Global material supply chain. Procurement database for 3D printing construction projects.

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Abstract

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Title of the thesis Global material supply chain. Procurement database for 3D printing construction projects
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Abstract

This work represents the special research study for a construction company. The main subject of the study is supply chain.

In this thesis I completed three aims. The first aim and the first part of my thesis work was to investigate what is the supply chain, why do supply chains are important, what are the benefits, how to integrate supply chain methodology in construction company, what are the barriers of this integration and how supply chains could be managed.

The second part of my thesis consists of practical research. I was writing my thesis work with Hyperion Robotics company, who are specialized on concrete 3D printing technology. In this part I was creating the supplier database for the public building construction project in Dubai. I was looking for and contacting the suppliers who provide raw materials and products that we use in our 3D printing technology. I gathered all necessary information and created the database.

In the third part I created the estimated project schedule which includes all works and the procurement schedule based on project schedule and logistical details from our suppliers.

Keywords

Construction, 3D printing, supply chain, supply chain management, procurement

Contents

1 Introduction

In the modern world, the construction industry is developing very rapidly. Construction projects becoming more complicated. Also, over time, customer needs are increasing, and the number of construction companies is growing as well as 3D printing companies. Due to this, competition in the construction market is growing strongly. To win in this competitive struggle, many companies enter into construction projects on conditions that are obviously unfavourable for themselves. And since the main goal of any construction organization is to make a profit, then construction companies must reduce the cost of their projects, which leads to a decrease in the quality of the final product.

The supply chain is a methodology that consider the involvement of all its members in a single process. Integration of SCM techniques into a construction project will help to avoid many problems. These problems are related to the quality of materials, terms and conditions of delivery, and communication difficulties between contractors, suppliers, and customers. Another major problem is the cost overrun of materials because of changes in design solutions. There is a wide range of building materials with different features, but 3D printing requires only special materials with determined characteristics. Also, there is a huge market of common construction materials in every country, but there is no special market for 3D printing companies.

According to the SCM methodology, contractors need to establish long-term relationships with suppliers of materials, creating their own base and maintaining business relationships in subsequent projects. This will improve communication between the links in the supply chain and will eliminate many problems.

In this thesis, I will do the research and build a database of material suppliers around the world for specific 3D printing construction company. This research was done in collaboration with Hyperion Robotics. This company was founded in 2019 and is based in Espoo, Finland.

This database will be able to help Hyperion Robotics company to implement its projects more efficiently and with minimum waste of money and time without losing the quality of the final product.

2 3D printing

2.1 3D printing technology in construction

The work of humanity in the field of digital technologies led to the idea of creating objects layer by layer using a printer according to a previously developed model. Throughout history, 3D printing has developed very actively in various areas. But in the construction industry, this technology has appeared relatively recently.

For the first time the idea of introducing 3D printing in the 2000s was proposed by a scientist from the University of South Carolina, Dr. Behrokh Khoshnevis. He developed a system called contour crafting. (Jamie 2018)

In construction, 3D printing is the creation of concrete structures. Despite the centuries-old history of concrete as a building material, 3D printing technology is not as easy as it seems. Concrete is the most versatile building material that is easy to manufacture and cost effective. The main advantages of concrete are strength, durability, as well as the creation of any shape thanks to 3D printing.

The difficulty of working with 3D printing lies in the choice of a suitable 3D printer robot, as well as in the selection of the correct composition of the concrete mixture. Each 3D printer has its own purpose and many features that are reflected in the composition of the concrete mix, as well as on the conditions of its preparation.

Today, there are several technologies for 3D printing in construction.

- Method for selective sintering.
- Spraying method
- Method of layer-by-layer extrusion. This method is used in our projects, so I will tell you more about it. This is the main printing method in construction. The essence of the method lies in the fact that the nozzle of the printer squeezes out the fast-hardening concrete mixture. The characteristics of the mixture, such as the rate of curing, workability, the strength of the finished structure, the required amount of water is regulated by special additives. Each next layer is squeezed out on top of the previous one, forming a certain structure.

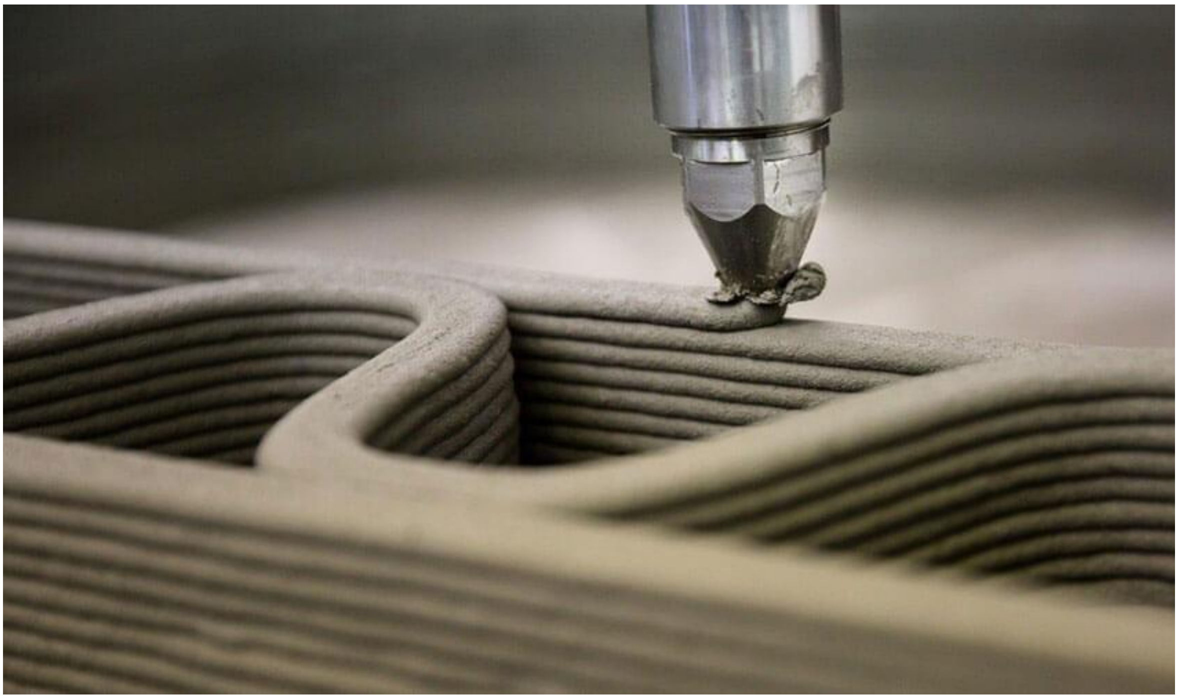

Figure 1. Contour crafting technology (Jamie 2018)

3 Supply chain management in construction

3.1 Communication between project participants

Communication between project participants plays a huge role in construction projects, namely between the customer, contractors and suppliers of materials, and various consultants and logistics providers can also be added to this list. There are 4 types of flows between all these project participants: material, financial, information and service. The essence of the SCM is to combine all these four flows into a single process and manage it. Changing one flow can significantly affect others or even the duration of the entire project. It is always necessary to consider the various volumes of material resources, the time of their delivery to the construction site, the constant change in design solutions. (Vrijhoef & Koskela 1999, 135)

All this requires balanced and regulated work between all departments, which leads to the need to develop a supply chain management system.

3.1.1 SCM. Characteristics, problems, and benefits.

Supply chain management is a concept originated and developed in the industrial sector. The first signs of SCM appeared in 1988 at the Toyota plant as a JIT (just in time) delivery system. This system was intended to regulate deliveries to the Toyota plant in the right small amount at the right time. The main goal was to decrease inventory drastically, and to regulate the suppliers' interaction with the production line more effectively. (Vrijhoef & Koskela 1999, 134)

According to Vrijhoef & Koskela (1999, 135), in the process of evolution, SCM has collected the features of several concepts such as: Total Quality Management (TQM), Business Process Redesign and JIT. Cooper & Ellram (1993, 16) in their study conducted a comparative analysis between the traditional management approach and supply chain management. The comparison was carried out according to 11 criteria. The results are shown in the table below.

Element	Traditional management	Supply chain management
Inventory management approach	Independent efforts	Joint reduction of channel inventories
Total cost approach	Minimize firm costs	Channel-wide cost efficiencies
Time horizon	Short term	Long term
Amount of information sharing and monitoring	Limited to needs of current transaction	As required for planning and monitoring processes
Amount of coordination of multiple levels in the channel	Single contact for the transaction between channel pairs	Multiple contacts between levels in firms and levels of channel
Joint planning	Transaction-based	Ongoing
Compatibility of corporate philosophies	Not relevant	Compatibility at least for key relationships
Breadth of supplier base	Large to increase competition and spread risks	Small to increase coordination
Channel leadership	Not needed	Needed for coordination focus
Amount of sharing risks and rewards	Each on its own	Risks and rewards shared over the long term
Speed of operations, information and inventory levels	"Warehouse" orientation (storage, safety stock) interrupted by barriers to flows; localized to channel pairs	"Distribution center" orientation (inventory velocity) interconnecting flows; JIT, quick response across the channel

Table 1. Characteristic differences between traditional ways of managing the supply chain and SCM (Cooper & Ellram 1993)

The traditional way of managing (as presented in Table 1) is essentially based on a conversion (or transformation) view on production, whereas SCM is based on a flow view of production. The conversion view suggests that each stage of production is controlled, whereas the flow view focuses on the control of the total flow of production.

High technologies such as: 3D printing, 3D modelling, artificial intelligence, VR and AR are gradually being drawn into the construction industry. But at the same time, most construction companies adhere to the traditional approach to supply chain management, which leads to some problems.

The competent integration of the SCM methodology helps to carry out a construction project in accordance with the needs of all its participants. The satisfaction of the project participants with the result of construction can be increased by placing more emphasis on the process of managing the supply of construction materials. (Blaževska-Stoilkovska et. al 2015, 725)

Also, in this article considered the issue of satisfaction of the participants in a construction project with the final and intermediate results of the construction process. In their study, they said that satisfaction cannot be expressed in numbers and that the value of satisfaction received cannot be compared with the value expected, but at the same time, a survey of employees of construction companies showed that when the SCM methodology is introduced into a construction project, the satisfaction of all stakeholders with the final product increases. This article is very useful in some cases and I will refer to it in my further research.

Vrijhoef & Koskela (1998, 5-6) advise their view on the SCM characteristics based on a study of the construction of a residential building. There are four types of SCM.

- Converging supply chain. In this supply chain, documents, materials, etc. are delivered to the construction site by subcontractors and suppliers under the control of the main contractor and always have one end user.
- Make to order supply chain. This chain assumes that the customer takes the initiative in his own hands and is directly involved in all supplies of materials.
- Fragmented supply chain. This characteristic is one of the most specific for the construction industry. In this case, contractors, suppliers, and other participants in the construction are active at different stages of the project and responsibilities change during the project.
- Temporary supply chain. This characteristic is that participants quit after completing their work. Such short-term collaboration can result in reduced productivity.

On the other hand, Muya (1999, 58-64) gives three other characteristics of SCM.

1. The primary supply chain. This includes the materials used in the final stage of construction. Such as sub-assemblies, components, raw materials and electrical and mechanical equipment.

2. The support chain. This chain is responsible for providing auxiliary inventory. This includes scaffolding, supports, sheet piles.

3. The human resource supply chain. This chain is responsible for the provision of measuring instruments and laboratory equipment to the construction site.

Issues which affect to the progress of a construction project (Yeoh & Ning 2002, 253):

- Budget overrun
- Delays in the manufacture and supply of materials
- Low profit - many lawsuits and counterclaims.

Classification of supply chain problems in construction (Cox et al. 2006, according to Al-Werikat 2017, 107):

- Poor public image. The construction industry does not look attractive to highly skilled and experienced professionals. The construction industry is also considered unhealthy and dangerous

- Inefficient methods of construction. This problem is most common in the homebuilding sector
- Poor quality. This problem arises from the simplicity of the rules for entering the construction industry.

3.2 Problems hindering the integration of SCM into 3D printing construction projects.

The integration of SCM into construction can help solve many management problems. The move towards integrating the supply chain into the construction project allows for the full involvement of the entire SCM (Al-Werikat 2017, 108). The benefits of supply chain integration are presented below:

- Risk reduction with a more accurate final project cost
- Cost reduction and waste reduction
- Value for the client
- Ensuring long-term planning
- Maintaining a business relationship with a client or supplier.

The integration of stakeholders into the supply chain is essential for the development of the innovations in the construction industry. In order to implement these improvements, several issues need to be addressed: (Hall 2001, 933-934)

1. When choosing contractors and suppliers, you must first rely on quality and not on cost.

2. Moving away from a contractor/client-oriented relationship to involve all members of the supply chain.

3. Moving from disbanding the team at the end of the project to maintaining relationships in future projects

Five key components for moving to an integrated supply chain (Tan 2010, 13):

- Transformation into corporate culture
- Correct communication and trusting relationships between projects participants.
- Exchange of knowledge and information
- Incorporation of supplier evaluation in the development process

- Sharing common objective regarding both increased efficiency and waste elimination.

In order to implement the SCM methodology, it is vital to get rid of the barriers of traditional relationships in the construction industry and move to a change management framework. These barriers include attributed to an adversarial contractual relationship, lack of trust and fragmented project delivery.

Several ways to address these barriers to supply chain integration (Dainty et al. 2001b, 170-171):

- The formal integration of subcontractors and suppliers regarding reporting and communication with the organizational structure of the project
- Development of communication skills among project participants.

List of barriers to integrating supply chain management (Akintoye et al. 2000, according to Al-Werikat 2017, 108):

- Workplace culture
- Unsuitable support structure
- Uncommitted senior managers
- Trust issues
- Unfamiliar regarding the concept of SCM and its implications.

Vrijhoef (1998, 67-83) evaluates supply chain management in construction with three case studies carried out in Netherlands and Finland. These three studies represent three different supply chains which are analysed separately. These studies provide insight into the problems and waste in modern construction supply chains.

In the first study he calculated a time buffer for a part of the concrete wall supply chain in a residential building. Time buffers were placed between subprocesses, which helped to cope with asynchrony.

The second study presented the problem of identifying and searching for controllability problems in the process chain of composite facade elements of a residential building. In a second study noticed that controllability problems resulted in large losses including temporary buffers.

The third study carried out a quick scan of the impact of trade practices used by the main contractor on material costs. This study showed that the additional logistics costs on site were caused by large and inconvenient materials to handle. In practice, it turned out that these materials were purchased from suppliers at a large discount.

The controllability problems in the second study were observed at earlier stages of the supply chain performed by previous participants.

From these three studies, Vrijhoef (1998, 87-88) drew three conclusions.

Firstly, he believes that even in normal situations, there are supply chain problems.

Secondly, most of the waste and problems are caused by errors at other stages of the supply chain, and not at where they were found, and their true cause is very difficult to find.

And thirdly, waste and problems are caused by non-long-range control of the supply chain. The participants in the chain are not interested in the further stages of the project, they only take the attention of their part.

3.3 Implementation of integration SCM into construction projects

Implementation of integrated supply chain planning is taking place in an evolutionary manner. There are four stages of building an integrated supply chain planning:

Stage 1. Integration of functions in the existing supply chain.

The first step of a company moving to the integration of the supply chain is the improvement of internal processes, the integration of functions within the organization, the introduction of corporate information systems. Almost all aspects of planning improvements are in the area of organizing an integrated planning system in a construction company. When developing the relationships necessary for collaborative planning, nothing can have more serious negative consequences than situations where one party regularly fails to fulfill its obligations to supply chain partners.

Stage 2. Increasing the degree of cooperation with suppliers and customers.

In the next step, the evolution of supply chain integration extends at the cross-functional level. The main focus is on improving the flow of products and services throughout the supply chain. Companies, starting to work on the principles of cooperation, form closer relationships with potential partners and exchange information related to the supply chain. At this level, collaborative procurement planning becomes an important factor as the company recognizes that accurate forecasts are key to effective construction planning and operations.

Information technologies are being introduced for joint planning and forecasting and inventory management, construction planning. However, when organizing such cooperation, the parties need an attractive value proposition, without which it is much more difficult to conclude a cooperation agreement.

Stage 3. Expansion of participants in strategic cooperation.

Business partners are involved in planning a construction company's projects and developing new products and technologies. In general, the use of modern technologies for cooperation and information exchange allows companies and its suppliers to achieve a high level of transparency of the entire supply chain, which results in a reduction in the production time for building materials or raw materials with the required characteristics and effective management of material resources.

Stage 4. Actual synchronization of the supply chain as a single, logically operating enterprise. The next level is theoretical rather than real. It is characterized by the information connectivity of all elements of the supply chain and the development of a network of supply chain partners working together to obtain mutual benefits. This network includes a wider supply chain. A synchronized supply chain ensures self-sufficiency and sustainability. At this stage, the competition is not between the enterprises in the supply chain, but between the supply chains.

The main barriers to the implementation of integrated supply chain planning are:

- The lack of clarity in the implementation by enterprises of their own plans and obligations. In practice, there are cases when a key supplier is able to violate an agreement or take advantage of a situation where certain conditions are not documented
- Distrust of the management of companies to suppliers or contractors and unwillingness to share information with them
- Poor development of information technologies and their application in the construction industry.

3.4 Supplier-contractor relationships

3.4.1 The idea of partnerships

In the research part, I presented a study on creating a database of suppliers of materials needed for 3D printing. The data was collected on the necessary materials based on the experience of previous projects of our company. Such a database is necessary to create a supply chain management system. One of the fundamental features of competent supply chain management is maintaining business relationships with suppliers after the completion of the project. Further I will call this contractor/supplier relationships as partnership.

The main idea behind creating partnerships between contractors and suppliers is to build trust within the supply chain. Such relationships are no longer focused solely on the purchase / sale of goods and services but become mutually beneficial and partnership. This kind of partnership stimulates both parties to develop in order to further be competitive and useful to each other (Compton et al. 1995, according to Vrijhoef 1998,36).

In addition to all the above, the continuous involvement of suppliers in their construction projects improves the quality of the supplied materials and reduces the percentage of waste.

3.4.2 Supply chain collaboration

In the SCM methodology, SCM refers to the phenomenon of cooperation and collaboration between two or more separate firms. SCM members plan and execute specific activities together to improve efficiency, improve production quality, reduce waste and waste of materials and, as a result, get the most profit.

There are two ways to collaborate supply chain members:

1. Vertical collaboration between contractors and suppliers. The most efficient form of organizing the structure of the supply chain. The most common in modern practice. It is also believed that vertical collaboration is easier to implement than horizontal.

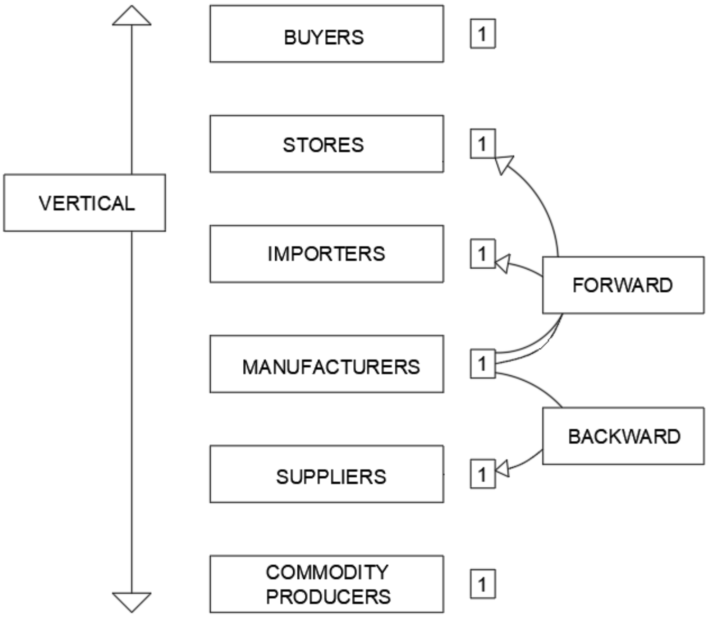

Figure 2. Structure of vertical collaboration between suppliers and contractors.

This diagram shows the direction of flows of information, goods, and services within the supply chain. In vertical collaboration, two or more organizations from different levels of the supply chain exchange resources and information vertically, between levels.

2. Horizontal collaboration. The essence of horizontal collaboration lies in the fact that at each level there are several representatives of this stage.

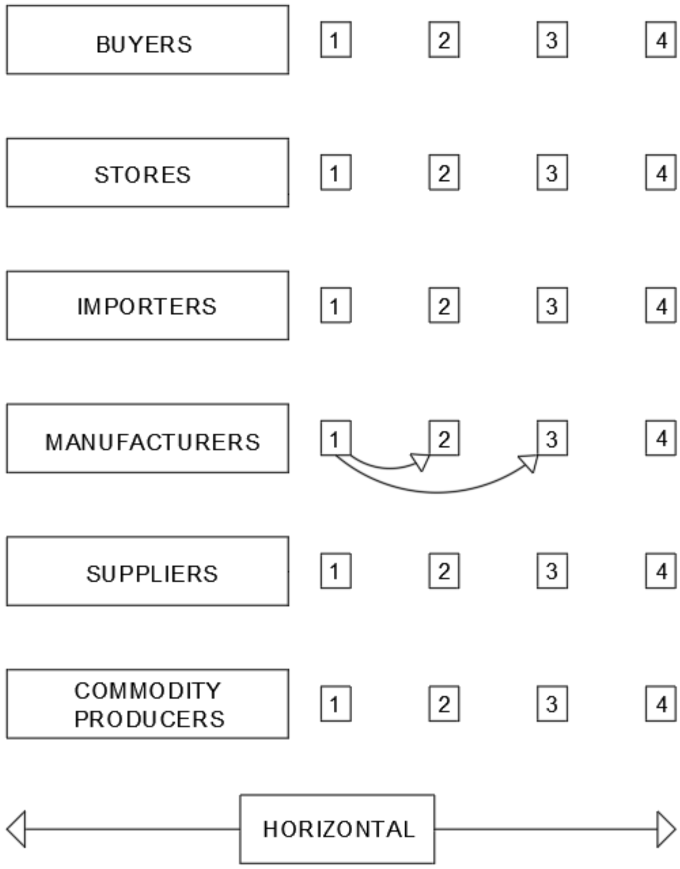

Figure 3. Structure of the horizontal collaboration between suppliers and contractors.

Basically, in the practice of SCM, vertical collaboration is developed type of collaboration, because it is a simpler and more perfect model of SCM.

It is believed that vertical collaboration is the most appropriate way to create and develop a product. Strategic cooperation is achieved through formal and informal agreements. (Renko 2011,185)

Sourcing of suppliers is based on vertical collaboration and depends on factors such as the number of levels in the supply chain and the intensity of supply process.

Four the most common stages of supplier search and selection (Praat et al. 1994, according to Vrijhoef 1998, 37):

- Price-based search criteria
- Selection by quality criteria from suppliers selected at the first stage
- Joint work with pre-selected suppliers at the previous stage to improve quality, logistics and optimize delivery times of materials.
- Integration of suppliers into the project in order to delegate them part of the responsibility for the development of materials and improvement of the rest of the supply chain processes.

Partnerships between contractors and suppliers provide a benefit not only for each other, but also for the end customer. Here are the most important benefits:

- Improved communication between members of the supply chain, as well as a more accurate exchange of information.
- Exclusion of unnecessary, useless actions.
- Balanced storage of materials at the construction site and no overspending of material.
- Material flow improvement.
- Improved customer service, faster production, and delivery of material to the contractor.
- Improved and more accurate planning.

Partnering with suppliers is a very strong strategy. This strategy forces suppliers and contractors to work together to improve product quality and reduce costs, and he says that this strategy will make assembly significantly cheaper by leveraging supplier-developed innovation and expertise in each area. (Lamming 1993, according to Vrijhoef 1998, 37)

To create partnerships between suppliers and subrecipients, it is necessary to move from traditional to team relationships to apply all the strengths and knowledge of the participants in the supply chain. This transition from a traditional system of relationships to a command system implies a rise from a low to a high level.

Low level	Hight level
Lack of fully co-operative attitude	Top level support of integration
Lowest price orientation for supplier selection	Philosophy of total continuous improvement
Supplier has not involvement in design decisions.	Total cost orientation
Infrequent communication	Frequent communication
Inability to see supplier's needs	Formal supplier evaluation programs Early supplier involvement in design of products Empathy with supplier
Inflexible attitude towards suppliers	Multifunctional acceptance of co-operation

Table 2. Levels of supplier partnership (Chadwick et al. 1995)

3.5 Supply chain management

Smyshlyaev (2014) described in his work 5 stages of supply chain management in the construction industry:

Stage 1. Planning.

Potential suppliers are selected as part of this process. Generalization and prioritization of consumer demand is carried out, stocks are planned, logistics requirements are determined, as well as production volumes, supplies of raw materials / materials and construction equipment.

Large construction companies that have their own raw material bases, at this stage decide for themselves whether to produce or buy materials on their own. Decisions related to all types of resource planning and product lifecycle management are also made at this stage. These processes allow you to find a balance between demand and supply to develop a course of action that best suits the requirements of Source, Make, Deliver.

Stage 2. Source.

At this stage, the key elements of supply management are identified, suppliers are assessed and selected, the quality of supplies is checked, and contracts are concluded with suppliers. It also includes the processes associated with the receipt and extraction of materials, such as: acquisition, receipt, transportation, similar control. It is important to note that the actions for managing the supply of building materials and equipment must correspond to the planned or current demand.

Stage 3 Production.

This process includes the production, execution and management of the structural elements of make, implying control over technological changes, management of production facilities (equipment, buildings, etc.), production cycles, production quality, production shift schedule, etc.

Stage 4. Delivery.

This process consists of order management, warehouse management and transportation. Order management includes the creation and registration of orders, pricing, product configuration, and the creation and maintenance of a customer base, along with maintaining a database of products and prices. Warehouse management involves a set of actions for the selection and assembly, packaging, creation of special packaging and shipment of the materials. The transport and delivery management infrastructure are governed by channel and order management rules, flow regulation for delivery, and delivery quality management.

Stage 5. Return

In the context of this process, the structural elements of product returns (defective, surplus, requiring repair) are determined: determining the condition of the product, placing it, requesting a return, scheduling returns, sending for destruction, and recycling. These processes also include some elements of the after-sales service.

4 Our company experience.

4.1 Projects implemented by Hyperion Robotics.

As I mentioned before the research was done in collaboration with Hyperion Robotics. This company was founded in 2019 and is based in Espoo, Finland.

Hyperion Robotics is engaged in 3D printing of building structures. When creating this company, this field of activity was chosen because 3D printing is one of the most promising and developing areas in innovative construction, as well as because the founders of the company had experience in this area.

The company employs 3 people: CEO, structural engineer and project manager.

At the moment, Hyperion Robotics has completed two projects.

The first project was in the Czech Republic. They were engaged in 3D printing of concrete inscription “Budejce” for an art festival. The project lasted 2 months. As a raw material, we used a special concrete mix intended for 3D printing from a BSF supplier. The robot was leased from ABB company. The robot was provided by client.

Figure 4. Concrete inscription in the Czech Republic festival printed by Hyperion Robotics

The second project was in Estonia. Hyperion Robotics built a 3D printed concrete house. This project lasted 2 months too. The raw material was provided by the client. There was a problem with raw materials. The client gave wrong material. Instead of slag they gave wrong admixture. The robot was leased from Kuka company.

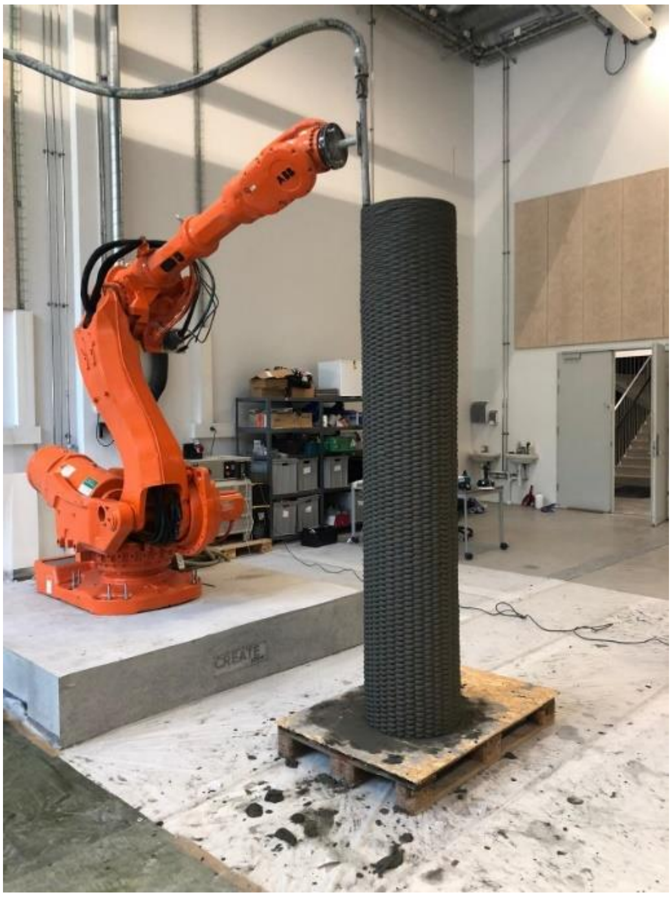

Figure 5. 3D printed concrete column made by Hyperion Robotics

Figure 6. KUKA robot for 3D printing

During this projects Hyperion Robotics bumped with some procurement problems, which were caused by lack of appropriate supply chain management. In my research I will create a database for our next project in Dubai. This database will help to avoid lots of problems referred to procurement and supply chain.

5 Research

5.1 The introduction for the research

In the research, I will compile a database of suppliers of materials used in construction projects using 3D printing technology. This database will be collected for a real project that Hyperion Robotics plans to implement in April 2021. The purpose of creating this database is to integrate supply chain management ideas into Hyperion's construction projects. As well as maintaining partnerships with suppliers operating in the international market for the successful supply of materials necessary for 3D printing in future projects.

This project is the construction of a one-story reinforced concrete public building in Dubai, UAE. Today Dubai is one of the fastest growing cities. And it is obvious that they love to adopt innovative technologies. This also applies to construction. Dubai is one of the top customers for 3D printed construction projects.

5.2 Materials for 3D printing

In this study, I will create a database of suppliers of building materials for a construction project of a building in Dubai using 3D printing technology. Therefore, first it is necessary to figure out what kind of materials are used in the construction of objects using 3D printing and what technical characteristics they should have.

The process of creating building structures and buildings using 3D printing technology is very different from traditional construction. In the process of 3D printing, certain building materials and components are used that are suitable for the construction conditions, as well as those that meet the requirements of a 3D printer-robot.

The cost of construction using 3D printing technology is comparable to traditional construction. However, when using 3D printing technology, special attention is paid to the cement mortar. The most important characteristics of a 3D print mix are:

- Compressive strength (adjustable with additives)
- The setting time of the concrete mixture (a very important parameter for splitting during the extrusion of the mixture of the upper layers of the structure, the lower layers must have time to shrink and gain the necessary strength to withstand the own weight of the new upper layers)
- Shape stability of each printed layer (controlled by additives as well as by a special design of the printing robot)

- Hydration rate (also a very important parameter characterizing the adhesion between the layers of the printed structure)

In addition to the technical characteristics of the mixture presented above, it is important that the mixture is financially economical for the competitiveness of 3D printing technology with traditional construction.

All basic properties of the solution are determined by the printing robot.

5.2.1 Characteristics of mixture components

The basis of the mixture for 3D printing is, of course, cement with pre-selected characteristics. Also, to give the mixture the necessary properties, various additives and fillers are needed to improve the properties of the solution for 3D printing.

Additives greatly change the properties of the solution. The resulting mixture must meet the performance requirements of the final hardened structure. (Pacewicz et al. 2018, 5)

The main characteristics that must be considered when creating a mixture are workability of the mixture, the amount of water required for hardening and the strength of the final product in compression and bending.

Next, I will describe what additives and admixtures which are used in the project and what requirements are presented to them. This list of additives will be the basis for compiling a supplier base.

Based on the experience of previous projects, additives which are used in the concrete mixture: fly ash, silica fume, as well as liquid additives such as plasticizers and accelerators.

1. Fly ash. Fly ash is a coal combustion product that is composed of the particulates (fine particles of burned fuel) that are driven out of coal-fired boilers together with the flue gases.

Fly ash is most used as an aggregate for PPS pozzolanic cement.

Fly ash particles have a unique circular shape and a wide range of particle sizes. It is widely used as an additive for cement mix to improve the workability of the mix. The reduction in concrete shrinkage is proportional to the amount of fly ash used. Improvement the workability of the mixture helps to improve the pumping process. (Pacewicz et al. 2018, 5).

Figure 8. Fly ash (Civil Engineering blog 2020)

2. Silica fume. Silica fume is a finely dispersed powder obtained in the production of metallic silicon and its slabs. This material consists of the smallest spherical particles with an average diameter of 150 nanometres.

This product has found application as an additive to concrete mix. When silica vapours are added to the cement mixture, the smallest particles of the material fill the space between the grains of cement and other aggregates, making the mixture denser. In addition, silica vapours help to improve the workability of the cement mixture while maintaining its viscosity.

Thus, by adding a pair of silica to the cement mixture, we improve the following characteristics of the mixture: compressive strength, adhesion strength and abrasion resistance of the final concrete structure.

Figure 9. Silica fume (Mozgeen 2015)

3. Plasticizers. Plasticizers are special liquid additives that are added to the concrete mixture in order to make it more plastic, reduce viscosity and reduce friction. Plasticizers are a by-product of the paper industry and are made from lignosulfonates.

In concrete technology, plasticizers and superplasticizers are also considered water reducers, that is, with additives, the amount of mixing water can be reduced.

In addition, when plasticizers are added to the concrete mix, they give it better workability and strength.

With the correct amount of water, the strength of the concrete mix is proportional to the amount of added water, in other words, the water-cement ratio. Thus, to increase the strength of concrete, the amount of water for mixing the mixture is reduced, but this entails a decrease in the efficiency and complexity of mixing the mixture, therefore, water-reducing plasticizers are used, which compensate for the loss of the quality of the mixture with a decrease in the amount of water.

4. Accelerators. Accelerators are another liquid concrete admixture. Accelerators, along with plasticizers and retarders, are one of the most popular additives used before or during concrete batching. The addition of an accelerator to the concrete mix reduces the setting time and thus the concrete gains the required strength earlier.

Acceleration of the concrete setting process occurs due to the acceleration of the hydration process.

For construction using 3D printing technology, this additive is especially important because the concrete of the lower layers of the printed structure must have time to gain strength in a short period of time in order to bear the load from the overlying layers.

Pacewicz et al. (2018, 6) in the research present a diagram showing the principles of the composition of mortar mixtures with the required properties. This diagram is based on the existing experience in 3D printing in construction.

The diagram takes into account the various conditions of the construction site, the types of building structures and structures, as well as the criteria and assumptions when selecting the composition of the concrete mixture.

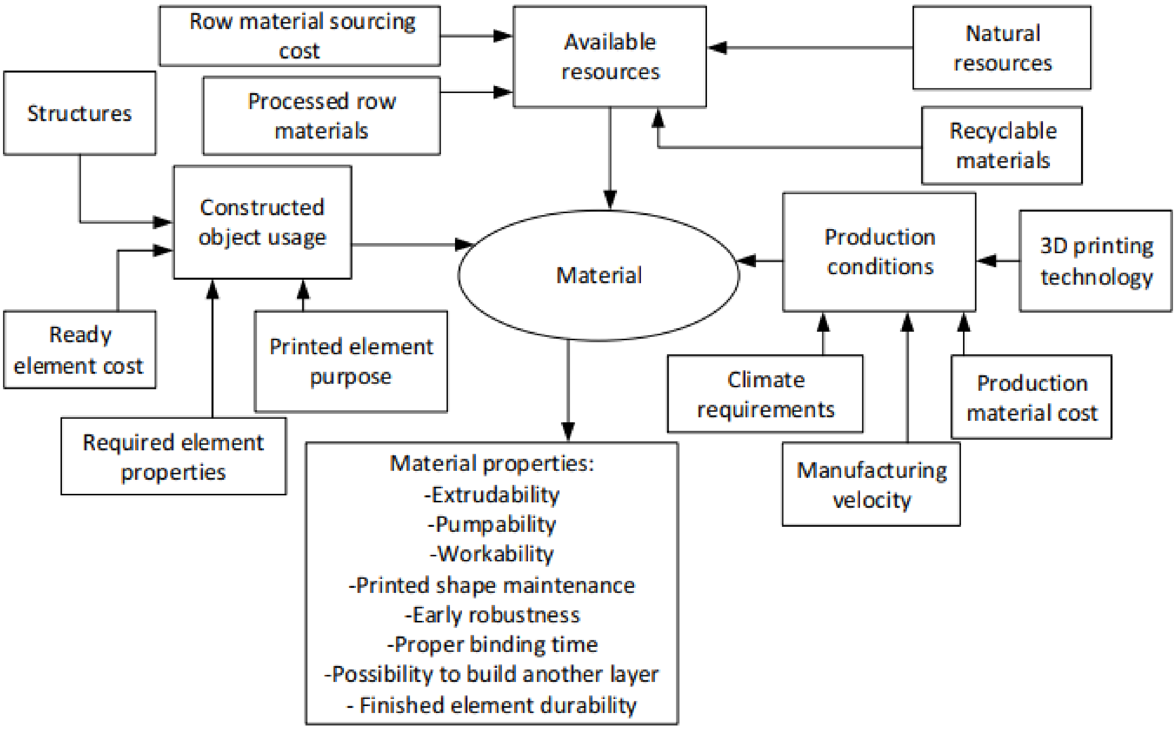

Figure 10. Building material composition for 3D printing and properties requirements (Pacewicz et al. 2018)

Obviously, our mixture also consists of cement and sand. I will explain the specific and requirements of this components in the next chapter.

5.3 Main findings. List of suppliers and what do they offer.

This section will consider the process of creating a database of suppliers of materials in order to implement supply chain management methods in a construction project using 3D printing technology. This database will be collected for a project in Dubai and will help Hyperion Robotics in the further implementation of the project.

Below is a list of materials and components required for the construction of a building using 3D printing technology:

- Cement
- Sand
- Steel rebars
- Silica fume
- Fly ash

- Plasticizers
- Accelerators
- Batching plant

Several suppliers will be represented for each of the materials and components. All suppliers have different prices and terms of delivery, and sometimes materials have different properties and characteristics. At the end of the section, I will present a list of selected suppliers for each of the materials based on their characteristics, terms of delivery and prices.

1. Cement. The cement market in Dubai and the Middle East is represented by a fairly large set of companies, but in this research, are used only those with whom I managed to establish constant communication and obtain the necessary information. One of the problems that was encountered in the course of this work is the difficulty of communication between the contractor and suppliers. Thus, I will collect the database from those suppliers with whom was made a good contact, because communication between contractor and suppliers is the main principle of supply chain management.

Below is a list of cement suppliers and the types of cements they propose.

- Dani trading.

This company is located in the UAE in the city of Dubai. This supplier offers several types of cement.

OPC (class 33) is an ordinary Portland cement with a strength of 33 MPa. This is the least durable cement from this supplier. It is used for all types of civil works in places with normal to moderate environmental conditions. Also, this brand of cement has certain strength limitations, so it is rarely used in projects where high-quality concrete is required.

OPC (class 43) is an ordinary Portland cement with a strength of 43 MPa. It is also used in general construction works, but since it has a higher strength, it can be used in more aggressive weather conditions than OPC 33 and does not have such strict restrictions on loads.

OPC (class 53) - the most durable cement from those offered by the company Dani Trading. This type of cement is used in RCC and prestressed concrete. This grade of cement can also be used for fast construction and high strength structures. These factors are the most important for 3D printing.

PPT is a pozzolanic Portland cement. This type of cement makes the concrete denser and increases its water resistance. In addition, this type of cement is less susceptible to sulphate and alkaline corrosion. He found the greatest application in the construction of water structures.

This is a list of those types of cements offered by this company. For construction using 3D printing, the most suitable brand is OPC 53.

- Rashidco cement.

This company sells the same types of cement as the previous one, however, there are several other types of cement in their range, such as:

White cement is a cement used to create decorative elements in the design of buildings and structures. It has a smooth surface and is white in colour.

PCC - this type of concrete is a pre-made mixture of OPC and fly ash. The addition of fly ash, as mentioned above, gives the concrete greater strength, and reduces the required mixing water.

Thus, here is a choice of two companies providing the required types of cement. In the next section on logistics details, I will compare the terms of delivery of materials and prices for these two companies and choose the most suitable one for the Dubai project.

2. Sand.

The second largest component of the cement mixture is aggregates, namely sand because crushed stone is not used in 3D printing technology.

In my supply chain, this material is represented by one company:

- ADSO

This company is located in the city of Abu Dhabi in the UAE. Oin are involved in the sale of several types of sand, namely white sand, red sand, sea sand and fine sand.

In the process of 3D printing, aggregates play a very important role. The bearing capacity of structures directly depends on the type and size of sand. When choosing a fraction of sand, it is necessary to take into account the specifics and features of the work-printer. In most robots, the nozzles are 40-60 mm thick, therefore the size of the sand particles should be no more than 40-60 mm. Otherwise, the nozzle of the robot could be blocked, which could lead to breakage, or the use of a larger filler could lead to instability of the print structure. When using coarse aggregates, the surface finish of the concrete can be rough.

Thus, fine sand will be suitable for the needs of Hyperion Robotics.

This diagram shows the distribution of the amount of sand particles of a certain size in relation to the total mass of sand.

Test Sieve Size (mm)	Percentage Passing
6.30	100
5.00	99
4.00	92
2.36	59
1.18	35
0.600	19
0.300	9
0.150	4
0.075	2.3

Table 3. Sand particles distribution table

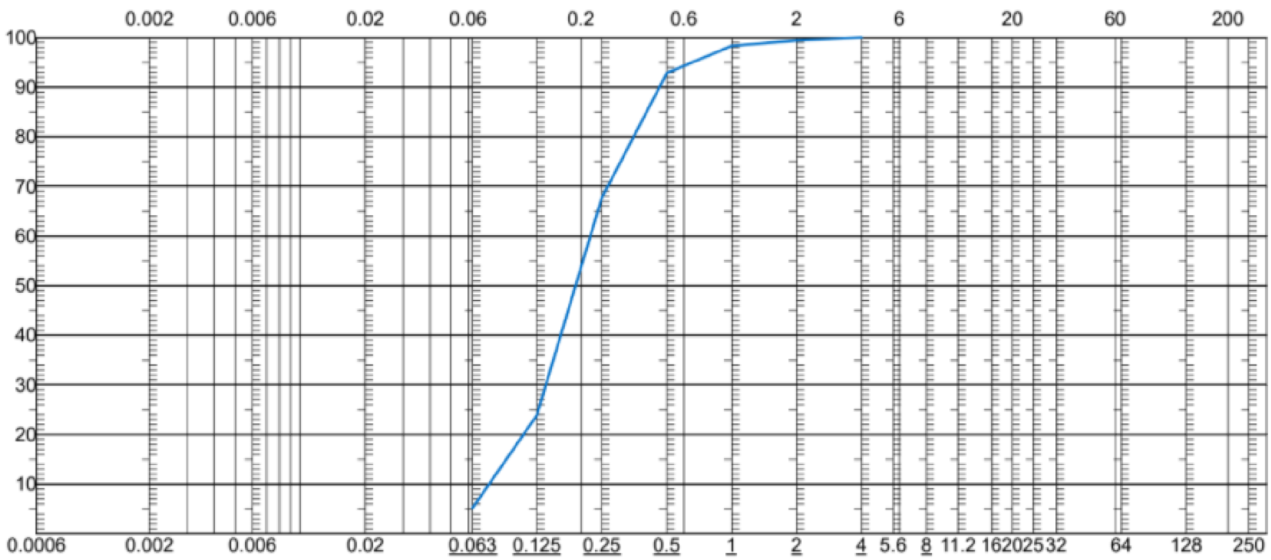

Figure 12. Sand particles distribution curve

2. Fly ash.

There are 2 classes of fly ash on the: class C and class F. These classes are defined and standardized by ASTM C618. The main difference between these classes is the amount of calcium, silicon, aluminium and iron contained in the ash.

In 3D technology, preference is given to class F, because this class increases the temperature of cement hydration more strongly, which will accelerate the setting of concrete.

Fly ash has not very many suppliers in Dubai and Middle East market. Therefore, for the supply chain and supplier database there are not only UAE products. Most developed fly ash market in India. There it is possible to find a wider selection of suppliers who are actively cooperating with contractors from the Middle East.

- Artha mineral resources.

This company is from India. They are engaged in the supply of various chemical additives and buy products. Among other things, they are engaged in the sale of class F fly ash. The chemical composition of the ash from this company is presented below:

Test Name	Test Results	Requirements as per ASTMC618
$SiO_2 + Al_2O_3 + Fe_2O_3$%	81.08	70 Min.
Silica as SiO_2 %	49.49	N.S.
Alumina as Al_2O_3 %	21.58	N.S.
Iron as Fe_2O_3 %	10.01	N.S.
Titanium as TiO_2 %	1.02	N.S.
Calcium as CaO %	8.57	N.S.
Magnesium as MgO %	3.24	N.S.
Sodium as Na_2O %	1.15	N.S.
Potassium as K_2O %	1.10	N.S.
Sulphates as SO_3 %	0.91	5 Max.
Retention on 45 Micron Sieve %	10-15.00 max.	34 Max.
Phosphorus as P_2O_5 %	0.35	N.S.
Chloride as Cl %	Less than 0.10	N.S.
Moisture as MOI %	0.09	N.S.
Loss on Ignition %	1.58	6 Max.

Table 4. Chemical composition of the fly ash from Artha mineral resources

- Daze trading.

This company is located in Dubai, UAE. The company is also involved in the sale of various secondary construction products. They supply class F fly ash with the following chemical composition:

S. No.	Test			ASTM C 618:19 Sp. Limits for Class N	Results
1	Loss on ignition	%	LOI	Max. 10	1.70
2	Insoluble residue	%	IR	-	0.26
3	Silicon Dioxide	%	SiO_2	-	56.6
4	Aluminum oxide	%	Al_2O_3	-	24.7
5	Iron oxide	%	Fe_2O_3	-	3.32
6	Calcium oxide	%	CaO	-	5.25
7	Magnesium oxide	%	MgO	-	1.41
8	Sulfur trioxide	%	SO_3	Max. 4.00	0.54
9	Chloride	%	Cl	-	< 0.001
10	Sodium oxide	%	Na_2O	-	0.26
11	Pottasium oxide	%	K_2O	-	0.79
12	Titanium oxide	%	TiO_2	-	0.14
13	Manganese oxide	%	Mn_2O_3	-	< 0.01
14	Total alkalis as Na_2O	%		-	0.78
15	Silicon dioxide + Aluminum oxide + Iron oxide			Min. 70	84.6
16	Fineness (Retained on 45 microns) %			Max. 34.0	17.0
17	Moisture content %			Max. 3.0	0.17

Table 5. Chemical composition of the fly ash from Daze trading

4. Silica fume.

Silica fume is represented in the supply chain by three companies. All three companies are located outside the UAE. All of the suppliers below provide silica dust standardized for ASTM C1240, which is the main standard for this product.

- Anyang Xinlongsen.

This company is located in China. They are engaged in the extraction, production, and sale of various raw materials all over the world.

They provide silica fume with a particle size of 0.1-0.15mm

The two main parameters that normalize silica fume are the content of SiO2, whether it is compacted or not. For the needs of our organization, unconsolidated silica fume with a SiO2 content of 92% is required.

Below is the chemical composition of the silica fume from this manufacturer.

Analysis Object(%)	Model No.				
SiO2 (Min.)	97	94	90	88	85
Al2O3 (Max.)	1	1	2	--	--
Fe2O3 (Max.)	1	1	2	--	--
CaO+MgO (Max.)	1	1	2	--	--
K2O+Na2O (Max.)	1	1.5	2	--	--
C (Max.)	1	2	2	2.5	3
NaOH (Max.)	1	3	3	4	4.5
PH (Max.)	4.5~6.5	4.5~7.5	4.5~7.5	4.5~8.5	4.5~8.5
Size above 45um (Max.)	3	3	5	8	8
Moisture (Max.)	15				
M2/g (Max.)	1	2	2.5	3	3

Table 6. Chemical composition of the silica fume from Anyang Xinlongsen

- Superior.

This company is also from China.

This company specializes exclusively in the production and sale of silica fume. Their assortment includes pressed and unconsolidated silica fume with a SiO2 content of 85%-96%.

Below is the chemical composition of silica fume with a SiO2 content of 92%

CHEMICAL & PHYSICAL ANALYSIS		
SILICA FUME	UNIT	RESULTS
SiO_2(Silicon Dioxide)	(%)	92.46
Fe_2O_3 (Iron (III) Oxide)	(%)	1.21
Al_2O_3(Aluminium Oxide)	(%)	0.4
CaO(Calcium Oxide)	(%)	0.59
MgO(Magnesium Oxide)	(%)	1.17
K_2O(Potassium Oxide)	(%)	1.21
Na_2O(Sodium Oxide)	(%)	0.55
LOI(Loss on Ignition)	(%)	1.69
Cl(Chloride)	(%)	0.002
C(Carbon free)	(%)	0.51
H_2O(Moisture Content)	(%)	0.29
P_2O_5(Phosphorus Pentoxide)	(%)	0.05
SO_3(Sulphur Trioxide)	(%)	0.29
Autoclave Expansion	(%)	0.007
Total alkalis	(%)	0.61
PH Value	(%)	6.95
Accelerated Pozzolanic Strength Activity Index with Portland cement(7 day)	(%)	119

Table 7. Chemical composition of the silica fume from Superior

- KFA

This company is from Kuwait. They specialized on production and selling silica fume. They sell silica fume with SiO_2 content 85-90%. For our concrete technology we use silica fume with 92% SiO_2 content but despite this, KFA was added to Hyperion Robotics' supply chain database for the future partnership.

5. Liquid additives.

From liquid chemical additives we need plasticizers and accelerators. These are one of the main additives most used in construction, designed to increase the strength of concrete, accelerate hardening and improve the workability of the mix.

Unfortunately, the market for liquid cement additives in the UAE is not very wide. There will only be one supplier of these materials in the supply chain.

- Fosroc

This company is located in Dubai, UAE. They are engaged in the production and sale of many concrete additives. Including plasticizers and accelerators.

Sprayset HBL 42 was chosen as an accelerator. This accelerator is an alkali-free admixture used in concrete where rapid setting is required. Setting time and hardening time can be regulated by the dosages of Sprayset HBL 42.

Sprayset HBL 42 advantages:

- Alkali-free, thus improving working environment.
- Low dust emission due to liquid form.
- Rapid set allows thick sections to be built-up.
- Minimum rebound.
- Excellent for overhead application.
- Can be used for 'wet and dry' processes.
- Non-flammable.
- Accurate dosage possible

As a plasticizer was chosen Conplast SP430. This plasticizer is used:

- To provide excellent acceleration of strength gain at early ages and major increases in strength at all ages by significantly reducing water demand in a concrete mix.

- Particularly suitable for precast concrete and other high early strength requirements.
- To significantly improve the workability of site mixed and precast concrete without increasing water demand.
- To provide improved durability by increasing ultimate strengths and reducing concrete permeability.

6. Steel rebar.

Steel rebars is the latest building material used by our company in this project.

The supply chain will have 2 suppliers of companies:

- Union rebar.

This company is from the city of Abu Dhabi, UAE. They are engaged in the production and sale of various types of rebars. In our case, reinforcement BS4449, 500B with a thickness of 19 mm is required. They also prestress the rebars, which is very important for 3D printing technology.

- Jabal Al Noor.

Another company from Dubai. They are engaged in the production and sale of various types of steel products and, like Union Rebar, are ready to provide us with the necessary rebars.

7. Batching plant.

The last position in our supply chain is the mixing plant. It will be installed in the 3D printing production facility and usually consists of the following parts:

- Concrete mixer
- Aggregates batcher
- Weighing system for water, cement, additive
- Fully automatic / semi-automatic control system
- Cement silo. Better when there are several
- Screw conveyor. It is also better when there are several of them in stock.

The main parameters are the capacity of the mixer and the productivity per hour.

There will be 3 mixing plant companies in our supply chain.

- Aimix group.

This company is from China. They provide everything we need for the above equipment. The plant they offer is called AJ-25 with a capacity of 25 m3 / h. The machine has 3 * 50T cement silos and 3 screw conveyors 8m * 219 as well as twin shafts concrete mixer.

Aimix Group provides assembly services for this unit.

- Elkon.

This company is located in Dubai, UAE. They offer ELKOMIX-135 mixing plant with a capacity of 120m3 / h. This unit consists of: Aggregate Inline Storage Bins (4x20 = 80 m^3), Aggregate, Water, Cement and Additives Scale, Twinshaft Mixer, Operator's Cabin and Control Panel, Cement Screw (Ø273) * 2, Cement Silo (100 tons) * 2.

This company does not provide assembly services but provides all the necessary instructions.

- D1.

This company is also from Dubai. They provide a Moby Mix 750 plant mixer with a capacity of 30m3 / h. It consists of: Aggregate Bins STAR type 4 bins 22m3 Total, scales for aggregate, cement, water, and additives, 2 cement silos and Operator's Cabin and Control Panel.

This company does not provide services for assembling the installation but provides control and instructions.

5.4 Logistics

5.4.1 Logistics in construction

Construction logistics is the process of planning, implementing, and controlling supply chains from the production of materials and raw materials to the end point of supply. A very important detail is the management of logistics processes since this has a positive effect on costs and delivery times. Thus, competent logistics guarantees the timely delivery of materials to the construction site, or in our case to the production laboratory, and as a result, the implementation of the project in accordance with the approved schedule. (Designing building 2020)

Two situations can negatively affect the construction process:

- When there are not enough building materials in the required volume.
- When building materials are in abundance.

The latter situation is especially undesirable if the construction is carried out once.

In this regard, the main task of the logistics system in the construction industry is the systematic management of all types of commodity flows in economic systems.

Thus, the properties of the logistics building complex can be distinguished by other parameters, such as periods of investment development, phases of the life cycle of construction products.

5.4.2 Logistics details in Dubai project

In this section, I will describe the conditions for the supply of materials and products from each supplier and choose the most suitable option for the Dubai project. This information about suppliers will be presented in the form of a table with data on the delivery time, packaging, and minimum order quantities.

Company	Country	Material	Delivery time	Minimum order
Dani Trading	UAE	Cement	12-24 hours or according to requirements	1000 bags or 100 bags (1 bag=50 kg)
Rashidco cement	UAE	Cement	12-24 hours or according to requirements	50 tons
ADSO	UAE	Sand	12-24 hours or according to requirements	75 tons
Artha mineral resources	India	Fly ash	10-15 days	28
Daze	UAE	Fly ash	This company does not provide delivery	35
Anyang Xinlongsen	China	Silica fume	10-15 days	16
Superior	China	Silica fume	33 days	24
KFA	Kuwait	Silica fume	7 days	No information
Fosroc	UAE	Plasticizers and accelerators	1 day	5 L
Union Rebar	UAE	Rebars	1-2 days	40 tons
Jabal Al Noor	UAE	Rebars	1-2 days	No information
Aimix group	China	Batching plant	50-55 with assembling	1
Elkon	UAE	Batching plant	30-35 with assembling	1
D1	UAE	Batching plant	30-35 with assembling	1

Table 8. Supplier database for the Dubai project

Then I made a choice of one supplier for each material and product. This selection was considered the indicators presented in the table above, as well as the prices. The price of materials is confidential information, so there is no information about it in the database, but it was taking into account when selection was made. In addition to the price, the main selection criteria were to ensure the uninterrupted operation of the 3D printer, while it is necessary to take into account the warehouse limits. The results are shown in the table below.

Material	Company
Cement	Dani Trading
Sand	ADSO
Fly ach	Artha mineral resources
Silaca fume	Anyang Xinlongsen
Steel rebars	Union Rebar
Plasticizers and accelerators	Fosroc
Batching plant	Elkon

Table 9. Selected suppliers for the Dubai project

5.5 Operations and project schedule

5.5.1 3D printing operations

In this chapter I will describe the main stages of a construction project using 3D printing technology.

In general, 3D printing of concrete structures is carried out in 3 stages: creation of an information model of a building or structure, selection of the composition and production of concrete mixture and printing of an object (Bos et al. 2016, according to Nadarajah 2018, 19).

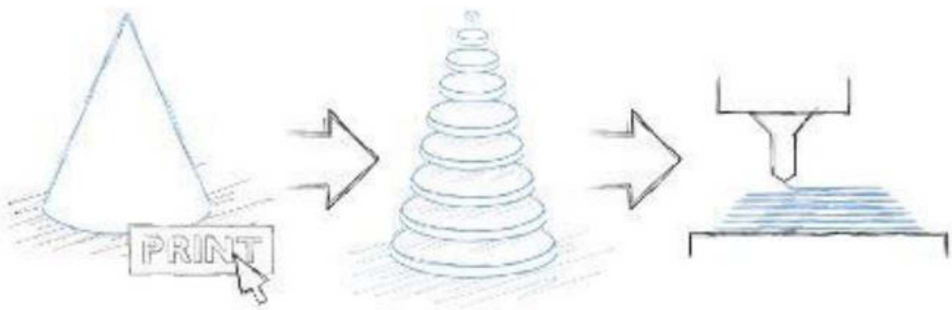

Figure 13. Stages of 3D printing (Nadarajah 2018)

The creation of an information model implies the creation of a 3D model of an object in a special CAD format. After that it is necessary to cut the created 3D model into layers in a special program. This program creates a plan for a 3D printer.

The next step is to create a concrete mix and feed it to a robot printer. The preparation of the concrete mix takes place in mixing plants. Concrete supply to the robot can be done in two ways.

1. The concrete mixture is prepared in special measured volumes and loaded directly into the container of the 3D printer.

2. Continuous feeding of the mixture.

The last third stage. The concrete mixture is squeezed out through the nozzle in layers according to a predefined plan programmed by the user. In accordance with the 3D plan, the printer squeezes out the concrete mix layer by layer.

5.5.2 Dubai project schedule and procurement schedule

The final goal of my research was to create a project scheduling and delivery schedule. The project schedule is the most important document necessary for the successful implementation of the project. I made the Dubai project schedule based on the previous experience of Hyperion Robotics company and the information provided to by the company's specialists. In the schedule are included all the processes and activities of the project. To create calendar schedules, I used the MS Project program.

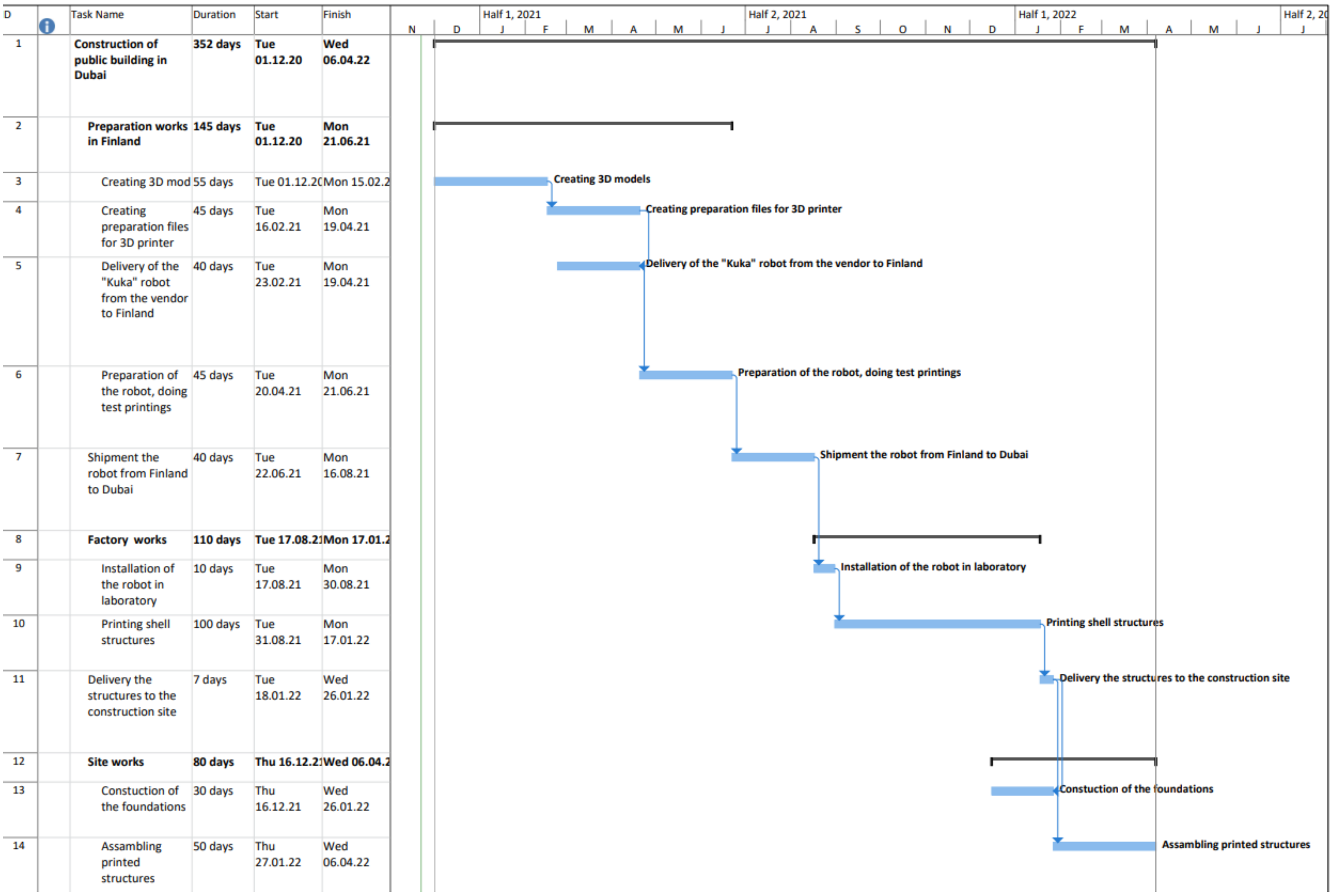

Figure 14. Estimated Dubai project schedule

The procurement schedule has been drawn up based on the project schedule, taking into account the logistics data provided by the suppliers selected in the previous section. The date on the graphs indicates the day on which payment must be made so that the materials are on the construction site on time.

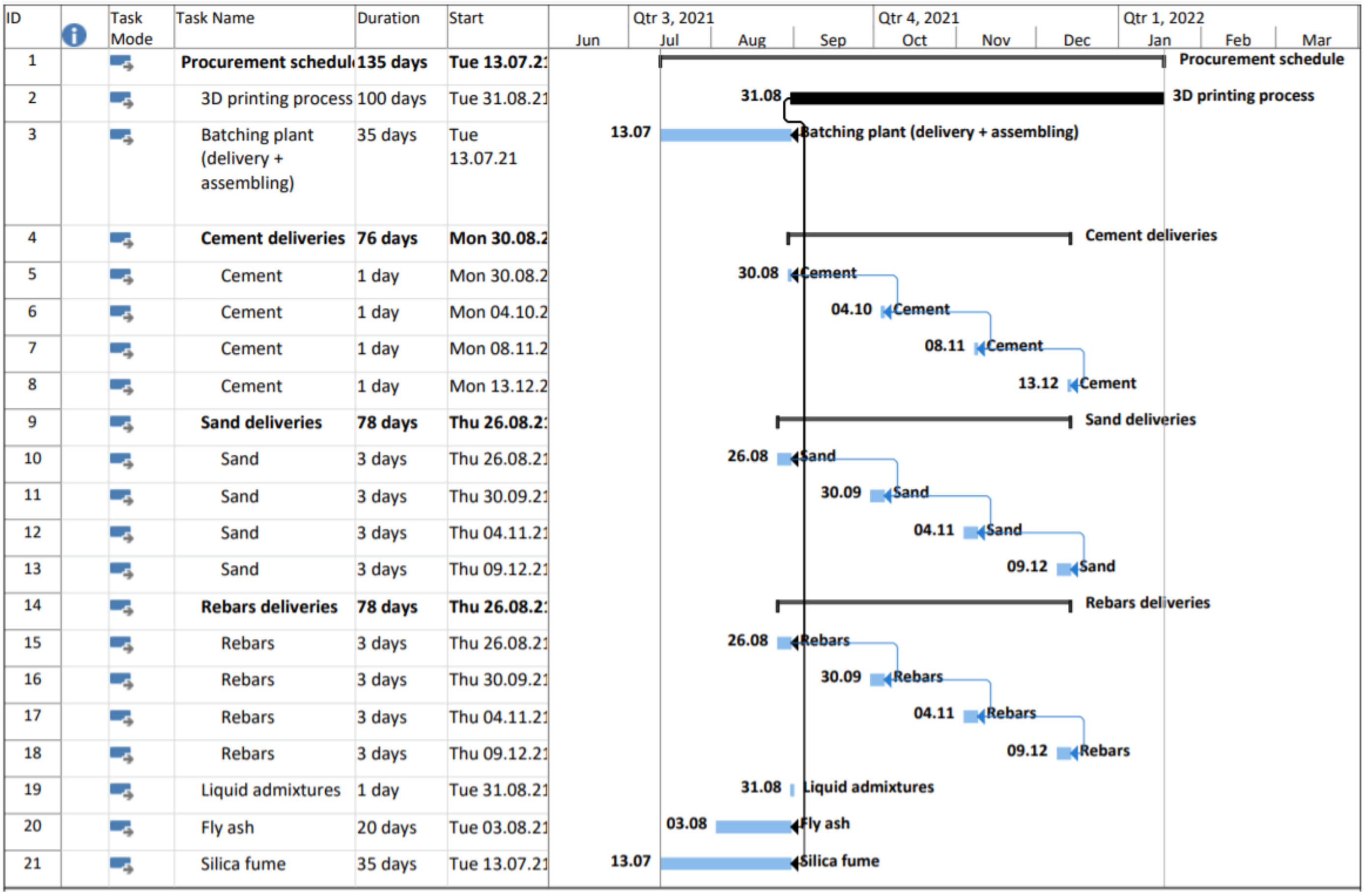
ID		Task Mode	Task Name	Duration	Start
1			Procurement schedul	135 days	Tue 13.07.2
2			3D printing process	100 days	Tue 31.08.21
3			Batching plant (delivery + assembling)	35 days	Tue 13.07.21
4			Cement deliveries	76 days	Mon 30.08.2
5			Cement	1 day	Mon 30.08.2
6			Cement	1 day	Mon 04.10.2
7			Cement	1 day	Mon 08.11.2
8			Cement	1 day	Mon 13.12.2
9			Sand deliveries	78 days	Thu 26.08.2
10			Sand	3 days	Thu 26.08.21
11			Sand	3 days	Thu 30.09.21
12			Sand	3 days	Thu 04.11.21
13			Sand	3 days	Thu 09.12.21
14			Rebars deliveries	78 days	Thu 26.08.2
15			Rebars	3 days	Thu 26.08.21
16			Rebars	3 days	Thu 30.09.21
17			Rebars	3 days	Thu 04.11.21
18			Rebars	3 days	Thu 09.12.21
19			Liquid admixtures	1 day	Tue 31.08.21
20			Fly ash	20 days	Tue 03.08.21
21			Silica fume	35 days	Tue 13.07.21

Figure 15. Procurement schedule

6 Summary

In conclusion, I would like to note that in this study and research I have fulfilled and described all the goals which were set.

The first completed goal was to study what supply chains and supply chain management are, their characteristics, the problems associated with this methodology, what advantages this methodology gives to construction companies, what are the methods of its integration and the difficulties arising from this.

The second goal was to work with Hyperion Robotics to create our supply chain for a construction project in Dubai using 3D concrete printing technology. The research consisted in finding suppliers of building materials and equipment for our project, as well as collecting information about the necessary materials and products and the terms of their delivery. In addition to finding suppliers, I have selected one for each product.

The third goal was to develop a material delivery schedule based on the project schedule which also was developed in this study.

Regarding the success of the results of my work, I can have a real conclusion only in practice during the implementation of the project. If Hyperion Robotics will not face problems with the characteristics and quality of materials, as well as there will not be any logistical problems, then it will be possible to implement the project in accordance with the schedule.

During this research, I faced some difficulties. The most significant in my opinion was the problem of communication with suppliers of materials. For this reason, my database is not very large.

This topic is applied and for the further creation, expansion, and management of supply chains, we need more real examples, as large developers do, working with hundreds of suppliers.

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