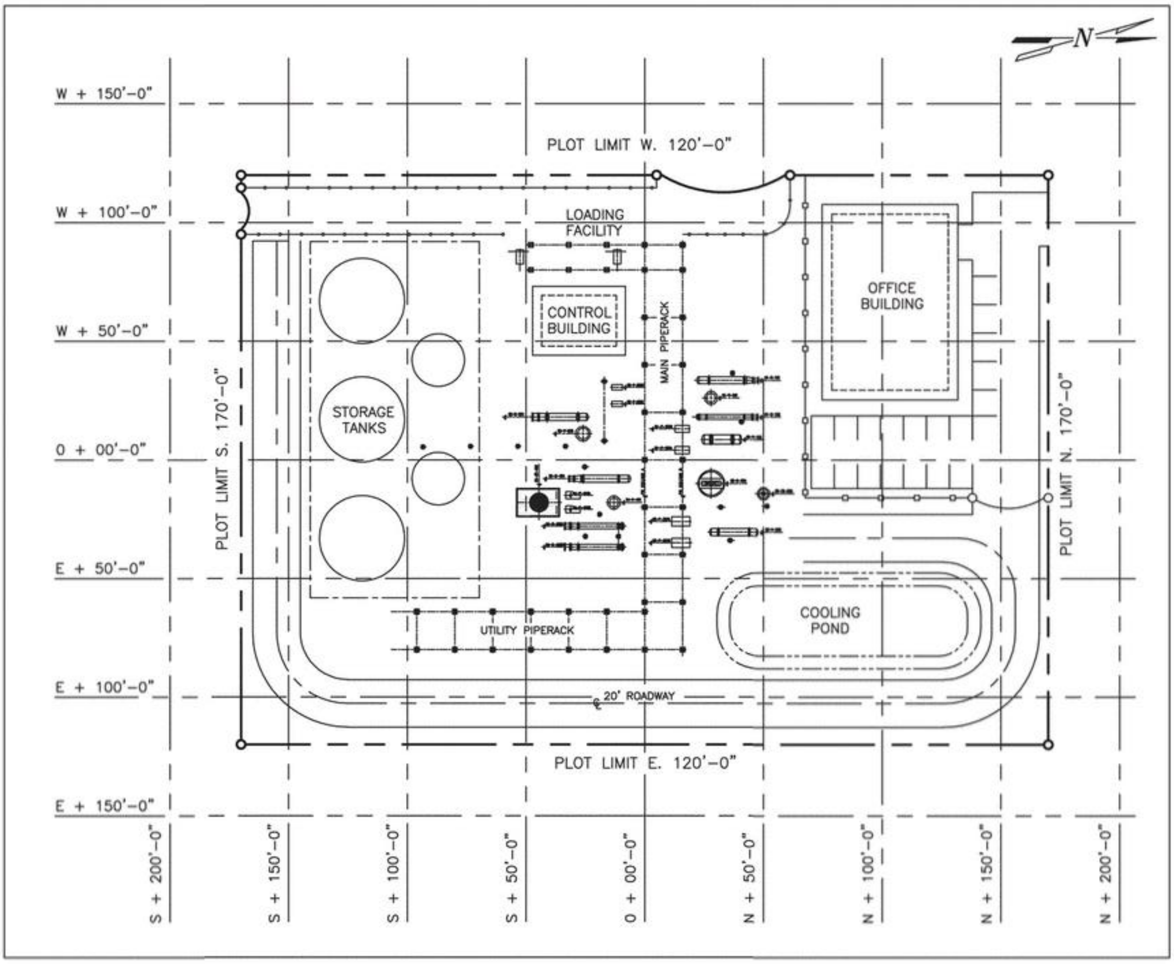

Figure 4. Example of unit plot plan (Parisher & Rhea, 2012)

To put unit plot plan into perspective, Figure 5 presents an example of process plant under construction.

Figure 5. Process plant under construction (Valmet, 2021)

Robustness of the layout is defined by how well the process requirements are met. Process plants for example have circulating fluids, so in order to meet the requirements, it has to be ensured that the system flow can utilize gravity, which would result the need of fewer pumps. System must operate at the planned availability with no surprising stoppages or failures. Many process plants are also modified or expanded in the future, so it is wise to leave room for possible expansion. (Moran, 2019, p. 243).

2.3 Creation of the layout

In layout design, few different methods can be used. In one layout design, it is very common to use many of the different approaches in different sectors of the layout. Intuition based on experience is an informal method, but it is still often used in layout design. The method in question means that the layout engineer or designer is utilizing previous knowledge and configurations on how the layout has been formed in the past. Successful layout configurations can be analyzed, and new combinations can be made. (Moran, 2016, p. 72).

Economic optimization is an approach where the goal is to minimize the distance that the material in the process travels. It can be utilized well with different software, by using economic optimization as one criterion when designing layout. (Moran, 2016, p. 72).

Critical examination is a technique where plant layout is evaluated by identifying critical issues, in example where the certain equipment is placed and why. Asking questions like, are there any other possible places for the equipment that might work better? (Mannan, 2014, p. 101). Moran (2016) remarks that even though critical examination could have value in academic settings, it has not been used among practitioners.

Rating approach is method that studies the relationship between plot, equipment, piping and so on, from the interconnectedness, hazards and other factors viewpoints. Values are assigned to these relationships that separation and grouping can be generated. (Moran, 2016, p. 72).

Mathematical modeling is more exact approach, where optimal layout is determined by using proven mathematical algorithms with predefined conditions. These algorithms are usually focused on achieving minimal cost. There have been many researches on mathematical modelling with different aims to reduce cost, these are for example related to equipment connections to piping and fluid pumping or safety equipment installation. These aims can be achieved in single or multi-floor scenario and models can be represented in 2D or 3D. (Jude, et al., 2018, pp. 488-489). Facility layout problem (FLP) has been mathematically studied in many research papers, but those are often limited to 2D layout design. In industrial layouts, 3D design is critical, since equipment is placed in buildings that have multiple floors with height restrictions. (Barbosa-Póvoa, et al., 2002, pp. 1669-1670).

Software-based approach is common modern method to design a layout. 3D -cad software can be utilized in layout design, equipment placing and piping route design. (Moran, 2016, p. 72). There are many commercial plant design software available and selecting the right software for the occasion depends on the available resources, plant sizes, support availability, design company size and so on. Software is expensive and therefore there is separate model review software available. They are used to review the designed plant models in 3D. Navisworks Viewer for example is a free review software that anyone can use to review the designed models. (Moran, 2019, pp. 78-81).

2.4 Modularity

Modularity is described in the literature from different viewpoints. Modularity-based manufacturing can be divided into three main elements: product modularity, process modularity and dynamic teaming. Product modularity has to do with standardized modules, which can be rearranged into different functional forms. Product architecture is the framework of successful product modularity. Process modularity means standardizing process manufacturing processes into modules that can be arranged quickly to respond a changing product's requirements. Dynamic teaming is human resources management tool, which uses modular structures to organize teams quickly when the product or manufacturing changes. (Tu, et al., 2004, pp. 151-152).

Miller & Elgård (1998) see the modularity as a structuring principle which increases clarity and flexibility, while reducing complexity. Modularity has organizational benefits as it enables parallel work and independent review of tasks. Miller & Elgård claim that there are always three basic drivers why modularity should be used. These are creation of variety, utilization of similarities and complexity reducement. This is presented in Figure 6.

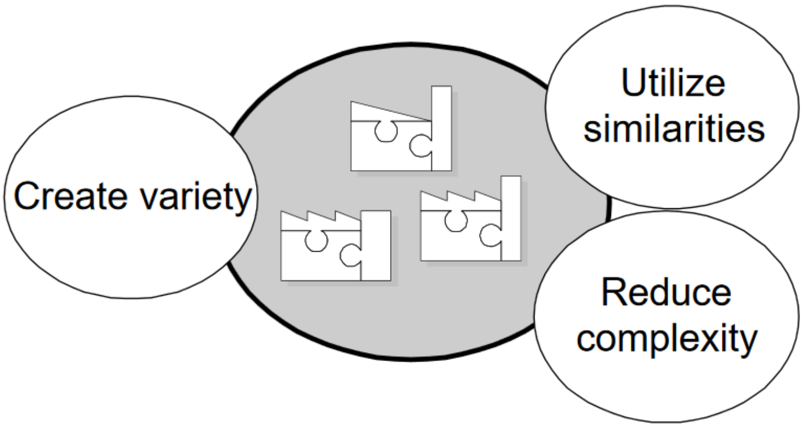

Figure 6. Three basic drivers behind modularization (Miller & Elgård, 1998).

Creating variety or customization enables the possibility to offer customer a suitable solution or a product. Customers want variety and that can be created by combining different modules. Customers, however, do not want external or internal variety if it is useless or does not add any value to the customer. Utilizing similarities means reusing resources and standardizing functional principles. It is not efficient to re-do the work, that has already been made. This enables faster working and reduces risks, when well-known solutions are used.

Internal variety should be reduced, since it does not add any value to the customer but increases the costs. Complexity is reduced to achieve better overview and handling. This includes breaking down independent units, parallel work, task distribution and better planning. (Miller & Elgård, 1998).

Designed systems can be complex and consist of many different parts. Modular design can be utilized to break down the system into smaller modules. Modularity is not a new technique, since it has been introduced as concept in variety development in 1965. Modules can be altered without affecting to the main infrastructure. Modularity has advantages in flexibility of the design and cost reduction. New modules can be introduced to the existing system and doing so, the system can be upgraded. In modular design, every products' components are constructed in a core platform as variant and common modules. (Tseng & Wang, 2019, p. 895).

In Figure 7, the system, its' subsystems, modules and components are presented in a schematic illustration.

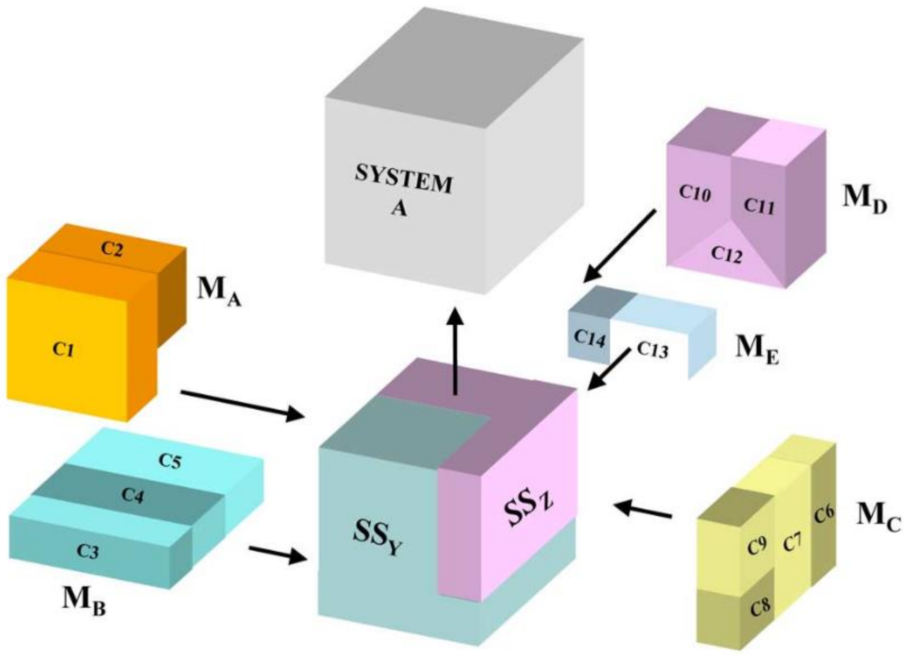

Figure 7. System A broken into subsystems, modules and components (Mikkola, 2007, p. 61).

As it can be seen in Figure 7, system A combines of two subsystems SS_Y and SS_Z. Both subsystems are divided into modules (M_A, M_B, M_C, M_D and M_E) which are then divided into components (C_1 to C_{14}). (Mikkola, 2007, p. 61).

Modular product architecture is described as methodology, in which the distinct modules are designed independently but together they meet the functional requirements of the product. Modular product architecture enables firms to have variety in their products with low cost. Unlike traditional product architecture, where modularity is not utilized, late engineering modifications in projects are not costly, if they can be achieved by inserting another module into the product. Product modularity concept has been extensively studied over the years, yet researchers have different opinions on the module identifications criteria and methods. Depending of the researchers, the modules have been defined and designed by reducing manufacturing and assembly costs, prioritizing the functional interfaces of components, maximizing the similarity index between components within a module or by implementing different heuristics to define modules. (Shamsuzzoha, 2011, pp. 21-22).

Process of modularity begins by designing number of modules that have specific functionalities. Modules need to interface with each other in order to create wide number of product variants. Shamsuzzoha (2011) paper’s framework of the modularization process is presented in Figure 8.

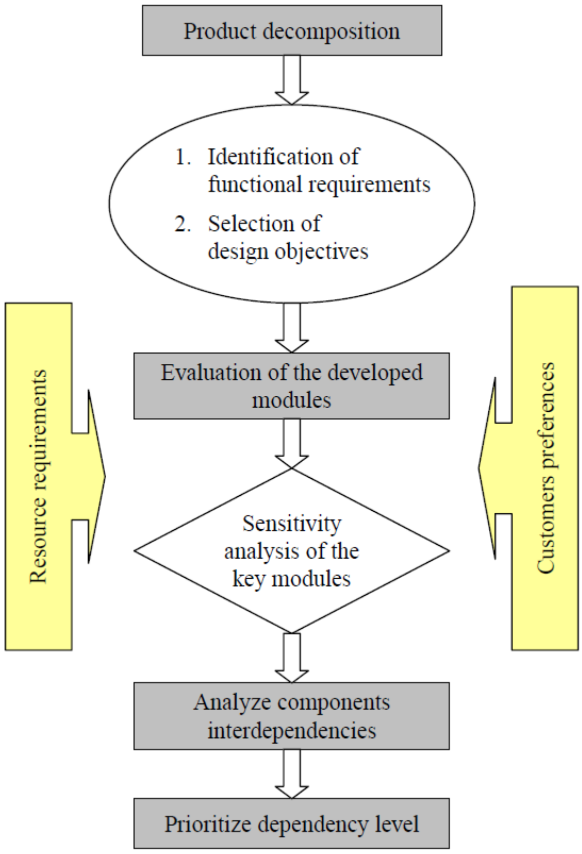

Figure 8. Example framework of the modularization process (Shamsuzzoha, 2011, p. 23).

From Figure 8, it can be seen that the first step in modularization process is to decompose the product, to find out what are the requirements and functions needed. Decomposition process helps forming the potential modules and fulfill the design objectives. Next step of the modularization process is to module evaluation. The developed modules are evaluated based on their costs, manufacturing and reusability. Third step in the process is sensitivity analysis, where modules go through testing and are prioritized based on the costs of the modularization and how it impacts the manufacturability of the modules. Last step in the process is to analyze the component dependencies of the modules. They are then prioritized based on their individual dependency strength. (Shamsuzzoha, 2011, p. 24).

According to Ulrich & Tung (1991) there are five types of modularity based on their interaction with each other. These types are component-swapping modularity, component-sharing modularity, fabricate-to-fit modularity, bus modularity and sectional modularity, these are presented in Figure 9.

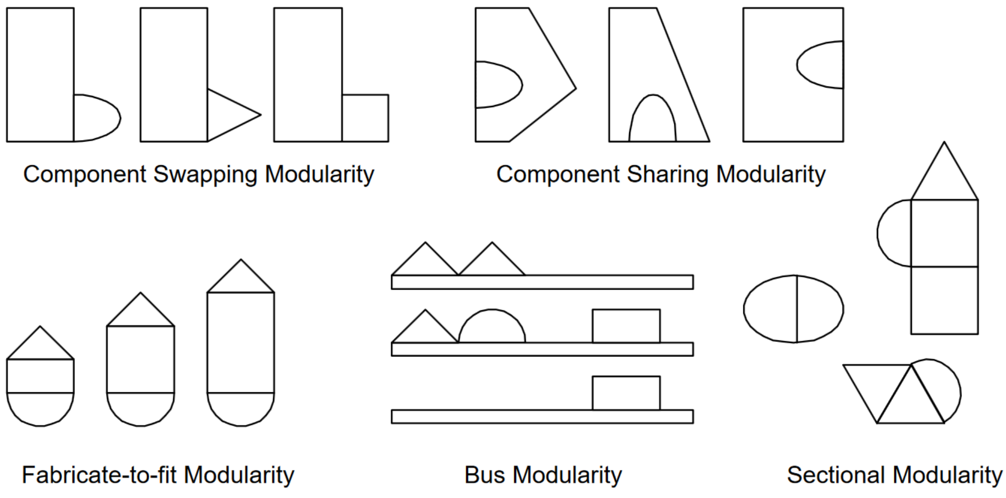

Figure 9. Types of modularity (Miller & Elgård, 1998).

In component-swapping modularity, different variations are achieved by swapping the components on the body of the common product. Example of component-swapping product is office desk lamp, where the base stays the same, but the lamp can be switched to different variations. Component-sharing modularity differs from component swapping in a way that in component sharing there is same components in different common product, whereas in component swapping it is the common product, which stays the same. In computers for example, different monitors can share the same microprocessor or in automotive industry, different cars can have same brake pads. In fabricate-to-fit modularity, couple of standard components are used with one or more changing components, in order to create different products. Example of fabricate-to-fit modularity is cable assembly, where cable lengths vary, but the connecters stay the same. Bus-modularity enables the use of multiple basic components in different locations. Bus-modularity is used in computers for example, where different components, such as memory units and central processing unit can be attached to same data bus, forming different types of data processors. In sectional-modularity components can be joined together in any way, as long as the connection happens by using the interfaces of the components. (Salvador, et al., 2002, p. 552) (Kärki, 2018) (Huang & Kusiak, 1998, pp. 68-70) (Kamrani & Nasr, 2010, p. 63).

2.5 Standardization

Standard as a term is a definition or a demand of how something should be done, presented by an organization. Standards can define object’s weight, size, and quality and so on.

Standardization on the other hand is a term of extensive utilization of products, components and processes in scenarios where predefined laws, rules and practices prevail. (Aapaoja & Haapasalo, 2015).

Aapaoja & Haapasalo (2015) addresses the standardization possibilites in the construction field. Standardization is divided into process and product standardization. Process standardization aims to reduce the costs by making the process more effective. Better processes can reduce the amount of people needed in the process, which increases quality because standardization helps all parties in the project to understand the customer needs and what is their own role in the overall process. Standardized processes have been found to decrease the needs for additional modifications and other conflicts, which would increase costs. Product standardization is claimed to achieve faster lead times, better quality and more efficient operative action. Disadvantage in standardization is that it makes flexibility more difficult. In some cases, excessive standardization can be blocking the design. That being said, Aapaoja & Haapasalo (2015) conclude that standardization in construction is not about product standardization, but standardizing the practices, making them more systematic. Gao & Low (2014) also speaks about the standardized work process as a part of lean methods, where workers inside the company should follow a detailed standardized procedure which touches all aspects of the company. Certain repetitive processes should be stadardized to the practice where quality, time, cost, safety and so on are reached in the best possible way. Gao & Low (2014) mentiones also that everyone who is associated to the standardiced procedure should be encouraged to improve the current standards. (Gao & Low, 2014, p. 673).

Product standardization aims to utilize same product design to similar needs. Standardization has both benefits and disadvantages in the commercial area. Standardization allows for smaller product portfolios and reduced costs. However, customer needs are usually in the area where adapted products with distinct features are more appealing. Customers do still value the low cost and high quality, which can be achieved with standardization. This means that in the organizational design, there is a confrontation between design control and design flexibility. Control favors standardization, where flexibility favors the adaptation. (Liu & Yongjiang, 2020, p. 1063).

2.6 Innovative plant design

Plant transformability can be considered as part of innovative plant design. It is relatively new subject, but it has been studied by researches and transformable plant designs are designed in practice also. Transformability can be defined by five factors: modularity, universality, compatibility, scalability and mobility. Wörsdörfer, et al. (2016) claim that if the system possesses all of the previously mentioned traits, it can be considered as fully transformable. Transformable plant designs are emerging because of the benefits they bring to the table. As it is known, in current market dynamics the customers want product differentiations and customized products in a market where volatility is increasing, meaning that demand uncertainty is rising. All of this added to the trend where design and logistics turnaround time is desired to be reduced. With transformable plant designs, these challenges in both engineering and market standpoint are seeked to be conquered. Schematic illustration of the fully transformable plant design and its derivatives can be seen in Figure 10.

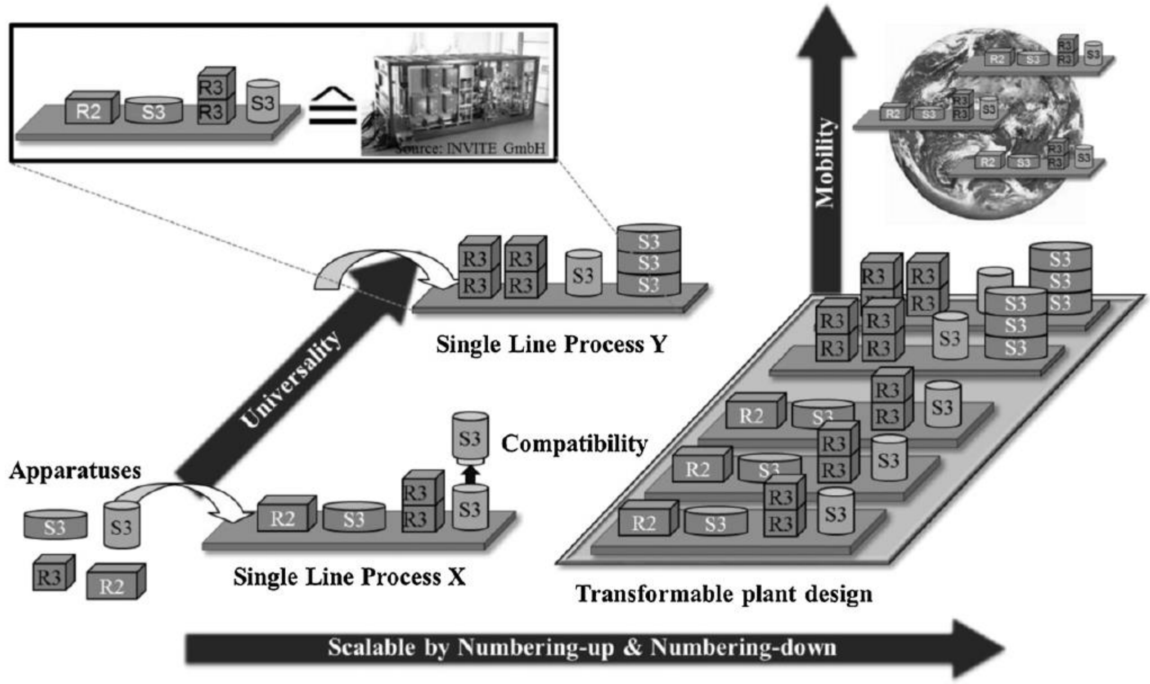

Figure 10. Illustration of a fully transformable plant design (Wörsdörfer, et al., 2016, p. 2).

As it can be seen in Figure 10, plant consists of number of single line processes (X and Y), which consists of number of different equipment.

Mobility can be achieved by constructing modules and shipping them into the site in standardized containers. While this is a good method for smaller process plants, it is hard to achieve in large-scale process plants. That is why partly transformable plant design is also an option. Scalability means plant’s ability to either expand or reduce if necessary. It can be considered as breathing ability from technical, organizational and regional viewpoint. Universality means that the object is capable of doing different tasks, functions and requirements. Compatibility means that objects can be linked together in a way that it enables material, information and energy flow between the objects. The most important enabler for transformable plant design is modularity, which most commonly means the usage of standardized working units, which are called modules. (Wörsdörfer, et al., 2016, pp. 4-5).

Road transportation of process plant equipment is presented in the **Figure *11***. Large components are more difficult to transport and the whole transportation process requires lot of planning, which begins even before the materials are bought. (Valmet, 2021).

Figure 11. Transportation of process plant components (Valmet, 2021)

Modules can be separated to apparatus modules and process modules. Apparatus modules include single processing step elements, which are standardized and prefabricated. One processing step can be heat exchanging for example. Process modules are much larger modules, as they include the whole production process, which means number of processing steps. Compatibility can also be separated into two different things: internal and external interfaces. Both interfaces are required to be standardized in function, placement and type. Internal interfaces allow easy connection between the equipment and external interfaces allow simple connection between equipment and its’ surroundings. Modules scalability can be achieved by increasing or decreasing the capacity of the module. This can be achieved by simply making the module larger or smaller. Other method to achieve scalability is to insert more similar modules so that they operate simultaneously, technique that is called numbering up or down. Universality can be achieved with versatile equipment, which allows the possibility for reconfiguration of the process. This can be achieved by designing equipment modules in a way that they are not specific for the certain process or application, but more generic so combination with other modules allows for different possibilities. (Wörsdörfer, et al., 2016, p. 5).

Companies like Zeton and EnviroChemie for example have used modular production solutions in plant projects. EnviroChemie have designed EnviModul, where components are designed and constructed into a container. Because of that, building permits are not needed. Modules are pre-assembled and pre-tested, which increases the quality. (Envirochemie, 2021). Zeton designs and builds the modules pre-hand as well. They point out advantages in costs control, since modules have fixed prices, it eliminates the possibility of cost overruns, which may occur in traditional design. Both of previously mentioned companies are capable of customer driven flexibility, meaning that modules can be designed in a way that they meet the customer's needs, standards and preferences the best way possible. (Zeton, 2021).

Modular construction has benefits in worksite safety since modules are fabricated outside of the worksite, in safe indoor location. Quality improves, because module is typically designed and constructed in same place, which enables better communication between designers and builders. Better communication between the two parties typically increases the equipment quality. Turnaround time is faster with modular plants, mainly because foundation work at the site can happen simultaneously with equipment modules fabrication. Sitework time is also reduced, since less time is needed with the pre-assembled and pre-tested modules. This reduces the amount of troubleshooting during startup, which often happens with traditionally built plants. Modular plants offer flexibility, which is hard to accomplish with traditional process plants. Small modules can be used in one centralized location or at several dispersed locations where needed. If the demand in production for example changes, the number of modules can be altered easily.

While modular construction has many benefits, it also has disadvantages. Transportation is one factor that has negative effect to modularity. In some cases, the equipment must be directly transported from manufacturer to the site, in which case there is no benefits in using modular structure. Large equipment means large modules, which leads to higher transportation costs. Roads have regulations, which restricts the size and weight of the cargo. Modules require high level of upfront engineering, which is also a disadvantage. In order to build the modules, full details of the equipment are usually needed, which is why experienced engineering team is great asset in order to reduce the amount of upfront engineering needed. (Roy, 2017, p. 29).

Modular structure being erected in the site is presented in Figure 12.

Figure 12. Plant module being erected in the construction site (Roy, 2017, p. 28).

Wörsdörfer, et al. (2016) claims that with transformable plants businesses are able to offer a product portfolio of multiple standardized plant designs. To achieve this, business needs a management model, which supports the design development and is able to offer highly tempting plant designs. This provides high degree of customer satisfaction, which leads to increased customer loyalty and stronger market position.

2.7 Interview process

Interviews are part of qualitative study data collection in most cases. Interview formats vary from open to highly structured. In open interviews there are only general list of topics to be openly discussed, whereas in the structured interviews there is list of specific questions to be asked in specific order. Interviews can be individual or contain group of people, they can be prearranged or happen spontaneously. (Saldana, 2011, pp. 32-33).

Sampling is the technique that can be used to find the interviewees for the research, it can be strategic, random or even fortunate selection of participants. However, if the interviewees must have a certain background for example, then participants should be selected from those cohorts. The needed number of interviewees are topic that has many different viewpoints. While some researches indicate that small group of people provides enough data for analysis, other researches indicate that interviews should continue until new information is no longer obtainable. Based on this, it can be said that there is no clear ruling in how many interviews are enough, as long as sufficient amount of data is gathered in order to do the analysis. (Saldana, 2011, pp. 33-34).

To obtain a comprehensive statement how the layout design progress is carried through in the quotation phase, it is best to select the interviewees based on their professional background. When selecting interviewees using this method, it can be ensured that different areas of specialization are presented. Interviews are done individually, with the aim of gathering as much information from the interviewee as possible. It is not necessary to interview more than two experts from one specialization area, which keeps the overall group size small.

In the interview process, professionals who have experience in working at quotation phase are interviewed. It is necessary to get first a grasp on how the whole quotation process works in practice. The assumption is that interviewing experts from different specialization fields will lead to various critical points and development ideas. After the results are analyzed, critical points can be discussed with the experts individually or in a group interview, but it does not require an official interview process. The results of the interviews can be utilized when preparing the questions and improvement ideas for the later analysis. When the critical aspects are found from the interview process, they are then studied more in depth.

Engineers and experts from the following specialization fields are interviewed: plant and layout, sales, estimation, process and project management. Plant and layout personnel are expected to offer more detailed knowledge of the plant layout design process, whereas sales personnel probably have the best knowledge of the customer needs.

Interviews are carried through as individual interviews, where only interviewer and interviewee are present. Interviews take place at Microsoft Teams conferencing app, since due to current restrictions caused by the COVID-19, many tend to work from home. Also, some experts are working in different city, which means that face-to-face interviews would not be possible even to begin with. Duration of the interview is planned to be one hour, but some interviews are expected to take more or less time. Interviews are held in Finnish if the interviewee is Finnish citizen or capable of speaking Finnish. In other cases, the interview is held on English. Interview session is recorded if the interviewee agrees to it, if not, only written notes are used in the later analysis.

2.8 Content Analysis

Before the actual content analysis can start, the data collected from the interviews must be processed. Voice recorded data is transcribed to text, and all the irrelevant things that are discussed in the interview are removed. This is the first step of the analysis, and certain themes will become evident already at this stage.

When reading, organizing and transcribing the collected date, themes will pop up and different theme patterns appear. These patterns can be located and labelled. Patterns reflect the ideas that have appeared in the data and they can be referred as codes. (Galletta, 2012, pp. 121-122). Codes can then be categorized, and these categories may be used as the highest level of results or if it is necessary to further, one can create themes. (Erlingsson & Brysiewicz, 2017, p. 94). Figure 13 presents an example of levels of abstraction, how data from the interview can be analyzed from citation to theme.

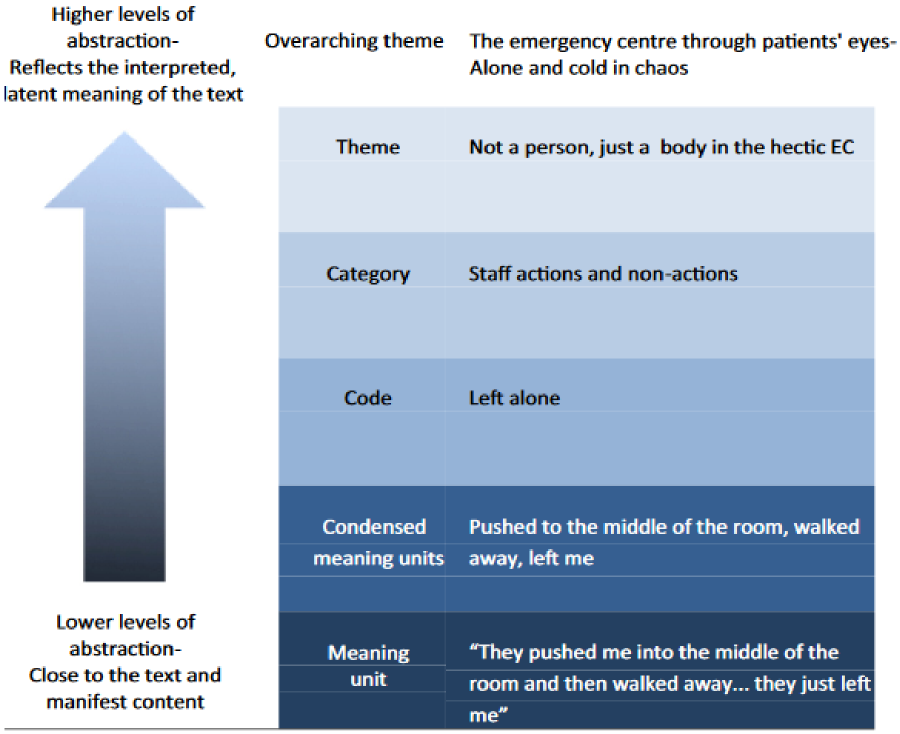

Figure 13. Example of the analysis levels from meaning unit to theme (Erlingsson & Brysiewicz, 2017, p. 94).

It can be seen that Erlingsson & Brysiewicz (2017) call interview phrases as a meaning units. They are then structured into condensed meaning units, where irrelevant words are removed from the original phrase. Code is formulated from the meaning unit and it consists of one or two words which describe the issue. When codes are formulated they are cross compared and codes that are related to one another are placed under same category. Thematic illustration of categorizing codes is presented in Figure 14.

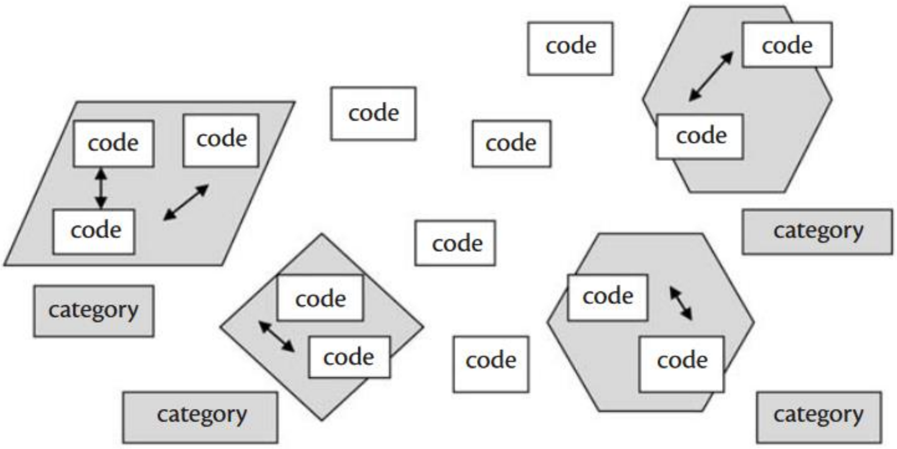

Figure 14. Illustration of codes and categories (Galletta, 2012, p. 127).

3 RESULTS

In this chapter current situation in target company's quotation phase as well as methods in layout design are presented. Results of this research are the critical improvement areas that were found when interviewing the experts who work in the quotation phase. Those improvement areas are listed and then couple of them are looked more into and development methods are presented to those. Improvement areas are selected based on the research questions of this study.

3.1 Current situation and resources

To find information and in order to get an idea about the current resources and practices that are used in the target company, in total of seven semi structured interviews were conducted. All of the participants either currently work in the quotation process or have worked with quotations in the past. Two of the participants were layout designers, two were from sales. One participant was a process engineer and one was an estimation engineer. One participant was manager in project engineering team.

Target company has business applications in the pulp industry. The pulp mill consists of multiple different production lines which are presented in Figure 15.

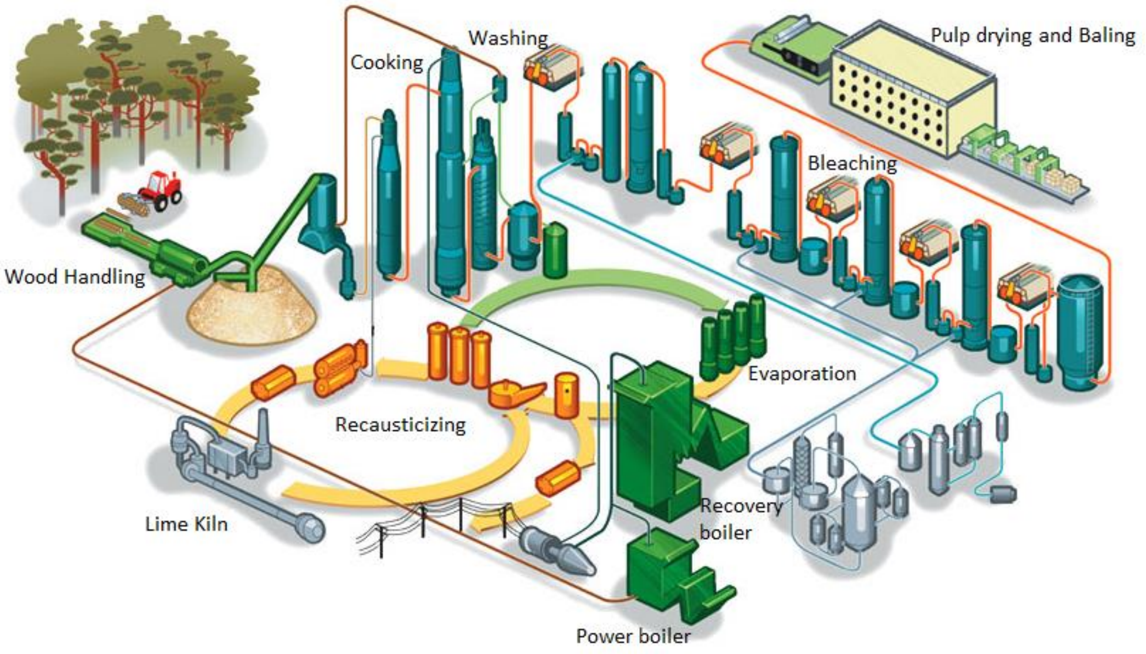

Figure 15. Different production lines at a pulp mill (Knowpulp, 2021).

Since all of the production lines presented in Figure 15 are large entities themselves, they usually have their own design and engineering departments.

Themes that were used in the semi-constructed interviews as a foundation for questions are presented in the Table 1.

Table 1. Themes used in the semi structured interviews

Project Execution	**Layout Design**	**Price Estimation**
Project model types	Design stages	Forming price estimate
Quotation content & stages	Potential use of copies	Needed calculations
Internal & External resources needed	Design period length	Critical points & areas
Needed information from the client	Layout importance	Accuracy of the calculations & estimates
Customer needs & requests	Shortages in design	
Benefits in faster layout production	Development ideas	
	Possibility of standard layout solutions	
	Possibility of modulation	

The interviews had three main themes: project execution, layout design and price estimation. Project execution included questions on project model types and what do they include, stages of the quotation phase, resources and customer related aspects. Layout design included design related questions, with questions on how layout design could be improved. Price estimation processed questions on how the price estimation is formed, what does it include and where are the most challenging points. Questions on standardization and possibility of modulation was also part of the interviews, in order to get a grasp on how both of those aspects are thought in the target company. These themes and questions related to those were selected because they were connected to the research questions as well as the theories presented in the literature review.

Table 2 presents the codes and related categories that were found when studying the results of the semi-structured interviews.

Table 2. Categories and Codes found in the answers of the interviewees

Time Management Challenges	**Input data Challenges**	**Layout Design Challenges**	**Price and Material Estimation Challenges**
Rush	Input data often insufficient	Draft layout includes mistakes	Challenges in piping, steel structures and tanks
Layout required at too short notice	Mill layout not always available	Lack of primitive models	Seismic areas are challenging
Layout updated too often in the final steps of the quotation phase	Capacity may change during quotation	Too many changes in the layout during the quotation	
Not enough time to orient to design software		Dimensions of purchased equipment not always known	

When the interviews were processed, four main categories were formed, based on the codes that came up. These challenges were divided into time management, input data, layout design, price and material estimation.

3.2 Target company's project delivery modes

Target company of this thesis is capable of providing all the main project models, from EPS to EPCC. EPS project include equipment delivery to the customer and usually it also contains installation supervision and factory start-up. In EPS projects the detailed plant design is out of the target company's scope, but process design still might be included in supplier's scope. From layout viewpoint, the EPS project requires least amount of work, because only a basic layout is designed. Also, equipment and maintenance levels' weights are calculated for the assembly purposes.

EPC projects are wider projects that include more designing. The EPC includes detailed plant design and installation. Depending of the case, it can include piping, steel structures and tanks. It is possible that customer will do the procurement of the products based on the project supplier's design. EPC projects require accurate documentation on everything.

EPCC project is the largest project that the project supplier can deliver. It can be described as a turn-key project delivery. It includes everything starting from civil engineering, piling, concrete work and building construction. On top of the previously mentioned, project supplier is also responsible for commissioning of the plant.

While EPS is the easiest project to execute, as it has the least things to be considered, the trend nowadays seems to be the EPC and EPCC projects. EPC and EPCC project models should be studied more, because they include more factors that have to be considered and designed, which leads to more mistakes if not done accurately enough.

3.3 Quotation phase

Quotation starts by customer requesting for quotation (RFQ). If the supplier possess technology available for the purpose and the resources are sufficient then bid is made. Customer describes what are the quality requirements for product that the process plant will produce and what is the capacity of that. In order to layout design to start, mill layout is needed. Customer typically provides a mill layout, which describes where the different subprocesses are located in the whole process plant. In pulp mill for example, this could mean power boiler, causticizing and recovery boiler processes. In EPC or EPCC projects customer have usually used consulting company to define the whole plot and how the previously mentioned subprocesses should be laid out there.

Quotation phase duration varies from customer. EPC or EPCC quotations last typically one year, but EPS projects can be done in month or so. Sometimes customers want to make quick decision even in larger projects and especially in EPS projects. Quotation starts by making a technical specification, which presents the selected technology for the process, equipment and their sizes. Once mill layout is available for use, first draft of the layout is designed. After the first draft, more people are involved in the quotation process. Installation and construction personnel are involved in early stages, in order to start the pricing process. Equipment engineers are also involved at the beginning of the quotation process, so they can see how the equipment are laid out, in order to know the directions of the equipment's connections. Process and technology engineers also need information from layout design, for example how many pumps are needed for certain process. This takes place at later stages of the quotation process, when the detailed layout design has started.

Layout is an important factor for the quotation and for the internal work progress. Since plant can include multiple purchased equipment from external providers, it is critical to know what size of conveyors, elevators and pumps are needed for example. Layout is critical, when calculating the pipeline quantity and weight, as well as steel structures properties. All of this is connected to pricing and how accurate that can be.

3.4 Customer needs

Customers are international operators in the pulp industry. In the quotation phase, the personnel who are responsible for the investment are involved in the negotiations. Plant desirability may be depending on the personnel who participates to the negotiations. If plant operators are participating to the negotiations, usability of the plant could be seen as a critical factor. However, if only commercial personnel are participating to the negotiations, plant usability may not be seen as very critical factor.

In customer driven industry it is clear that competition is present in quotation phase. Customers want to select the provider who is capable of fulfilling the customer needs in the most optimal way possible. What is optimal to customer varies, but similarities can be found between the customers. One important thing is obviously the fact that the required capacity of the plant must be guaranteed.

Based on the interviews it can be said that perhaps the most important factor in desirable process plant is the price. Most customers typically try to make the process plant investment at the best possible price. This means that the layout must be designed in a way that it can be constructed with optimal amount of materials.

Customers often want to take part in layout design, since they often have own preferences that they want to include to the layout. Example of these are usually some maintenance related aspects, like additional space reservations for forklifts, trucks and so on. Experts pointed out that customers usually have some sort of ideas to leave their own handprint to the plant layout, but it is often more expensive for customer if they do that. Many times, customer demands are reasonable, but they can also affect the layout in negative way, that can be price related for example.

Sales experts pointed out that customers would appreciate a well thought layout, which would be optimally priced. Faster lead time in layout design would probably also be appreciated. Detailed layout should be designed and ready in earlier stages of the quotation and it should be justified why that kind of layout is designed.

3.5 Layout design process

Layout design affects many other engineering departments and it includes lot of different aspects that needs to be taken care of. This chapter processes the current layout design process that occurs in the target company.

3.5.1 Initial data

Layout design currently starts by designing a draft of the department layout, which is based on the offered equipment, capacity and the customer provided mill layout plan. Mill layout describes the locations of each department within the mill site, possible connections to existing plants or departments, traffic arrangements, mill orientation, coordinate points, mill site boundaries and gates, hazardous substances loading and unloading areas, pipe and conveyor bridges, underground structures, power transmission line, expansion reservations and so on. From the mill layout the important factors that affect the design are plot dimensions for the plant department and where the incoming pipelines are located in relation to the plot. Outgoing pipelines are also important factor that restricts the layout design. Another important factor is other subprocess plants that need to be accounted for. If the layout has equipment that needs to be connected to another process equipment, it should be placed next to it. All of the previously mentioned factors reduce the number of degrees of freedom that are available in layout design. Plot can be various different shapes depending of the customer and provided mill layout. Sometimes it can be rectangle shaped with two sides long and other two narrow, or it can parallelogram shaped. Selected equipment must be able to fit into the given space. All of the needed input data is gained from the mill layout, process diagrams, equipment drawings, technical specification, existing layouts, standards and customer requests.

Example of the site ground plan can be seen in Figure 16.

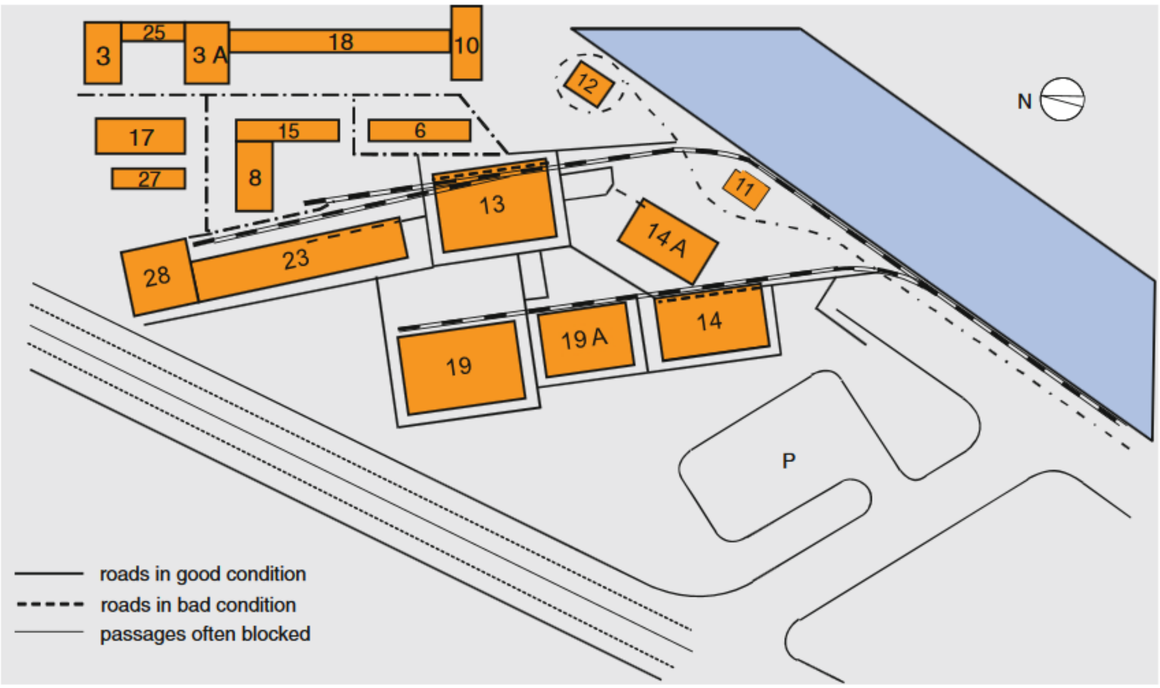

Figure 16. Example of site ground plan (Wiendahl, et al., 2015, p. 388)

As it can be seen in Figure 16, site plan is large layout that includes departments and roads in this case, but in pulp mills, the mill site typically includes pipe bridges, common stacks and other pulp mill related aspects as well.

Department layout is the layout in which this thesis focuses, it is the detailed layout of the process plant. In one pulp mill, there are many departments as mentioned before, and thus there are many department layouts. When designing the department layout, important factors are site boundaries, expansion and space reservations, equipment and tanks, buildings, traffic arrangements, service and installation, piping, power transmission line and areas outside of the buildings.

Site boundaries as well as expansion and space reservations are self-explanatory. Layout designer needs to be aware of the given plot restrictions and if there are anything that needs to be kept empty for future expansion. Space reservation is especially important for automation, electrification, cable trays and HVAC (Heating, ventilation and air conditioning). Large pulp mills require lot of space for electric rooms and cables require space in the pipe bridge.

When it comes to equipment and tanks, there are more details that need to be taken into account. Locations and positions of the equipment are one aspect, but layout designer needs to be aware of the loads of the equipment. Both tanks and equipment have nozzles which connects to the piping and possible other equipment. Pressure equipment can have relief valves that need to be accounted for. Equipment are maintained, which means that they need service platforms and space reservations for the maintenance work. Equipment temperatures are also important factor when making space reservations for example. Figure 17 presents detailed view of the equipment, its piping connections and service platforms. Service platforms need to be designed in a way that the equipment is safe to be maintained, but that there is room to make the maintenance procedures needed.

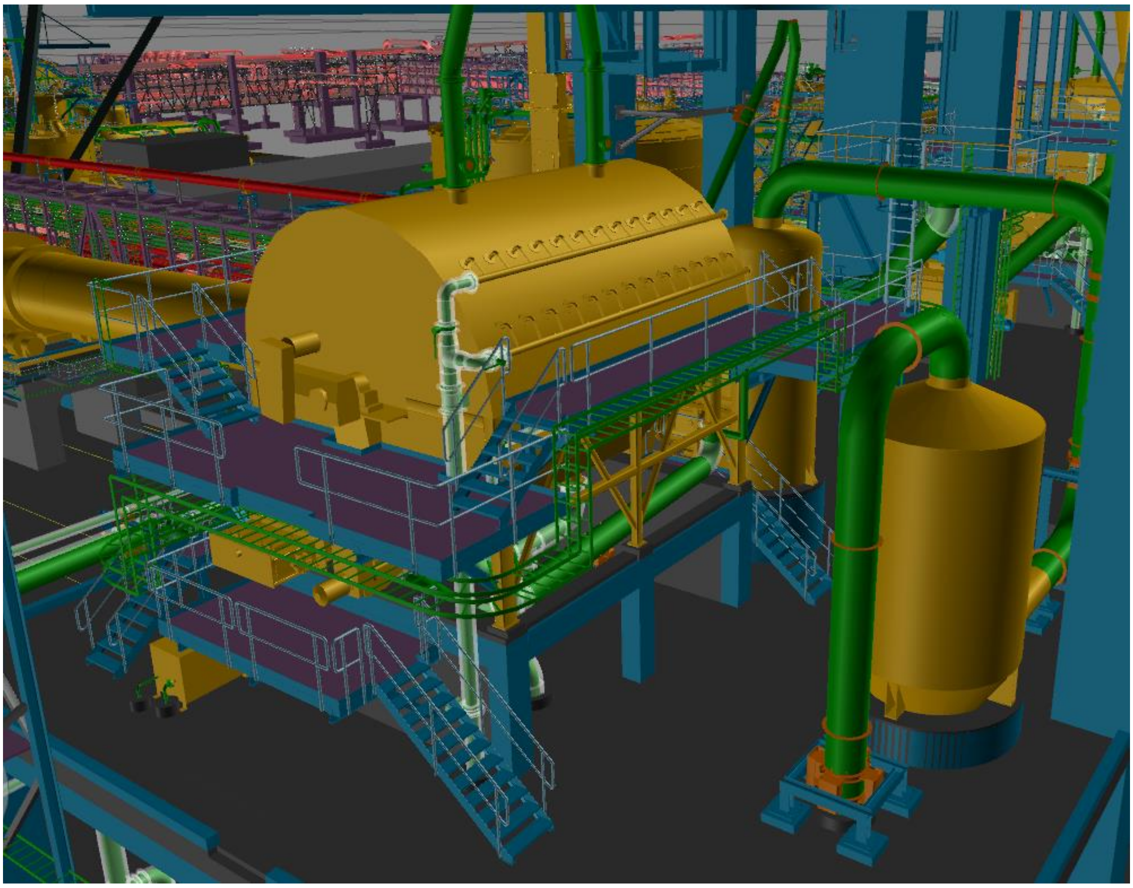

Figure 17. Equipment (yellow), piping (green) and service platforms (blue/violet)

Important factors in building design is the location within the department, dimensions of the building, beam lines and level height. Floor channels, sewerage and bunkers must be able to fit. Some pulp mills are located in sites, which are warm all year around and thus walls are not necessary, but if location is exposed to cold conditions, it must be ensured that walls fit to the building.

Traffic arrangements needs to be accounted, which include freight transport, such as loading and unloading areas, as well as other traffic arrangements, like routes for pedestrians and rescue services.

When it comes to the service, installation and assembly, the important aspects to notice are equipment freight location, loading to area where equipment is lifted in place, installation requirements for equipment placing inside buildings. Other things to note are space for transporting, access and doors. Information on loads are needed for cranes and lifting hoists.

Piping routes are important, since it is more cost-effective to utilize natural slopes for liquid flow, rather than using pumps in every place needed. Pipes are heavy and because that they need supports. Pipe bridge can be found in most process plants, it supports multiple pipes and cables throughout the plant. Pipe bridge can often work as a platform for operators to move within the plant, from building to building. Example of a pipe bridge is presented in Figure 18.

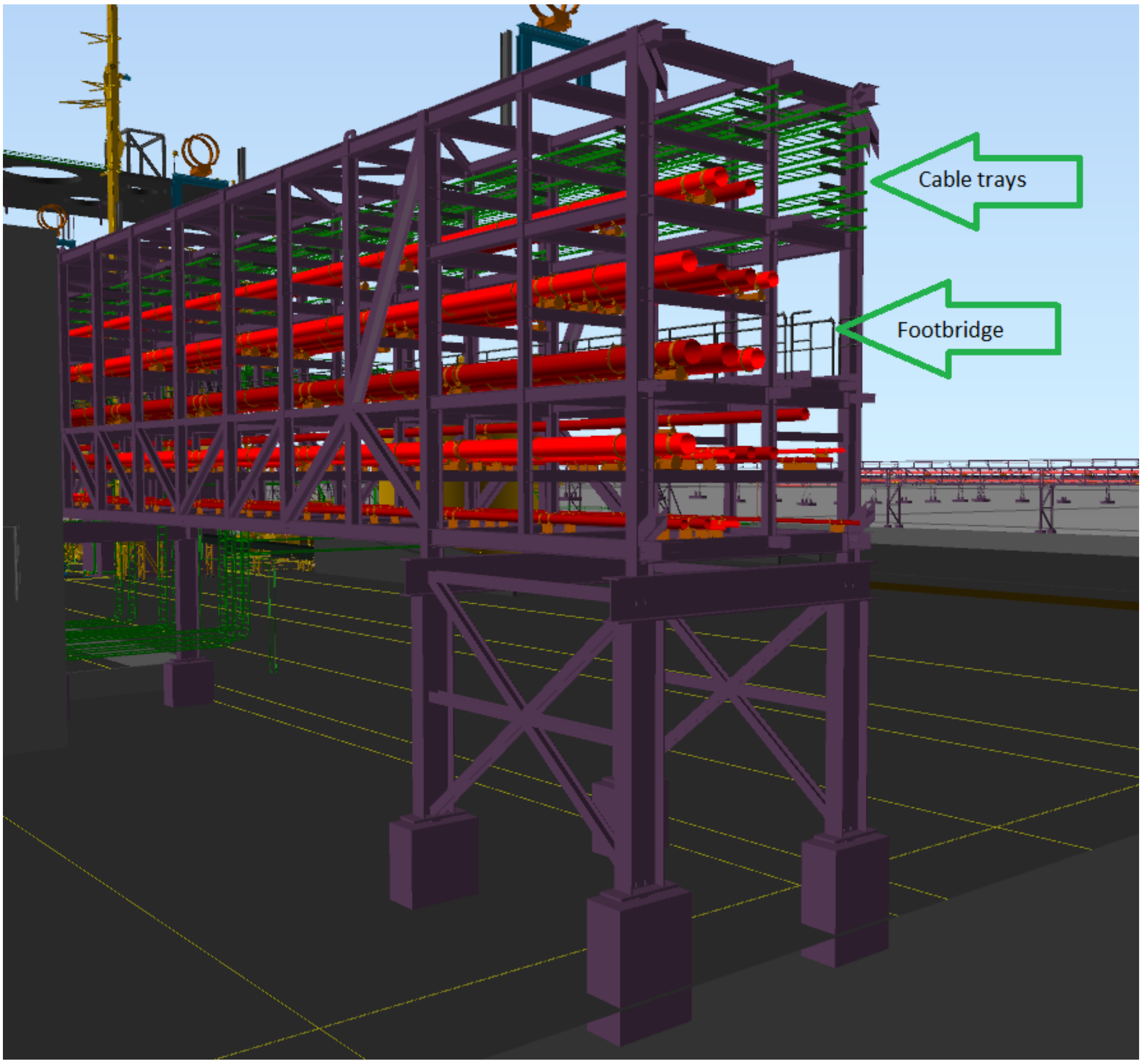

Figure 18. Section view of a pipe bridge

In addition to pipe bridges, other areas outside of buildings that need to be accounted for are spill walls, underground connections, stair tower placements and conveyor bridges. Delivery limit or so-called battery limit is boundary point between areas of responsibility, in process plants with multiple departments pipe bridges typically have a delivery limit. Delivery limit, which included also underground piping is described in the process diagrams and layout drawings.

3.5.2 Project-specific influencers

Each project and thus quotation also have unique features that need to be accounted for. Projects are worldwide, which means that each country have their own standards when it comes to plant safety. Customers can have different regulations about the bunker sizes, tank area spill wall size and tank distances from each other. Spill wall surrounding the tank area can be seen in Figure 19.

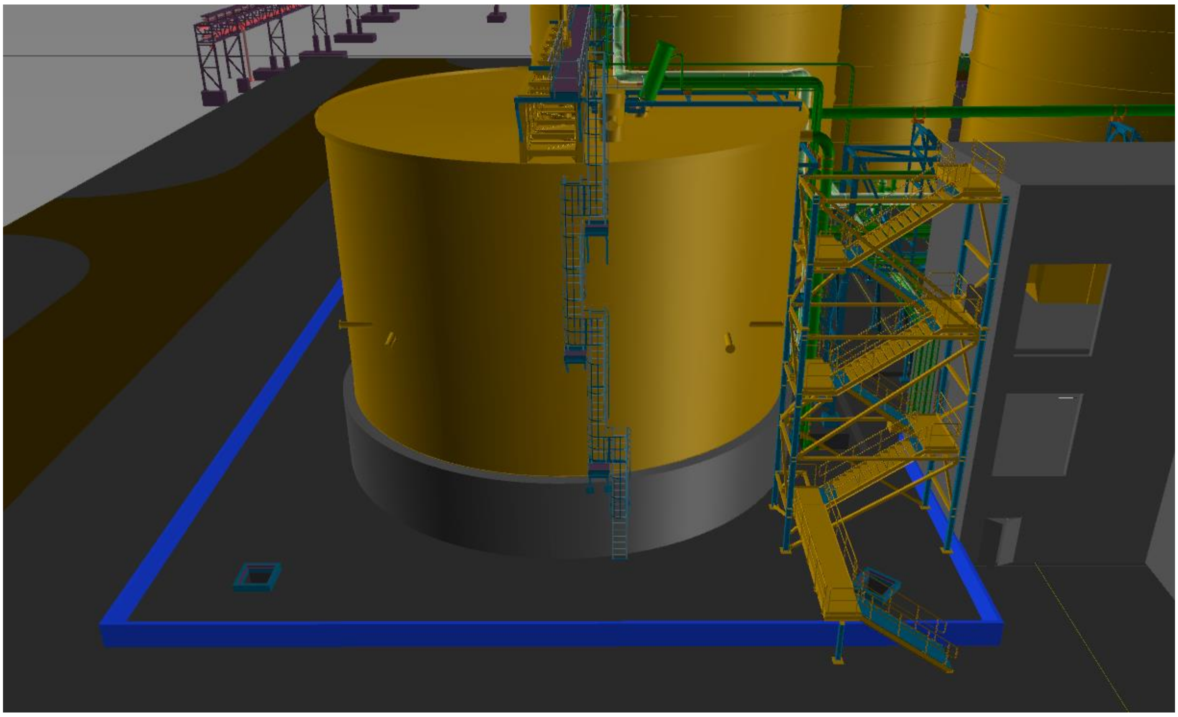

Figure 19. Spill wall

Spill wall is colored with blue color in Figure 19. It secures the plant if tanks would spill the contents. Spill wall may interfere with maintenance procedures, which means that it needs to be accounted when designing the layout and locating equipment.

Some locations are exposed to seismic activity, which means that in the design phase additional thought must be put into the support structures of the equipment, tanks and buildings.

Most important aspect that is dependent of the project is the piping code used. ANSI and ISO standards are the most commonly used in process piping industry. Nominal wall thickness is larger in ANSI pipes, which means that ANSI piping is heavier than ISO piping. Heavier piping leads to larger pipe bridges and supports.

Customer-specific preferences is also one aspect that cannot be predicted beforehand. These preferences are usually maintenance related aspects, which could mean extra space reservations for trucks, cranes and other vehicles. Customers can also have thoughts where waste for example are collected and how they are transported out of the pulp mill.

3.5.3 Modeling

Modelling is done with AVEVA E3D software, which is used in industrial 3D design. Equipment usually do not need modelling, since most equipment can be found in target company’s own library. 3D plant layout is used during the quotation phase as well as in the actual project phase. If equipment cannot be found in the library, they should be modelled in the software as a primitive models, because even though it is possible to use lighter STEP file models of the equipment, they are still too heavy for the plant layout to move seamlessly. In addition to the 3D layout model, also 2D drawings of the plant are produced. AVEVA E3D is used for the drawing production of the plant, but sometimes AutoCAD software can also be used when drafting the layout in relation to the mill layout.

Delivery limit and mill layout has a significant role in layout design, as mentioned earlier. If incoming and outgoing pipelines as well as other restrictions are favorable, then plant layout follows certain formula, where subprocesses are laid out in specific areas. Currently used layout creation technique can be described as a mix of critical examination and intuition based on experience. This is inferred from the fact that there are pre-agreed courses of action to be followed. Other method currently used is economic optimization, since the subprocesses are laid out in a way that the pipelines between them are as short as possible, which minimizes the piping material.

Design in E3D is based on hierarchy levels. In the model, the highest level of the hierarchy is the ‘Site’, which in good modelling technique divides to building sites, steel structure sites, piping sites, equipment sites and so on. This means that all equipment of the process plant should be modelled under the model site. Equipment site further divides into different 'zones', where one zone can be tanks for example and other zone could be pumps. Under zone, there can be several products that fit in to the category. For example, under the equipment site, there is tanks zone, where are three different tanks. One tank consists of different sub-equipment, which consists of primitive shapes, such as cylinders and dishes. Example of the hierarchy is presented in Figure 20.

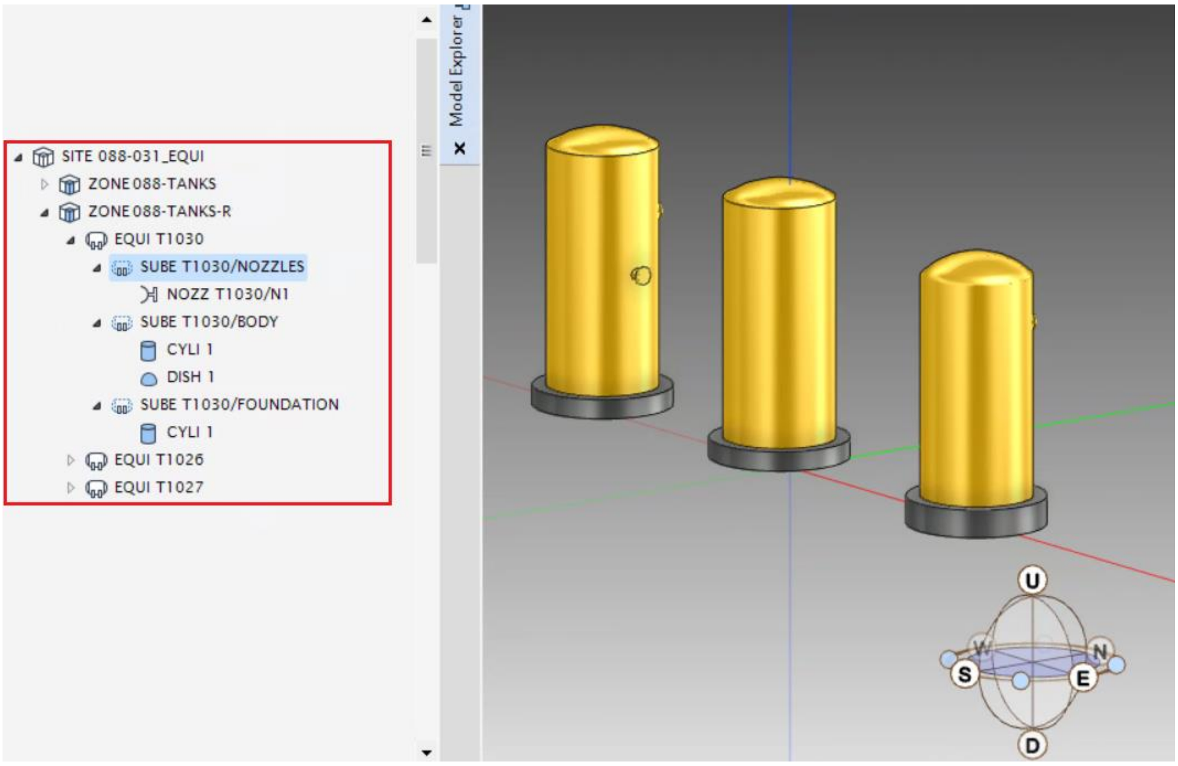

Figure 20. Example of the hierarchy levels in AVEVA E3D

In the case of Figure 20, three simple tank models are modelled. Yellow body of the tank consists of two different primitive shapes: cylinder and dish. Nozzle of the tank is sub-equipment such like the body and it is made with nozzle tool inside the software. Foundation of the tank is modelled grey, and foundation is also its' own sub-equipment, which consists of simple primitive cylinder shape.

3.5.4 Needed calculations and estimates

In addition to the actual layout, also documents with material calculations and estimates and prices are needed. Calculations are made to specific subprocesses of the plant. Calculations varies from project model type and customer. Usually calculations are needed for piping, service platforms and other steel structures. Sometimes equipment insulation calculations are needed, for HVAC in example.

Pipes are divided to straight pipes, bends, elbows, reducers, flanges and other pipe components. Weight, length and quantity of the components are listed. For the service platforms, components calculated are the platform area, handrails, stairs, ladders, hand and knee rails, kick plates and supports structures. Steel structures are used in places such as pipe bridges and in some buildings. Pipe bridge is large part of the process plant, and it is calculated as a separate entity. Calculation process requires resources, since it cannot be fully automated.

3.6 Critical improvement areas

This chapter includes the critical improvement areas in the target company’s current layout design processes. They were found by conducting the interviews and studying the current methods that are used. Some of the topics are not relevant for this thesis, but they are presented so they can be viewed more in depth in later studies. Critical improvement areas that were found were:

- First draft is designed without proper attentiveness
- Layout undergoes too many changes during the quotation phase
- Initial design data is insufficient
- Layout is requested with too short of a notice
- Primitive 3D models of the equipment are missing in the design software
- The geometry of the purchased equipment is not always known
- Standard layout solutions are partially missing in the company
- Material estimation includes inaccuracies

These improvement areas are explained in the following chapters.

3.6.1 Draft layout

One topic, which emerged from the interviews, was the fact that due to urgency, sometimes draft layout may include mistakes. These mistakes can be result of working too fast, without proper review. Mistakes made in the draft layout will carry from quotation to the project phase and then fixing them is more difficult and expensive.

Draft layout refers to general layout with equipment and tank positions, buildings and pipe bridge. Piping, cabling and some service platforms are most likely missing from the first draft. Draft layout is presented in the next chapter 3.6.2.

Fixing the problem would mostly require more time and other resources, which means that this subject will not be directly improved in this thesis, but it is possible that the layout design process could improve in a way that the end result is better. Other possible solution for fixing the issue is by creating a manual for layout design in the quotation phase, where common pitfalls are presented and ways to avoid them.

3.6.2 Layout variability during quotation

The one aspect which was mentioned by nearly everyone who participated to the interview was the fact that the layout undergoes serious changes during the quotation. Which means that the designer must update the model several times and thus also update the needed calculations and estimates. Updates are usually customer-oriented, typically related to desired capacity, equipment and technology, as well as maintenance aspects.

Example of a layout changes are presented in the following figures, where target company's quotation phase lasted approximately six months, in which layout was designed in total of seven times. Figure 21 presents the first layout that was created to the customer inquiry. Only input data that were known at this stage were the technology and the capacity.

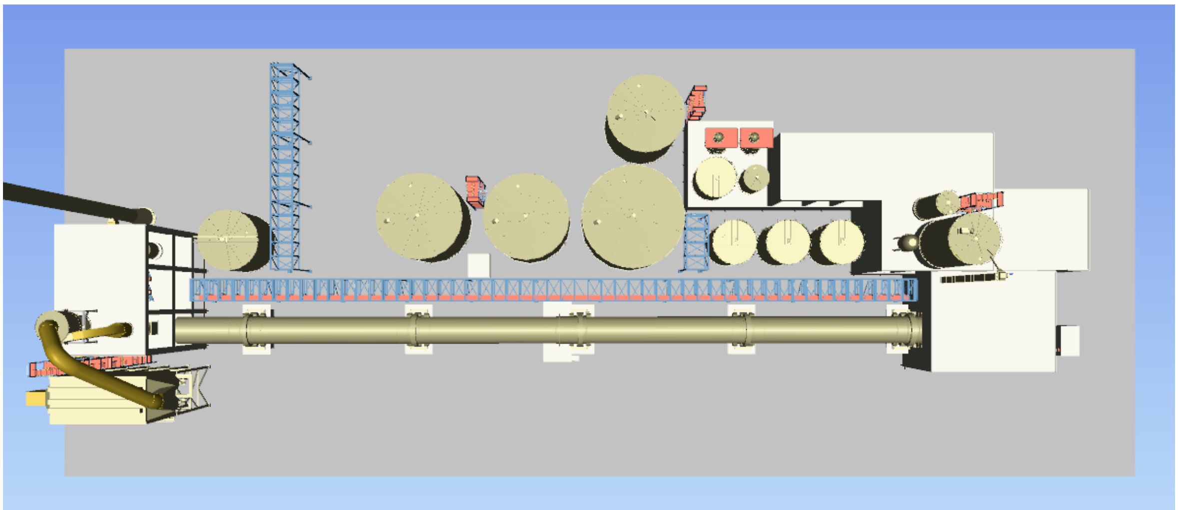

Figure 21. Top view of the first draft layout of the quotation

As it can be seen from the Figure 21, it includes only the equipment and tanks, which are needed for the technology that the target company uses for the process. Equipment and tanks are dimensioned to match the capacity that the customer desires. At this point, there is no customer mill layout available, which means that there is no guarantee that this layout is applicable to the actual site, if the plot is shaped differently for example.

First update to the layout happened approximately two months after the first layout was designed. This is presented in Figure 22.

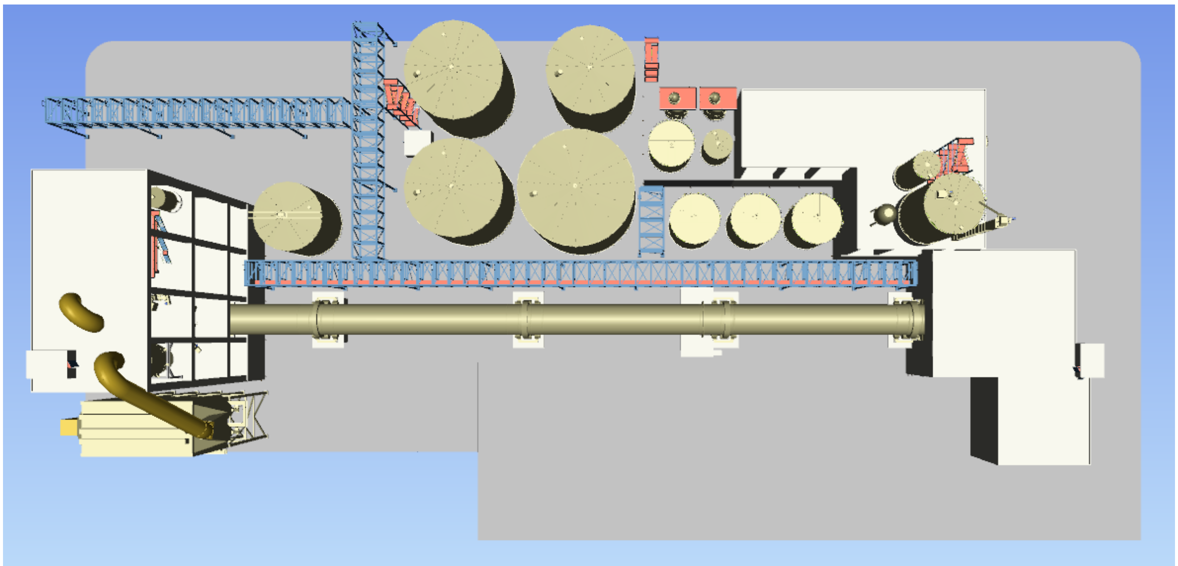

Figure 22. First update to the layout during quotation

As it can be seen in Figure 22, layout changes affected equipment sizes, building size and tank locations. Also pipe bridges were added and plot was refined. The equipment and building size changed due to the change in technology customer wanted. Second update to the layout is presented in Figure 23.

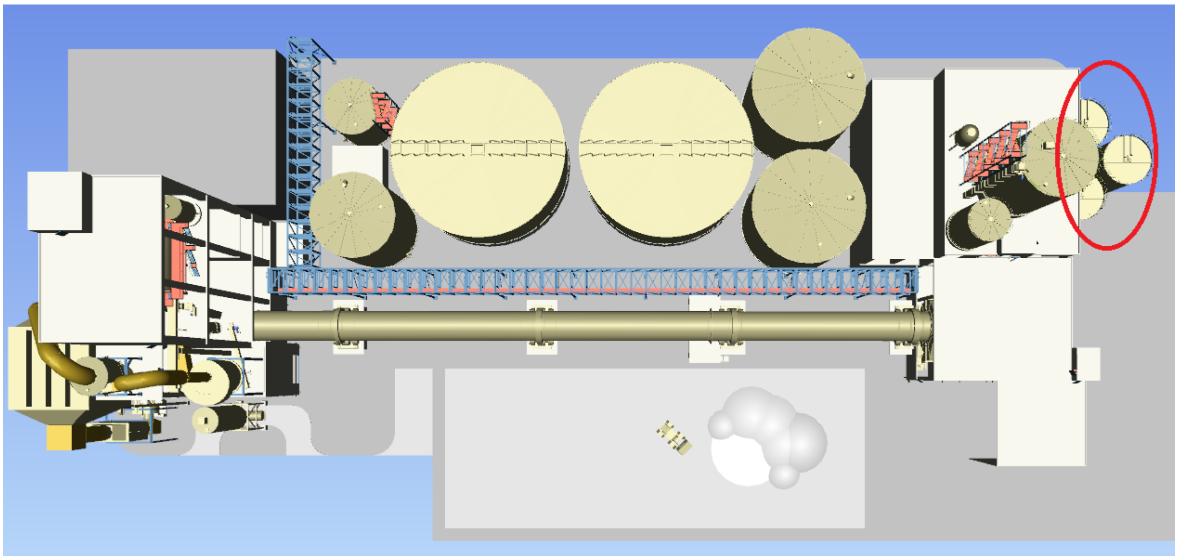

Figure 23. Second update to the layout

As it can be seen in Figure 23, radical changes have occurred to the layout. Space reservation is made to the top left corner, tank area has changed, and plot is reshaped. This is also an example what can happen in layout design, when plot is not big enough for the process. Some tanks in this case do not fit into the plot, they are circled in the figure.

Layout underwent another four updates until the last update was made in the end of the quotation phase. Last update is presented in Figure 24.

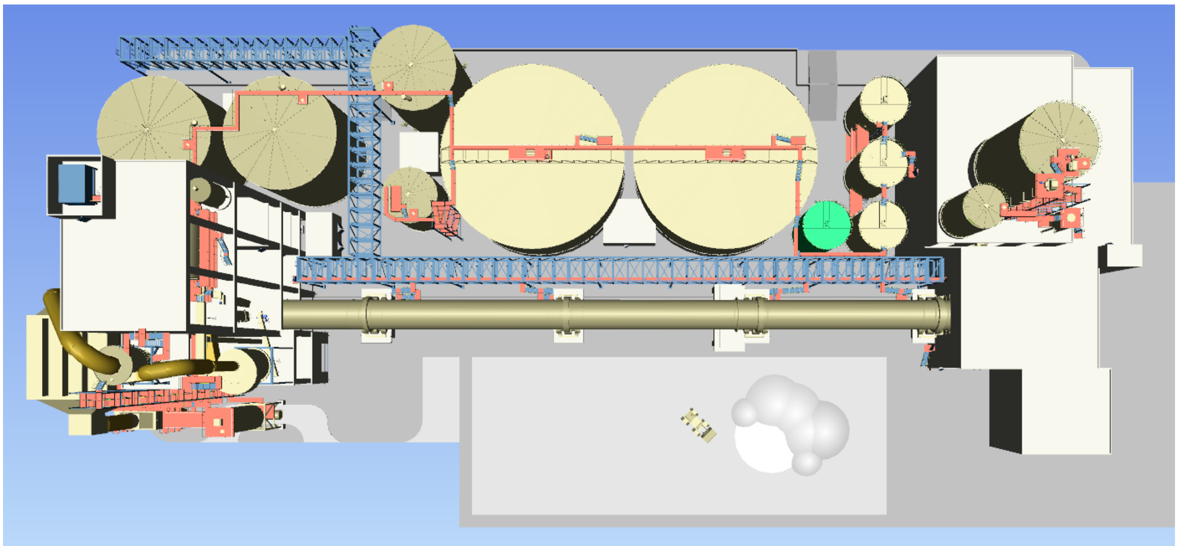

Figure 24. Final layout of the quotation

In the final layout, which is presented in Figure 24, the former space reservation on the top left corner is removed, which made room for tanks and therefore no tanks is no longer outside the plot. Service bridges between the tanks and equipment are also added to the layout, with other details also.

As the previous figure series presented, the layout typically changes a lot during the quotation. Designer must be alert at all times and remember to notify everyone who is involved, when the layout is updated. Also, every time the layout changes, the calculations and estimations must be updated as well.

3.6.3 Initial data and time management

Initial data given at the beginning of the quotation was one theme that could be found from the expert interviews. Many times, the first draft of the layout is needed fast and only data known is the equipment and the plant capacity. Sometimes the general mill layout is not given, or it is available only on request.

Since initial data is almost entirely customer oriented, it is difficult to influence in this thesis and therefore it is not studied more in depth. Solution for that issue could be solved by customer having right personnel present in the negotiations, who would know to ask the right questions as well as provide the needed information.

Time management was a theme which was mentioned by the layout designers. Sometimes the layout is requested with only one- or two-day notice period by the sales personnel. Quotation is structured in a way that the layout needs to undergo severe changes at the last moments of the whole process. Time should be distributed more evenly to the layout design throughout the quotation process. One aspect that could be found from the collected data was the rush, which is sometimes present, due to customer. Multiple quotations need to be handled simultaneously with other possible projects as well. Thus, designers have not had time to learn the new design software. Rush is also one reason why subcontracted engineering is used in the layout design.

While time management is important factor in quotation process, it is often customer and resource oriented, which means that those areas cannot be developed in this thesis and are not studied more in depth. From the company standpoint, one potential contributor could be a manual on how sales project is executed and what are the timeframes that each department needs to accomplish the task. Tasks could also be prioritized based on the affect they have to the preparation of the tender.

3.6.4 Lack of primitive models in the modelling software

As mentioned before, in modelling software AVEVA E3D, equipment consists of general primitive shapes, like cylinders and dishes in example. AVEVA E3D is essentially industry design tool and therefore equipment design in target company is done with other CAD software. Due to rush and other design related reasons, often a STEP file model is used in the layout, since it is quicker to use a STEP model rather than modelled primitive model of the equipment.

Lack of primitive models and use of STEP models is affecting the layout design in terms of design time, since AVEVA E3D does not recognize the equipment STEP model as its own. This means that in piping design for example, the software does not recognize the equipment’s nozzles properly, which slows down the piping design.

In addition to lack of primitive models, the equipment library lacks service platforms of the certain equipment, which means that service platforms need to be modelled from the beginning each time, which increases the design time.

While this is a clear improvement area, it is only fixable by modelling new primitive models of the equipment with service platforms and stop the use of STEP models in layout design. Therefore, this subject will not be studied more in depth in this thesis.

3.6.5 Geometry of purchased equipment

In process plant industry it is almost without exception that every single equipment of the plant is not designed and made by the contracting company. This means that plant consists of equipment which is not company's own. This equipment can be referred as purchased equipment. Different suppliers can have different technology approaches to same application, which means that one's device may not be same size or shape as the other's device. In some cases, the supplier does not deliver a dimensional drawing of the equipment, which can lead to some issues.

Where this could become problematic is when the supplier of certain equipment is not known, but the equipment must be placed into the layout already. If a purchased pump must fit into the certain room for example, it is impossible to know how big space reservation must be made to the equipment. If space reservation is made too big for the application, it increases the material used in the building, piping and so on, which increases the expenses. On the other hand, if the space reservation is not sufficient, the equipment will not fit into the space and modifications need to be made, which also increases expenses.

If supplier does not deliver dimensional drawings and there is no previous history of the equipment inside the target company, the only way is to invest to the layout design in a way that it is robust to the changes that need to be made if equipment will not fit properly. More resources should be used to get a dimensional drawing from the supplier.

3.6.6 Standardized layout

Perhaps the most important factor that experts expressed was the need of standardized solutions for the process plant. While layout is generally designed the way that it follows certain design laws, there still is not specific rule or design model how it should be made. Standardized layout would mean a fully functional process plant, which would include every single equipment, tanks, piping, buildings and so on, which are needed for the process. All of the previously mentioned would be optimized by selected criteria, that could be price for example.

Experts pointed out that having a standardized layout would be beneficial in the quotation, since all the material needed would have been already calculated and thus an accurate pricing would be achieved. Standardized layout would include all the necessary drawings and other related documents, which would potentially make the inquiry of the purchased equipment faster.

Another aspect in standardization is modularization. Experts mentioned that different subprocesses should be modularized in a way that one subprocess would be optimized and calculated, meaning that every pipeline, steel structure and other aspect related to the subprocess would be made into a module.

3.6.7 Material estimate accuracy

Large process plants include a lot of material that needs to be calculated. In certain areas it is difficult to make estimates on how much material is needed for the process and it can cause pricing errors. Experts agreed that the most difficult places to get the estimations correct were in the piping, steel structures and tanks. In seismic areas it was mentioned to be difficult to estimate how much material is needed for the support structures.

Calculations and estimations are one aspect which takes a lot of time during the quotation process, and constant risk of either undercutting or overcharging is present.

4 ANALYSIS

In this chapter critical improvement areas are selected based on the theoretical background of this study, and the most important factors for development are identified so that targets can be developed the best possible way.

4.1 Selection of development targets

In addition to find critical improvement areas in the layout design process, reducing layout design process lead times as well as refining price estimation were part of research questions of this study. Based on the findings made during the study so far, the following improvement areas are being selected to further study, in order to get answers to the remaining research questions:

- Layout variability during the quotation
- Standardized layout
- Material estimate accuracy

Topics are different to one another, but they are linked to each other in a way that they can all be improved by applying singular solutions. These topics are the ones that can be improved by applying the theories which were presented in the theoretical background of this study.

4.2 Improving development targets

In this chapter improvement methods are presented to the layout design, with the aim of reducing layout variability and making material estimates more precise. Development areas are analyzed based on the requirements that are needed, and by using extended SWOT analysis of the traits which methods possess.

4.2.1 Creation of standardized layout

Demand for standardized layout is real and it does have potential to solve multiple development areas, that is why it should be studied more. Standardized layout would benefit the target company in multiple areas in the quotation phase. Standardized layout in this case could mean fully functional plant layout, where every component is included. Standardized layout could also work as starting material layout, where every single component would not be necessarily included. Standardized layout requires lot of resources for the design and management, which is why it should be carefully thought out where it could be utilized optimally.

First, it should be clarified what kind of requirements are needed from the customer standpoint as well as from the target company standpoint. From the customer standpoint, the most important factors that need to happen are produced capacity of the plant and site plot dimensions. If target company does not have a layout solution for required capacity, it is difficult to offer one right away, and if layout solution does not fit to the given plot it would cause difficulties. Other important factor from customer standpoint are the standards to be used. If customer have standards which are not equivalent in the standard layout solutions, it could cause issues. From the company viewpoint, there is demand of resources to both design the layout as well as managing the layout. Design phase would require layout designer, plant-, piping- and process engineer expertise. Once the layout is ready it still needs proper management. Every update occurring in equipment, technology and so on should be updated to the standard layout.

As mentioned before, layout design has restrictions in degrees of freedom, depending of the incoming pipelines and other limiting factors. Because of this variant, it is impossible to claim that only one standardized layout would function the best possible way in every scenario. For example, if standard layout has been created with incoming pipelines coming to the plot from the left side, it is no longer optimized layout if the incoming lines happen to come from the middle of the plot. Another aspect that limits the degrees of freedom besides incoming and outgoing pipelines are number and location of stacks for example. If department has own stack, it will increase degrees of freedom but if flue gases need to be transported to another plot, it requires lot of piping and therefore would limit the degrees of freedom. This being said, there should be more than one standard layout solutions, that would be optimal for different scenarios.

In addition to restrictions in degrees of freedom, material selection can also affect the layout design. Material selection might seem related to project model type, but that is not the case. Since EPS projects require only basic level of layout design, there is no need to create standardized layout solution only for that, because standardized EPC or EPCC layouts can be stripped into simpler design for EPS projects. EPC or EPCC layouts should not have variations between each other, since material optimization cannot be made by only thinking about one aspect. If steel structures are reduced, it will increase the need for concrete structures and total costs of the plant stays the same. Plant layout should always be designed by thinking about the total costs and by trying to reduce them with good design. Material costs are however aspect, which is good to keep in mind, since different countries have different material costs. In seismic areas, steel structures are preferred since they are generally more flexible compared to concrete. Steel structures are also generally faster to assemble, than concrete structures.

Standard layout could potentially have many direct benefits. Layout can be optimized to any criteria wanted, for the most inexpensive price for example. Other criteria's how layout could be optimized can be maintainability, minimizing operating costs or something else. No matter how the layout is optimized, the important thing is the fact that the price of the layout is accurate. Since everything is designed to the very end, there should be accurate information on how much material has been used in any area. Other great benefit of using standardized layout solutions is the fact that it can be quickly provided to the customer. Layout solution can be potentially presented immediately during the first negotiation.

Standardized layout solutions do also have weaknesses that need to be taken into account. Firstly, the standardized layout requires continuing management. Continuous development occurs in almost every department, which leads to new technology and equipment. Technology updates typically leads to changes in equipment geometry, which means that the layout must be updated. In minor equipment updates the layout updates may require only little work, but if technology undergoes major changes, then the layout must be updated in a way that larger entities are redesigned and calculated. Updates in equipment and tanks weight are important issue; if the weight increases, it must be ensured that the supports are sufficient to carry the objects. It can be said that the standard layout is sensitive to changes, so proper management is required. Another important aspect that can be seen as a weakness is the suitability of the standardized layout. It needs to be known that the standard layout solution cannot fit to every scenario. Customer may have restrictions in plot dimensions as well as internal restrictions in pipe bridge size for example. Scalability of a layout is key factor, since plant layout should work with multiple plant capacities. Creating standard layout for only specific mill capacity would be short-sighted, since often capacities are rarely quite exact. Geometry of purchased equipment is challenging in standard layout solutions, as well as in any layout design projects. Since purchased equipment may undergo series of updates as well as any equipment, it is crucial to keep track of the equipment's updates in terms of geometry, if any external changes happen. Other aspect is the criteria how the purchased equipment is selected to the standard layout. If the goal is to make layout solution, which is optimized by price, then the purchased equipment should be selected by the same criteria. Supplier of the purchased equipment may change over time, which may often lead to change in geometry.

Standardization mindset enables opportunities with current modelling software. Price optimized layout solution is typically lacking some optional extras when it comes to comfort for example, but it could have these comfort features hidden. If customer want to add additional rooftop it can be easily added to the layout view, because it already exists in the layout structure. This illustration is presented in the Figure 25.

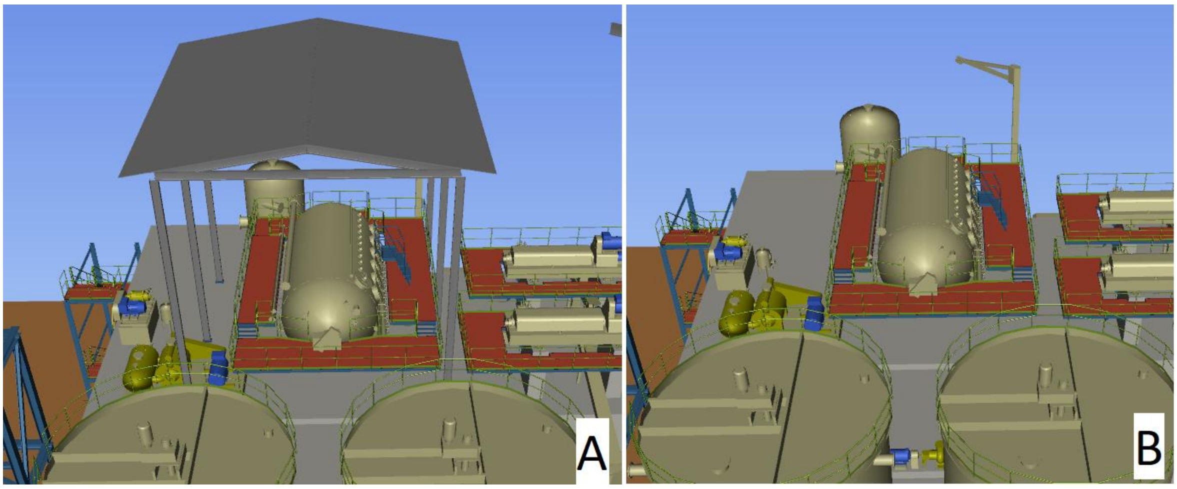

Figure 25. Equipment with additional rooftop (A) and without rooftop (B)

As seen in the Figure 25, the rooftop could be modelled to the actual layout, but the layout can be presented by showing only the version B, especially if the layout is optimized by cost reduction. If customer then decides that rooftop is needed, it can easily be added by enabling the feature in the modelling software.

In the negotiations the standard layout could give the company a competitive advantage, because the layout solution is immediately available for the customer to review. If competitors do not have similar standardized layout solutions, it could give an advantage to the company and work as a benchmark in the negotiations, which can be seen as an opportunity.

Ability to react to sudden changes can be seen as a threat when studying standard layout solutions. Completely blind trust cannot be given to the standardized layout. If it does not fit to the purpose, there must be enough resources to react to the situation. Customer may require changes at the end of the quotation, and it must be ensured that company does have enough resources to design layout without using the standard solution. Another threat to standardized layout solution is the potential trend of customers wanting to invest in tailormade solutions, where they have participated in layout design.

Table 3 summarizes the characteristics of standardized layout using extended SWOT analysis, where factors are divided to existing and potential factors. Unlike traditional SWOT (Strengths, Weaknesses, Opportunities, Threats) table, extended SWOT has eight categories of classification factors.

Table 3. Extended SWOT table of standardized layout solutions

		Inside of a territorial system and its features	Environment and factors influencing development in territorial system		Inside of a territorial system and its features	Environment and factors influencing development in territorial system
Favourable	**EXISTING FACTORS**	Strengths: Available immediately Optimized to criteria(s) Accurate price monitoring	Stimulants: Customers prefer quick solutions	**POTENTIAL FACTORS**	Internal Opportunities: Possibility of optional extras	External Opportunities: Competitive advantage

Table 3 continues. Extended SWOT table of standardized layout solutions

		Inside of a territorial system and its features	Environment and factors influencing development in territorial system		Inside of a territorial system and its features	Environment and factors influencing development in territorial system
Unfavourable	EXISTING FACTORS	Weaknesses: Need for constant updates Suitability Sensitivity	Counter stimuli: Supplier of purchased equipment	POTENTIAL FACTORS	Internal Threats: Responsiveness to change	External Threats: Desire for customer-specific solutions

In extended SWOT, presented in Table 3, existing factors include strengths, stimulants, weaknesses and counter stimuli. Strengths and weaknesses are company's existing attributes where stimulants and counter stimuli are active external attributes. Potential factors include both internal and external opportunities as well as threats.

Target company may approach the standardized layout solutions in two ways; either creating fully functional layout, which is on a par with the layout of the actual customer project, or by creating simpler starting material layout, which would include main equipment, pipe bridge, main pipes and buildings. Fully functional plant layout does include more risks and management than the simplified layout, but the former requires less work in the quotation phase, if it works correctly. Therefore, if decision is made purely for resources, then the better decision is to only make simplified standard layouts. If resource situation is improving, it is possible to continue working with the simplified layouts and make them into fully functional layouts.

Number of standardized solutions should be decided by examining both relevant factors: project location and restrictions it brings as well as general restrictions in degrees of freedom. First it should be studied what are all the limitations in degrees of freedom. Since it is impossible to know every single limitation that could happen, it is best to make assumptions on possible limitations, that has occurred in the past. By studying the recent history of the plant restrictions in degrees of freedom, the main limitations are incoming pipelines, connectivity to another department and location of the nearest stack. Limitations that are location dependent are seismicity and whether the buildings require insulation walls or not. Some of the restrictions happen simultaneously, while some of them cannot happen at the same time. One calculation of possible solutions required is presented in Table 4.

Table 4. Example matrix for determination of standardized layout solutions needed

Pipeline location in relation to the plot	**Left**	**Middle**	**Right**
Stack in own plot / stack somewhere else	2 - 4	2 - 4	2 - 4
Needs to connect to another department	1 - X	1 - X	1 - X
Insulated/Open buildings	2	2	2
Area seismicity (seismic / not seismic)	2	2	2

Table 4 presents an example of possible scenarios, where horizontal axis includes general restrictions in degrees of freedom, where only one scenario can happen at once. Vertical axis includes project and location related aspects, which either may or may not happen. In the example shown in Table 4, the total number of standardized layout solutions needed is large. Stack in this example could be in own plot, or it could be located according to the main air directions. Department in question can either connect to another department, which can be located anywhere in relation to the plot, or there might be no need to connect to any other department. Buildings can be either insulated, which requires walls, or they can be open concept buildings, without walls. Plant can be located either in seismic area, where extra supports are needed, or in location that is not exposed to seismic activity. This table is not applicable to all cases in every process plant’s layout, since there can often be more restrictions to degrees of freedom, than only the incoming pipelines. In this example, vertical row includes only aspects that have been found restricting in target company’s previous projects.

When resources are not sufficient, the layout modelling in target company would require subcontracted engineering. It is not wise to start creating multiple different layout solutions at the same time, it is better to finish one and then according to need continue to develop another layout.

The first standard layout solution should be created by studying recent history and finding out what are the most common restrictions of freedom that has occurred in the past. As seen in the Table 4, there are multiple different plant scenarios that could happen in projects. When it comes to management, there should not be any more than couple of standardized solutions to make everything controllable. The most efficient solution would be to design standard solution in way that location related aspects would both fit into solution. For example, buildings should be designed in a way that walls would fit into them if needed. This technique should be applied for originally open-sided buildings, rather than insulated buildings, because using insulated buildings with walls removed in the warm climate locations, the material costs are increased. This applies especially in locations where wall panels are used for dust protection rather than cold weather. Standard solution should be designed with own stack in its' plot, since it is difficult to estimate where the stack would be if it is in different department's plot. These compromises would reduce the number of needed solutions.

On the other hand, creating simple general arrangement layout would require much less resources and same layout could be potentially used in multiple different scenarios which are project location related. Simplified layout would still work in the quotation phase since layouts are not designed in detail at that point anyway. Simplified layout could also work great as a marketing material.

4.2.2 Modulation inside the process plant

Modulation and standardization go hand in hand; therefore, modulation of different sub-processes or structures require similar resources that standardization requires. Unlike standardized layout solution, modulation focuses to smaller sub-assemblies inside the plant. Before starting the modulation process, it needs to be known what kind of modulation is pursued. As mentioned in the chapters 2.4 and 2.6, there are many different types of modulation.

In this case the target company would not benefit from component-swapping modularity for example, since the desired outcome of modulation would be standardized subprocesses, that could include everything that is related to certain process. This would mean main equipment, auxiliary equipment and tanks, piping, service platforms and other safety related structures.

However, certain structures of the process plant can be modulated using the common modularity types.

Significance of piping and instrumentation diagram (P&ID) is great, when modulating the subprocesses, since P&ID presents the functionality of a process system. One module could potentially be created by one P&ID. Typically larger processes require couple of P&ID drawings, where one presents the main equipment and other presents the auxiliary equipment. Figure 26 presents part of P&ID of a wastewater pumping station, which includes three pumps. In the Figure 26, P&ID only consists of two pumps, other apparatus are presented in the other P&ID drawings.

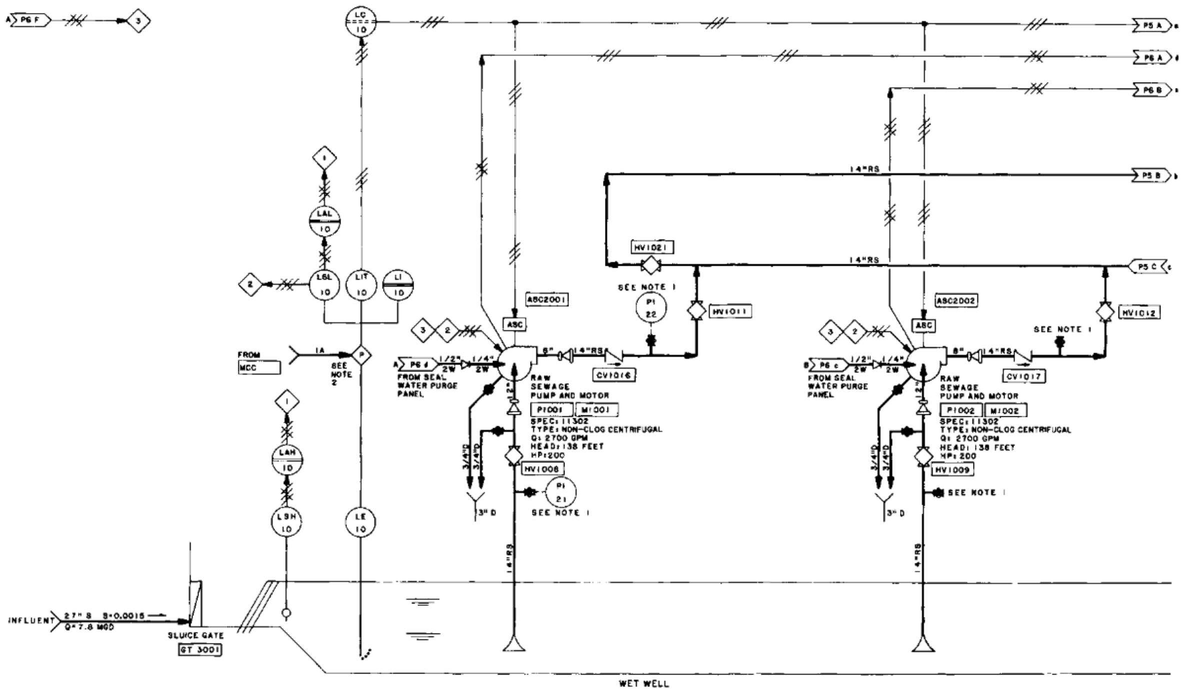

Figure 26. Example of wastewater pumping station P&ID *(Jones, 2008)*

Figure 27 presents a pump room plan of the wastewater pumping station, which includes all three pumps and other auxiliary equipment.

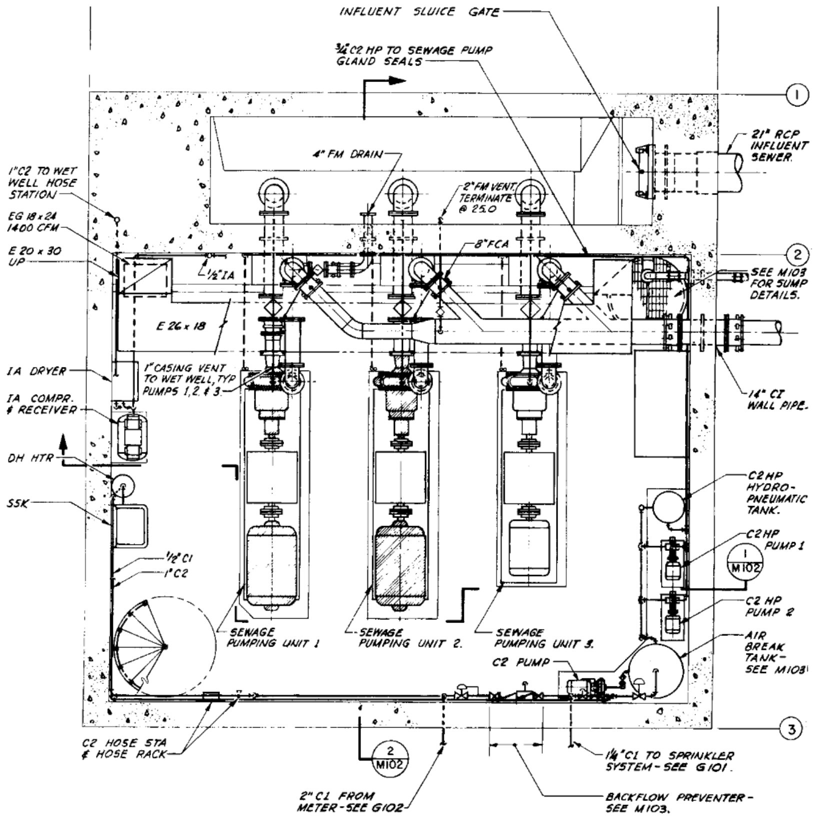

Figure 27. Example of a pump room plan of the wastewater pumping station *(Jones, 2008)*

Creating modules from sub-processes require same resources as any layout design project would, and therefore it needs to be approached with same thought model. Standardizing sub-processes and making them into modules is analyzed by using extended SWOT analyses. Direct benefits gained by modulating sub-processes inside the plant include similar aspects as standardization has, only in smaller entities. These benefits are already mentioned accuracy of the material calculation for example. Modules are mobile, which enables better flexibility in plant design, without affecting too much to the plant as a whole. Modules will also increase the customer satisfaction, since customers could possibly participate in layout design, by turning or relocating the whole module. As presented in the Figure 27, modules should have own 2D drawings, which would present everything that is included in the module. When module is fully designed, there is no need to design service platforms and piping again in the project phase. This saves design time as well as reduces recurrence of errors in design. When the whole block is being designed as a whole, the safety is increased, since service platforms and can be designed knowing where every equipment and pipe is located. Fully designed module has benefits provided by modelling software AVEVA E3D, since it is capable of providing exact information on the weight properties of the piping and steel structures, which makes the material estimates more precise.

Weaknesses in modulation include the number of solutions needed for different capacities, thus a certain staggering is required in order for module to exist. One weakness is the variation of the modules. Whether it is required to have different types of standard modules, or whether only one type of module is needed, where minor changes can be made by utilizing traditional modularity types. While modules are versatile by nature, it still needs to be known that larger sub-process modules will not be suitable to any case without minor modifications.

Modulation provides extensive opportunities both on the design and commercial side. Commercially modulation of sub-processes has very potential benefits especially in EPS projects. Target company could make the modules into a product, which means that instead of providing only equipment in EPS project, a whole module including equipment, auxiliary equipment and tanks, piping and safety structures could be provided. By doing this, the value of the order would be increased.

Threats of modulation include the delivery limit of the supply, especially if scope of supply includes only module products. There is possibility of tight negotiations on who is responsible for objects close to the delivery limit. As in standardization, in modulation as well the capability to react to sudden changes is also threat, if resources are not sufficient. If module does not fit to the certain scenario, there must be enough resources to create solution using traditional methods.

Table 5 summarizes the characteristics of modular sub-processes by using extended SWOT analysis.

Table 5. Extended SWOT table on modulation of sub-processes

Inside of a territorial system and its features	Environment and factors influencing development in territorial system		Inside of a territorial system and its features	Environment and factors influencing development in territorial system

	EXISTING FACTORS		POTENTIAL FACTORS	
Favourable	Strengths: Detailed designs Accurate material information Optimized safety Mobility Saves design time and errors	Stimulants: Customer friendly	Internal Opportunities: Larger value in EPS projects	External Opportunities: Competitive advantage
Unfavourable	Weaknesses: Cannot be built for every possible capacity	Destimulants: Minor modifications always needed to fit the purpose	Internal Threats: Ability to react to sudden changes	External Threats: Probable tight negotiations on delivery limit

In addition to modulating different sub-processes, target company could modulate certain structures inside the plant. One example of this is pipe bridge, where height and width of the bridge could change, based on the capacity of the plant. Larger capacity requires larger piping, which would increase the size of the bridge. Modulation would be based on the history of delivered projects, where largest capacity and pipe bridge width used in it can be located. Pipe bridge was mentioned in draft layout mistakes, where too small pipe bridge was designed to the first draft of the layout, and then it caused issues in later stages when piping design started. Pipe bridge itself is one of the largest entities inside the process plant, which means that its significance in whole plant's material estimation is enormous.

Components included in pipe bridge module should be pipe shelves, cable trays, walking platform and also empty space. Component swapping and component sharing modularity can be utilized in pipe bridge modules. Figure 28 presents an example of how pipe bridge could be roughly designed, when thinking components as blocks.

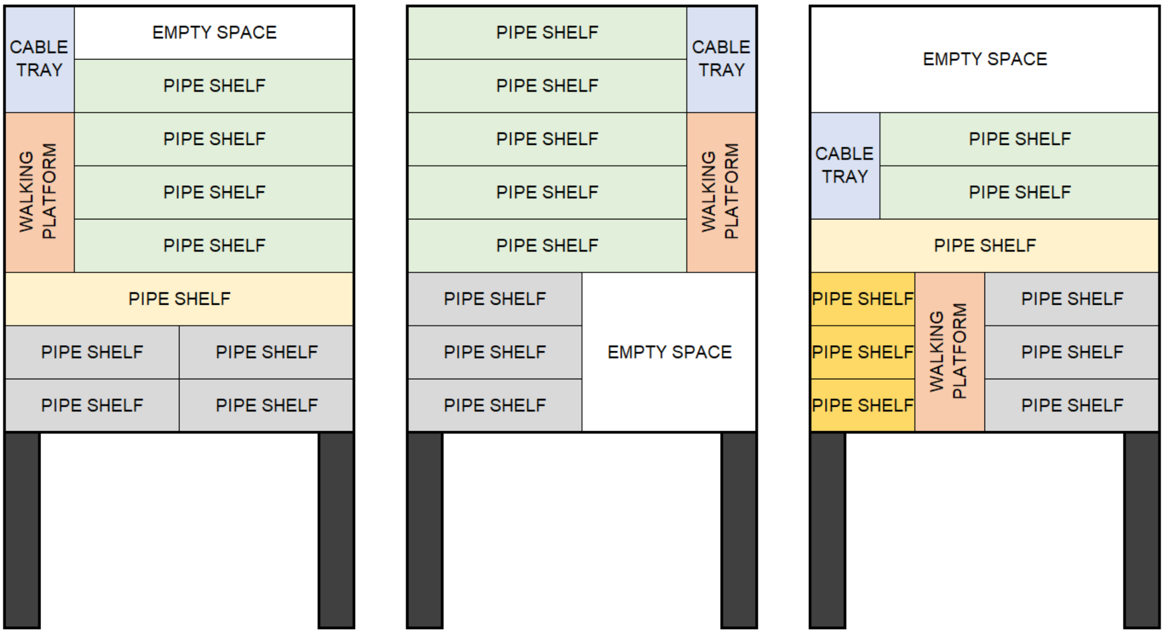

Figure 28. Example of different configurations of pipe bridge components

If the frame of the pipe bridge would be side structures which would always remain the same, the modulation in case of Figure 28 would be classified as component swapping modularity. The width of the bridge could be configurated by the desired capacity and then the bridge could be customized using the modules from customer requests. In addition to example configurations, the walking platform and cable trays can also be located above the bridge, or outside the bridge, as they are in the Figure 29.

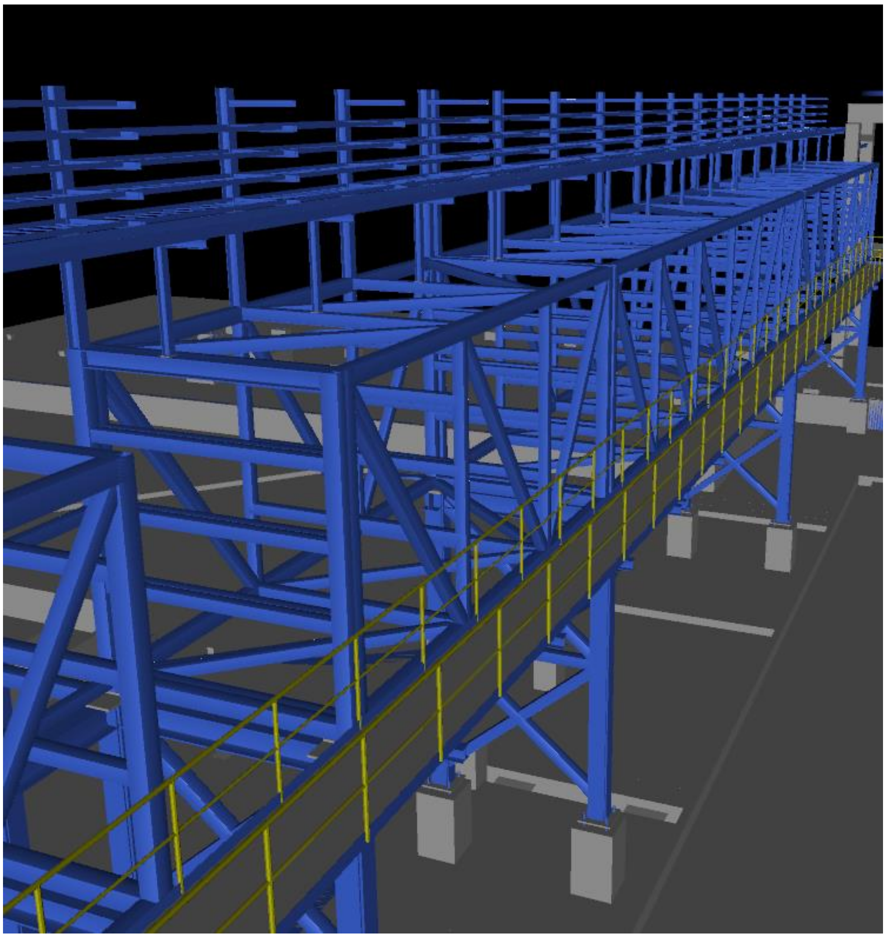

Figure 29. Pipe bridge where cable trays and walking platform is outside the bridge

Walking platform can be easily installed on the side of the bridge as it can be seen in the Figure 29. It is installed without using weldments. In addition to fast installation, it leaves room for piping and empty space in the pipe bridge.

Pipe bridge can be divided into modular blocks, which all are certain standard length long, and the height as well as the width can be changed step by step according to capacity of the plant. Dimensions of the block are presented in the Figure 30.

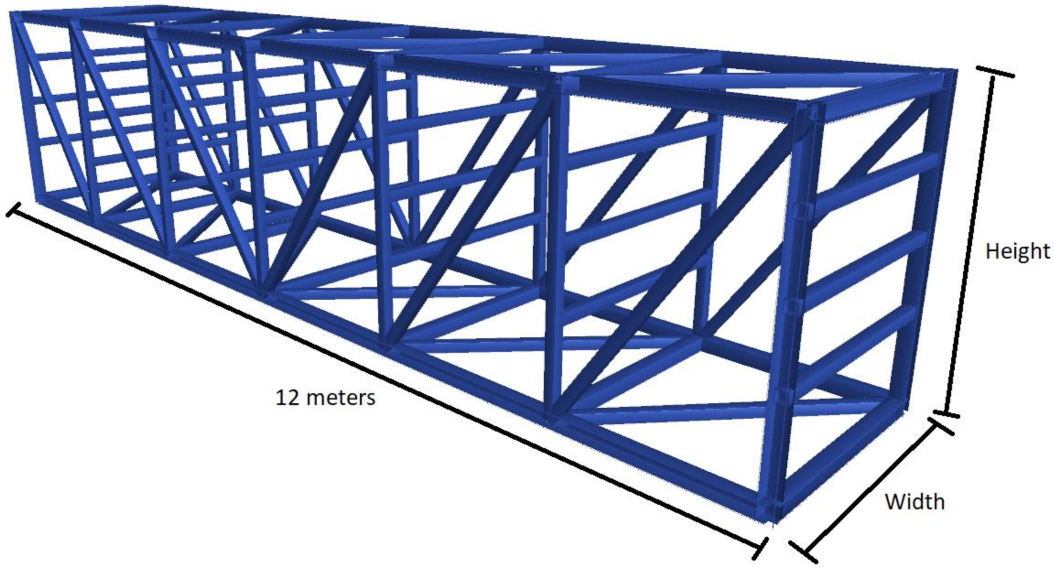

Figure 30. Pipe bridge module dimensions

As seen in the Figure 30, length of the module is set to 12 meters, since length is defined by the gap between the legs of the bridge. Also, length cannot be over the transportation limit that needs to be obeyed. Bridge width minimum dimension could be 2.5 meters and height minimum 3.0 meters. The size would be increased step by step by half a meter.

Pipe bridge modulation brings advantages in two different fields: in the quotation phase and in the assembly phase. In the quotation phase, the first layout draft can already be designed by using pipe bridge blocks. By doing this, the material estimation is significantly easier and faster to do, since blocks material properties have been calculated beforehand.

Pipe bridge is a structure where modulation enables mobility and faster assembly, by prefabricating the modules and then shipping them to the site. Module is built in separate workshop, where every component of the module can be built safely and quickly. The ready module can then be transported to the site, where it is lifted in its' place. Module includes pipe slides, which means that pipes are easily connected. Since module installation can be done quickly, using bolted joints, it reduces the assembly costs. Figure 31 presents a pipe bridge module, where piping as well as cable trays are included.

Figure 31. Pipe bridge block module with piping and cable trays installed

Modular pipe bridge requires attention in design and purchasing departments. In the design, modules must be designed as individual models, as well as the piping, which means that each module has its’ own material list. In the purchase phase, it needs to be noted that the whole pipe bridge consists of several material lists.

Another aspect to be noted in the module design is the strength analysis. When increasing the size of the module, it needs to be made sure that the module carries the structure and weight of the pipes. As with any standard solution, sudden changes can be challenging, which can be seen as a threat to modular pipe bridge.

Table 6 summarizes the features of modular pipe bridge by extended SWOT analysis.

Table 6. Extended SWOT analysis of modular pipe bridge

Inside of a territorial system and its features	Environment and factors influencing development in territorial system		Inside of a territorial system and its features	Environment and factors influencing development in territorial system

Favourable	EXISTING FACTORS	Strengths: Fast installation Installation cost savings Accurate material estimation	Stimulants: Safe assembly	POTENTIAL FACTORS	Internal Opportunities: Modelling may be facilitated	External Opportunities: Competitive advantage
Unfavourable	EXISTING FACTORS	Weaknesses: Management requires work	Destimulants: Road transport limits	POTENTIAL FACTORS	Internal Threats: Ability to react to sudden changes Purchase phase needs extra attention	External Threats: Pipe bridge blocks are not applicable

4.2.3 Material calculation

Generally, there are two different approaches when it comes to calculating the material estimate of structures, those are comparison to previous ones and systematic calculation. First possible approach is rough estimate based on history projects, where weight of steel structures and piping is estimated by studying similar projects from history and seeing what the material masses were then. This is more inaccurate method and it requires executed project history with material information. Systematic calculation means that each pipe, and each steel structure is calculated by hand, meter by meter, using the materials specific gravity. While this is more accurate and reliable method, it requires more time to do so.

The comparison method requires that company has references of similar cases, where material calculation has been done to the finished project. If the references are not sufficient, there is no possibility to make the comparison and therefore it is not suitable method for every company. Similar case does not only mean same capacity, because as mentioned earlier, plant layout can be designed many different ways. Therefore, having only same capacity is not sufficient reference, there must be similar layout and material thickness with the reference project.

Systematic calculation on the other hand can only be done when every single component is designed to the model, which means that in the first drafts in the layout design, the method in question does not work properly. Design software's such as AVEVA E3D are capable of calculating the weights of the structures and piping, as long as the properties of the objects are correct.

There is no one correct way to estimate the material consumption, since it is dependent on resources. Time is critical one, since in the quotation phase, first draft with material estimate and costs are needed. In that case, systematic calculation is out of question. Figure 32 presents a chart of different factors in quotation phase and what method of material estimation should be used in different scenarios.

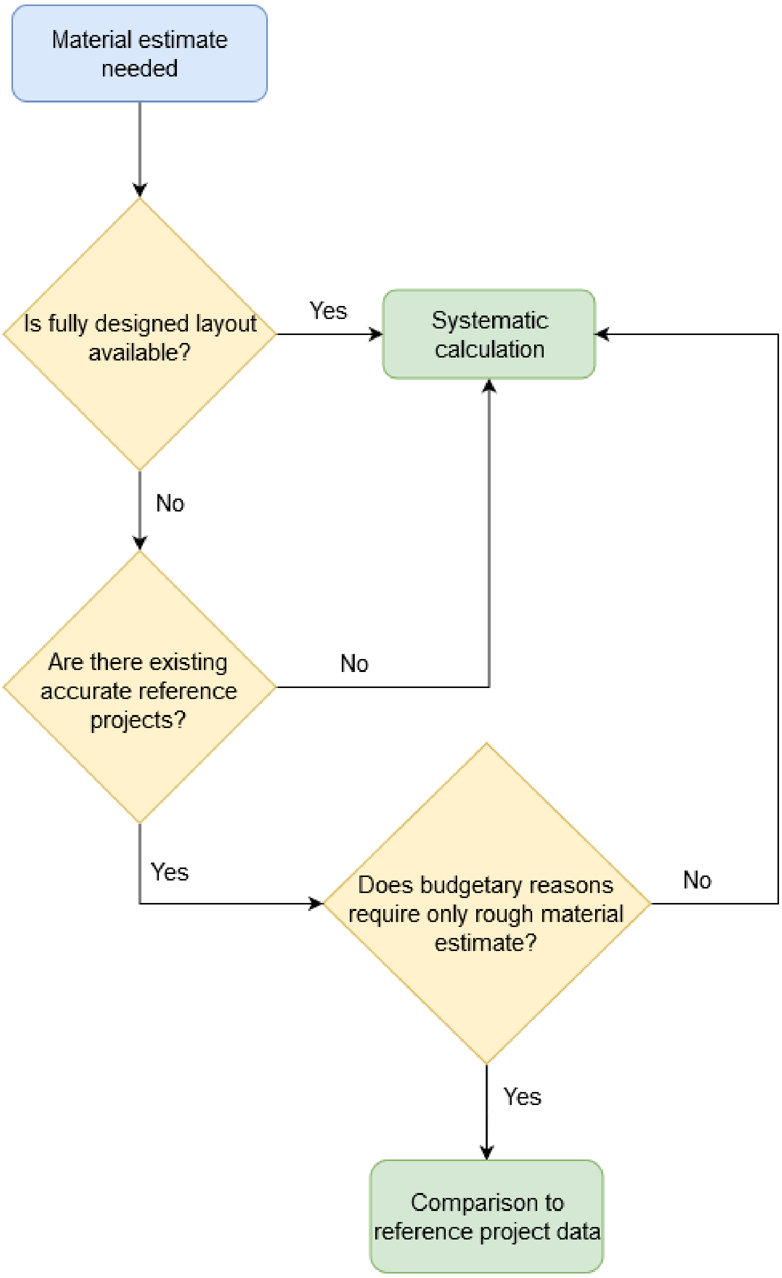

Figure 32. Chart of what method should be used in different scenarios

As presented in the Figure 32, it should be checked first if the layout is fully designed including piping. If that is the case, it is best to use systematic calculation with the help of AVEVA E3D, which produces accurate weight information. If detailed design is not available, then the question is about whether company has reference projects that include material information, and how accurate those are. If accurate references exist, it is better to use them, especially if budgetary situation requires to do so. In potential copy projects, it is definitely better to use reference data, since it is probably even more accurate than the calculation would be.

It can be said that if accurate material information is required or desired, systematic calculation should be done, unless the project is a direct copy of another project, where referencing is better method. Naturally, the quotation phase can be hectic, with multiple different quotations ongoing. Therefore, due to budgetary reasons there are not always enough resources to use calculation method. In those situations, referencing previous projects is a good choice. However, some rough calculations should always be done even though reference method is used, to ensure that the reference is suitable.

4.3 Analysis of the practical proposes

Generally, the improvement methods would all be beneficial for the improvement of layout design lead time as well as the material estimate accuracy. However, some of the solutions require many resources, which makes the development difficult to do in-house, especially if current workload is large.

Creation of standard layout is a method, which would need the most resources, if the layout were designed as fully detailed. There should be at least couple of different layout variations, which means that both design and management of the layouts would require resources that may be overwhelming. Simplified standard layouts require far less design work than fully detailed layouts and they are easier to manage. Simplified layouts include less material information, but with largest buildings, pipe bridge and tanks modelled, material estimate can be formed accurately enough. Based on the variability and customer demands during the quotation phase, the best possible solution with current resources would be to create simplified standard layouts that would include the general arrangement of most important objects in the process plant.

With modulation, the benefits of fully detailed standardized layout can be achieved in smaller areas of the process plant. Productization is crucial benefit of modulating sub-processes, which can potentially bring benefits in increase of the order value. Management of the modular sub-processes require similar resources as fully detailed standard layout, but since sub-process is smaller entity, the management is not overwhelming. Modular structures inside the process plant, pipe bridge for example would benefit the company in both design and assembly. Pipe bridge is also a structure that is significant part of a layout, so making it modular would be recommendable. Summarizing mind map of the development methods and their properties are presented in the Appendix I.

Material calculation is often more accurate when using systematic calculating, rather than using comparison method to previous references, unless the new project is a direct copy of an old project. Multiple different quotations may be running at the same time, which means that due to budgetary purposes, in some projects it is better to use references if it is possible. Modular structures, as well as standard solutions include material information, which means that material estimate can be calculated easily.

Figure 33 presents pyramid that summarizes the needed amount of input for each possible improvement method. Input in this case refers to the resources and workload, which are needed in order to achieve the result. At the bottom of the pyramid, the solution that requires the most resources and work is presented, whereas top of the pyramid presents the improvement solution, which requires the least amount of resources and work.

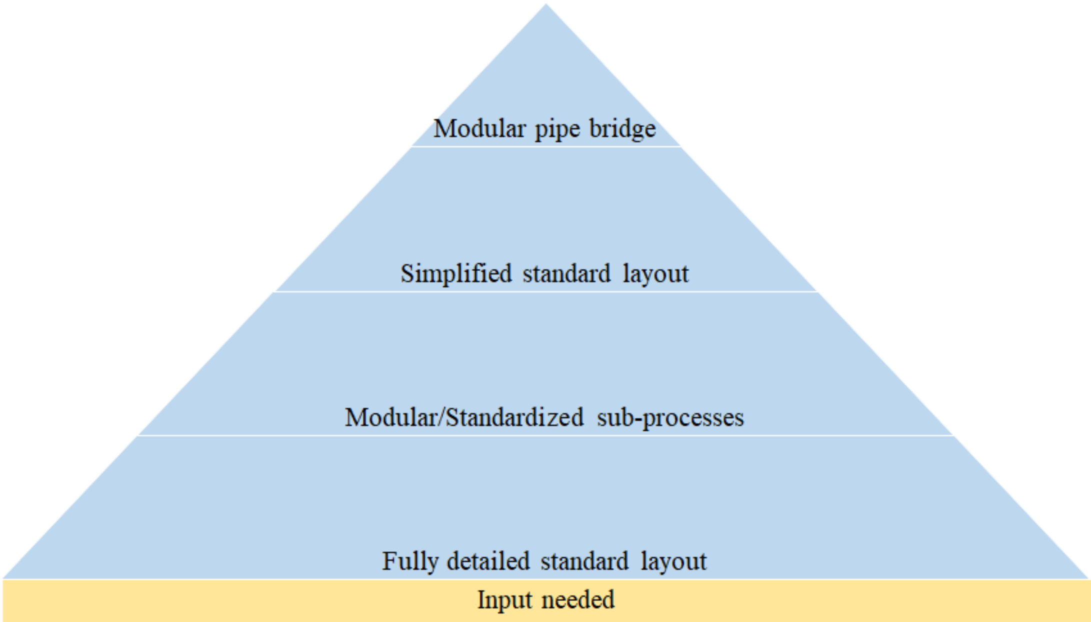

Figure 33. Pyramid of how much input is needed for possible improvement solutions

Modular pipe bridge would be optimal place to start the development of layout design, since it requires the least amount of resources and still brings great benefits. Chain of impact in the Appendix II explain the input, output, outcome and impact of every solution more in detail.

In order to reduce layout design process lead time and to improve the price estimate, best possible solution for target company with current resources is to create simplified general arrangement standard layout solutions, where modular pipe bridge and modular sub-processes are integrated. With this method, the layout design is more manageable, since pipe bridge and sub processes could potentially be placed to the layout from library, with material information included. Other benefit in this method is the fact that both pipe bridge and the modular sub-processed can be both maintained and used individually, without affecting the layout as a whole. If standard layout is not applicable, modular pipe bridge and modular sub-processes can still be utilized, which will still make the design faster and price-estimation more accurate.

4.4 Discussion

Development areas presented in the chapter 3, were found by using semi-structured interviews. Results can be considered reliable, especially for the target company. However, since all interviewees were personnel working for the target company, it can be said that all the areas that prevail in the target company may not exist in every process plant supplier. All the interviewees were personnel with comprehensive experience of the subject, which means that data gathered can be trusted. As the interviewees were not merely layout designers, the end result is not one-sided, where only layout design could be taken into account. To avoid incorrect information, only those aspects that were repeated in the interviews were selected as potential improvement areas. More improvement areas could have been found by iterating the interviews, and by refining questions to a particular area. However, one can be confident that the biggest issues will come up in one round of interviews.

During the study, while conducting the interviews, it turned out that there are several improvement areas, which by improvement could reduce the time used for the layout design process. However, quotation phase is customer-centric, which means that the most critical factor in reducing lead times is the customer itself.

In an ideal world, customer would provide complete input data, which would not change during the quotation phase. Better pilot study of the whole process plant site layout would allow for optimal layout design results immediately, since surprising aspects or changes would not emerge during the design.

Customers and their demands are unique; therefore, it is difficult and does not make sense to try to predict the possible challenges that may occur. More sensible thing to do is to create layout design technique that is able to adapt to sudden changes. Such methods are modulation and simplified standard layout design.

Interesting finding was the importance of time management. Obviously, time management is always going to be challenging factor in the world of projects, but by standardizing the process practices in quotation phase, time management could be improved. Other interesting finding of this study were the by-products which emerged. As a by-product of this study, both productization and assembly benefits came up, which proves that with good design, benefits apply to several areas.

In the future customer needs may change, and plant desirability may be viewed from different perspective. Therefore, following current and future trends in industrial design is definitely something that layout designers should keep in mind.

5 CONCLUSIONS

In this master's thesis, process plant supplier's current methods during the quotation phase were studied with the aim to find areas of improvement when it comes to layout design. Once the improvement areas were found, they were analyzed based on the criticality and whether or not it is possible to be improved by only focusing on layout design. Target company's customers are operators in the international process plant industry, which means that due to location and customer standard, process plant layouts tend to differ from each other. Some of the customers are actively participating to the layout design by presenting own demands and preferences, while some customers do little to address the design.

To find out the possible improvement areas, seven semi structured interviews were conducted. Interviewees were personnel with experience of working with quotations. This worked as a qualitative study. From the interviews it was possible to find repetitive codes, which by utilizing thematic analysis, could be placed into different categories where challenges occur. These categories were time management, input data, layout design, and material as well as price estimation. In total of eight improvement areas were formed, which were mistakes in the first draft layout, layout variability during the quotation phase, insufficient initial design data, too short of a notice when requesting the layout, lack of primitive models in the design software, lack of geometry of the purchased equipment, partial lack of standard layout solutions and inaccuracies in material estimation.

After quick explanation of all the improvement areas, the layout variability during the quotation phase, lack of standard solutions and material accuracy were selected as the most important areas that were linked to the research questions of this study, which were reducing the lead time and refining the price estimation. Altogether four different development methods were presented to improve layout design. Those were modular pipe bridge, modular or standardized sub-processes, fully detailed standard layout solutions and finally simplified standard layout solutions.

Potentially the fully detailed standard layout would fulfill the current needs that exist in layout design. However, it turned out that fully detailed standard layout requires the most resources and in order to have layout solution ready for most of the possible scenarios, many different configurations are needed. This means that while fully detailed standard layout has the most potential benefits, it is the hardest to implement. In this case, it is better to focus on simplified general arrangement layouts, which require far less resources, but still can provide great benefits. Modular or standardized sub-processed based on P&ID also requires fair amount of resources, but still significantly less than fully detailed standard layout would require. Also, standardizing some of the sub-processes require less resources compared to other sub-processes. By splitting the process plant into smaller sub-processes and focusing on those individually enables easier approach to layout development. Modular pipe bridge requires the least resources of all the mentioned methods and is the easiest to implement. Therefore, it is the best method to begin the development process, especially since the importance of the pipe bridge in relation to whole process plant is substantial.

5.1 Future aspects

Digitality has been a trend in industrial design for a while. Process plant design is no different in that field. In the future, it can be assumed that process plant design will utilize the current digitalization tools, such as digital twins to track plant performance. Interactive plant models can help with maintenance planning, which improves occupational safety. With digital plants, the possible disturbances can be located easier, thus allowing for faster repair and shorter downtimes. Maintenance and conservation of the existing models is also an important point, since having accurate models from previous projects is always helpful when references are needed.

In addition to digitality in actual plant models, linkage between design tools is one point that will probably be developed in the future. Increasement of the cooperation of different software’s such as process design and layout design tools, will improve the design for both areas, since information flow is smoother between the two.

Since digitalization features will eventually add another variable into the integration of the process plant, it is better if the integration can be done to a standard solution, so that digitalization does not have to complicate the current design process.

In the following studies, it would be useful to further refine the development methods, that were presented in this master’s thesis and new studies should be made regarding the critical improvement areas, that were not covered in this research.

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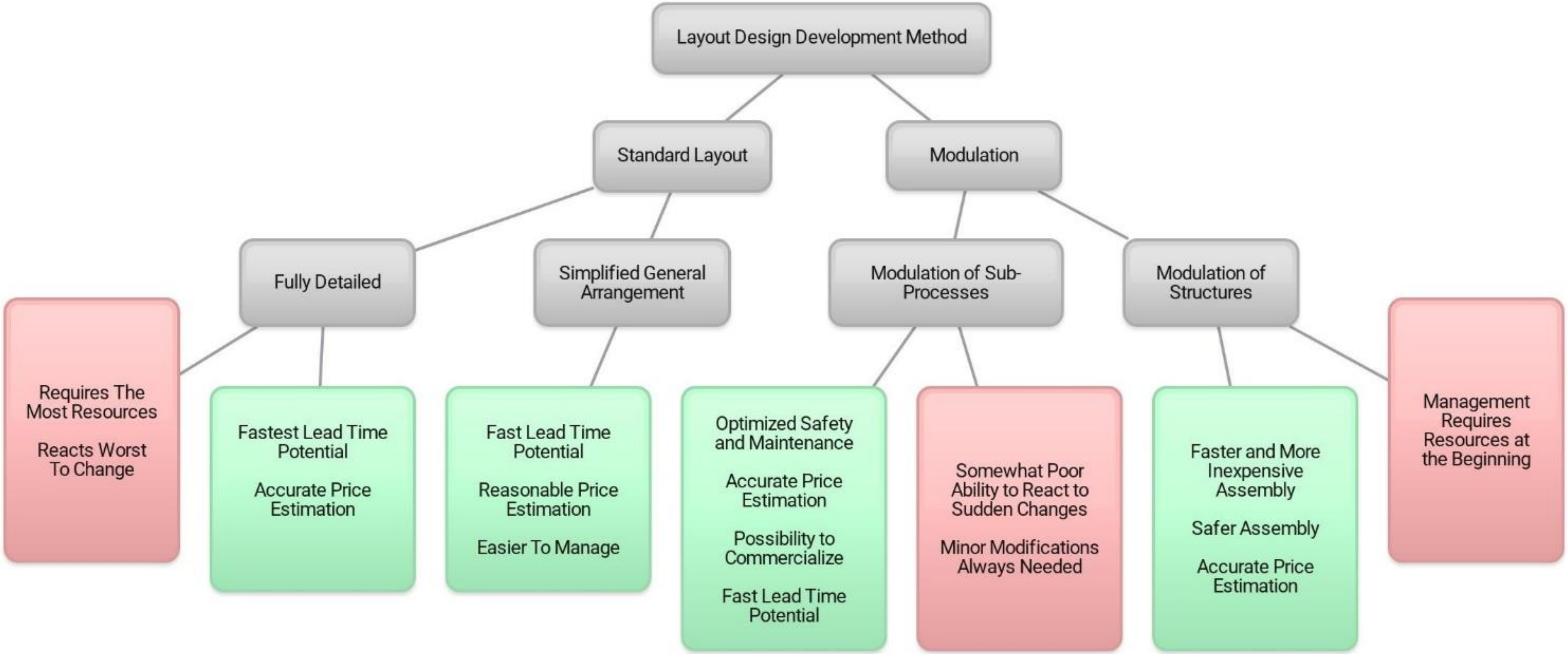
APPENDIX I

Summary mind map of the development methods



APPENDIX 2

Chain of impact analysis of the development methods

	CHAIN OF IMPACT			
	INPUT	**OUTPUT**	**OUTCOME**	**IMPACT**
Modular pipe bridge	**Personnel:** Layout designer **Time needed:** Relatively small amount **Degree of difficulty:** Relatively easy to design, initial investment is required	**Quantitative:** Different sizes of pipe bridge blocks **Qualitative:** Accurate material information of the blocks	More accurate material and therefore price estimation of the pipe bridge Possibility for prefabrication and safer assembly in the site	More accurate layouts from the start of the quotation
Simplified standard layout	**Personnel:** Layout designer **Time needed:** Requires a little time **Degree of difficulty:** Requires knowledge about process plant design	**Quantitative:** One or more simplified layout solutions that can be selected and then detailed **Qualitative:** Good starting point for detailed layout design	Simplified solution(s) for the layout, used as a design boundary in detailed layout design	Potentially reduces the element of surprise during the layout design phases
Modular/Standardized sub-processes	**Personnel:** Layout designer, Process engineer **Time needed:** Requires some time **Degree of difficulty:** Requires knowledge about the process and maintenance of the equipment	**Quantitative:** Standardized modules for different sub-processes **Qualitative:** Accurate material information, optimized safety and maintenance	Optimized solutions for sub-processes, enables the possibility for productization	Faster layout design, better value in EPS projects
Fully detailed standard layout	**Personnel:** Layout designer, Process engineer; AEI Engineer, Civil Engineer **Time needed:** Requires a lot of time **Degree of difficulty:** Requires knowledge from every viewpoint that is needed in process plant design	**Quantitative:** One or more standard layout solution, that can be sold as it is **Qualitative:** Completely accurate material and price information for the whole plant	Optimized solution(s) for the whole process plant	Potentially radical shortening of layout design lead time