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The role of modularity in the construction industry

Supervisor: Prof. Margherita Pero

Author:

Rodolfo Costa Neves FRANCISCO

Matr. 781496

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Summary

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Abstract

A lot of efforts have been made with the aim of increasing the civil construction industry productivity and reduce its high waste rate with the governments encouraging researches in the area.

In other industries, such as automotive and electronic, the employment of modularity principles and its impact in the supply chain has been researched a lot recently and its use has been encouraged as a tool to increase product variety, reduce cost, increase speed to market and increase flexibility.

In order to enhance the construction industry issues about productivity when comparing to others emerges the idea of industrializing the construction, this is the transference of the work usually executed on site to factories that are more controlled places capable to increase the productivity of the sector. A part that takes important role in the industrialization of the construction is the construction technique adopted and can be classified into pre-fabrication, pre-assembly and modularization. The latter can be compared to the employment of modularity principles in the other industries. The others ways of industrializing the construction without being the technique was rationalization, new technology and standardization.

However, the industrialization of the construction has several impacts in the supply chain and in the complexity of project coordination with the employment of modular coordination to ease this issue. Therefore, the aims of this research was to evidence that the industrialization actually integrates the actors belonging to the same supply chain and also increase the complexity of project organization. In addition, the size of the construction company was individuated as a contingent factor that also has an important role in the integration of the supply chain.

The goal of the research, thus, also became exploratory and explanatory. This made it suitable to use qualitative case studies to study the links described in the previous paragraph as they can provide deeper and richer data than quantitative methods.

Abstract in italiano

Molti sforzi sono stati fatti con lo scopo di aumentare la produttività dell'industria delle costruzioni e ridurre il suo elevato tasso di rifiuti con i governi incoraggiando ricerche nel campo.

In altri settori, come nel automobilistico ed nel elettronico, l'impiego di principi di modularità e il suo impatto nella catena di fornitura è stato molto studiato e il suo uso è stato incoraggiato come uno strumento per aumentare la varietà dei prodotti, ridurre i costi, aumentare la velocità di commercializzazione e aumentare la flessibilità.

Con l`obiettivo di migliorare i problemi della industria delle costruzioni circa produttività in confronto con altre emerge l'idea di industrializzare il modo di costruire, cioè, il trasferimento del lavoro generalmente eseguito in opera per fabbriche che sono luoghi più controllati capaci di aumentare la produttività del settore. Una parte che assume ruolo importante nella industrializzazione della costruzione è la tecnica costruttiva adottata e possono essere classificati in prefabbricazione, premontaggio e modularizzazione. Quest'ultima può essere confrontato con l'impiego di principi modularità nelle altre industrie. Gli altri modi di industrializzazione della costruzione, tranne la tecnica, sono evidenciate come essendo la razionalizzazione, impiego di nuove tecnologia e padronizazione.

Tuttavia, l'industrializzazione della costruzione ha diversi impatti nella catena di fornitura e nella complessità del coordinamento del progetto con l'impiego di coordinamento modulare per alleviare questo problema. Pertanto, gli obiettivi di questa ricerca è stato quello di dimostrare che l'industrializzazione integra effettivamente gli attori appartenenti alla stessa catena di approvvigionamento e anche aumenta la complessità di organizzazione del progetto. Inoltre, la dimensione della società di costruzione è stata individuata come un fattore contingente che ha anche un ruolo importante nell`integrazione della filiera.

L'obiettivo di questa ricerca, quindi, è diventato anche esplorativo ed esplicativo.
Questo ha reso adatto da utilizzare studi di caso qualitativi per studiare i

collegamenti descritti nel paragrafo precedente in quanto possono fornire dati più profondi e più ricco di metodi quantitativi.

1 Introduction

There is an increasing concern in increasing civil construction industry productivity, seen as very low productive and wasteful (Cardoso et al., 2002) when comparing to other industries, such as automobile and electronic industries, gives a great relevancy for this work. The characteristics of the sector has been said to be the reason behind this low productive rates such as adversarial relationships, one off projects and the support in the individual skills of the workers (Egan, 1998). This concern about the civil construction that is lagging behind the others has made many governments such as the UK government to promote research in the field. In the serial industry the adoption of modularity principles and its impact in the supply chain has been researched a lot recently and its use has been encouraged as a tool to increase product variety, reduce cost, increase speed to market and increase flexibility (Salvador et al., 2002). However, there has been little research exploring the nature and scope of construction modularity using the modular concepts and tools commonly applied to electronics and automotive industry sectors, where modularity has been used extensively and successfully (Sako and Murray, 1999; Helper et al., 1999; Camuffo, 2000).

When studying the other industries and the construction industry to understand the reasons of this low productive and wasteful industry emerges the lack of collaboration and partnership among the companies belonging to the same supply chain. Egan (1998) urges to the need of long term relationships in the construction industry in his research “An essential ingredient in the delivery of radical performance improvements in other industries has been the creation of long term relationships or alliances throughout the supply chain on the basis of mutual interest. Alliances offer the cooperation and continuity needed to enable the team to learn and take a stake in improving the product. A team that does not stay together has no learning capability and no chance to making incremental improvements that improve efficiency over the long term. The concept of the alliance is therefore fundamental to our view of how efficiency and quality in construction can be improved and made available to all clients, including inexperienced ones.”

The other industries have realized that their success depends on the success of the entire supply chain they belong to, giving up of competing within the supply chain to increase its margin profits. This is consistent with Cooper, M.C., Lambert D.M and Janus, D.P. (1997) who claimed “Executives are becoming aware of the emerging paradigm of internetwork competition, and that the successful integration and management of key business process across members of the supply chain will determine the ultimate success of the single enterprise.”

In addition to the importance of the partnership in increasing sector`s productivity is also the technological development with the emergence of new construction techniques. As industrialization of construction advances, a growing amount of work is transferred to factories permitting less reliance on individual skills and increasing the sector productivity since the factories are more controlled places with their production based on processes (Pasquire and Connoly, 2002). However, the adoption of new construction techniques such as prefabrication, pre assembly and modularization implies on the necessity that the companies change their way of work. Tatum, C. B., Vanegas, J.A. and Williams, J.M. (1987) says “[…For example, these methods can alter the project organization, change planning and monitoring, require great coordination, and alter project results. They can also add new activities and change conventional operations.]”

The first great change in the way of constructing was fostered by the emergence of the industrial revolution in the United Kingdom in the middle of the nineteenth century. The mass production of standard components in factories started to change completely the sector once the components were just assembled on site. This new method of construction was for the first time used to construct the Cristal Palace in London, designed by Joseph Paxton and built between 1850 and 1851 for the Universal Exhibition of London. "Since then, architects and engineers from various schools and nationalities, sensitive to changes caused by an increasing industrialization and the mass production began to submit the architectural process to a deep revision work to put the resources of industrialization in the service of a new revolution, the social, whose wishes should be fulfilled "(Rosso, 1976). In this construction, the project was executed taking into account the dimensions of the glass panels and the steel bars that were the main components in order to make

possible the assembly in the construction site. This was the first appearance of the modular coordination and the module adopted was the dimension of the glass panels that was 2,40 meters (Greven and Baudalf, 2007). Bellow there is a picture of the Crystal Palace.

Figure 1: Crystal palace

The employment of the modular coordination arises in this scenario as a tool to reduce cost in many phases of the construction process. This reduction is due to the optimization in the use of the raw material and to the agility in the decision process. Moreover, in this period in which there is a great concern regarding sustainability, the modular coordination is an ally to help reducing the civil construction sector environmental impact (Greven and Baudalf, 2007).

Furthermore, employing the modular coordination is essential to the employ new construction methods that increase productivity, such as, making use of pre-fabricated, pre assembly and modularization. However, in the design phase, when there is the choice of the technique that will be adopted with the aim of increasing value for the client, often these new techniques are not taken into account as a possibility. Changing the way to construct from a way based on the skills of specialist

craftsmen for one that is based on workers able to undertake a range of functions based around processes is not a simple task once it is necessary to change the culture.

The employment of these methods implies also a change in the supply chain. This change depends on the construction method being used, the strategic position of the enterprise and its size. The supply chain management has been seen as a powerful mechanism of enhancing supply chain competitiveness in other industries and a change from a push supply chain in which the companies compete for the profit share within the chain to a pull supply chain has been suggested by some authors (Cooper, M.C., Lambert D.M and Janus, D.P., 1997). Being the construction industry very particular, characterized by a customer hiring a contractor for constructing one-off projects entails a non regular demand of raw material challenging inter-organization integration. However, for certain relationships, the integration is a powerful way of increasing the competitiveness of the supply chain. Egan (1998) suggests that the design part should be properly integrated with construction and performance is use.

A matter of this work is also to link the characteristics of each construction company with these two subjects demonstrated above, which are partnership and construction`s industrialization, as important to increase productivity. Moreover, the characteristics of each single construction company were taken into account as possible explanations for its adopted supply chain strategy.

1.1 Structure

This work is structured in six chapters, being the first one the introduction encompassing the motivation for this research and a brief description about the theme discussed.

The second chapter is the Literature Review and covers what has already been researched in the area. In addition, it brings essential definitions that need to be understood in order to understand the whole work.

The third chapter is the Research Model. It provides a guide for the research through the placing of the research questions and the construction of a research model that

has been based in the literature review. In addition, it brings the reasoning behind the links proposed in the model and the explanation of all variables belonging to it.

The fourth chapter is the Case Studies chapter and its function is primarily describe all the interviews and the characteristics of each construction going on.

The fifth chapter is one of the most important and is in it that the analyses of the case studies are presented. Moreover, it contains the reasoning behind the answers given for the research questions placed in the Research Model Chapter.

The last one, the Conclusions, summarizes the findings answering the questions placed. In addition, it contains a critical analysis of the research and suggestions of future research path.

2 Literature Review

In this chapter my aim is to present what has already been studied regarding the employment of modularity principles, especially in other industries, since the topic has been less studied in the construction industry. Furthermore, this chapter contains the definitions of the main concepts necessary to understand this research.

2.1 What is: modularity, module, modularization and modular coordination?

First of all, understand the concept of modularity and how it is related to the development of new construction techniques is essential to understand this research.

The use of modularity principles have gathered significant pace during the last decade and especially dominate those industries that produce highly complex products to satisfy constantly changing consumer demands. (Gadde and Jellbo, 2002)

Carliss and al. (1997) speak of building a complex product or process from smaller subsystem that can be designed independently yet function together as a whole.

Langlois (2002) describes modularity as “a very general set of principles for managing complexity”. Within construction industry, modularity has been described as the production of panelized and volumetric systems, and major prefabricated components within a manufacturing environment. Following this definition, it is possible to evidence that the modularity is correlated to the industrialization of the construction industry sector since the tasks that were used executed on site are transferred to factories that are controlled environments, specialized in the production of a certain component, making possible to increase the productivity of the sector.

Tatum, C. B., Vanegas, J.A. and Williams, J.M. (1987) say that the degree of industrialization depends on the amount of work transferred to off-site facilities, being the most industrialized construction method the modularization, in which the main task executed on site is the assembly of the modules produced in factories.

According to them, a module is a major section of a plant resulting from a series of remote assembly operations and may include portions of many systems. It is usually the largest transportable unit or component of a facility.

Below are the definitions of the more industrialized methods from Tatum et al. (1987). The methods are presented from the low industrialized to the more industrialized one.

> -Prefabrication. – Prefabrication is a manufacturing process, generally taking place at a specialized facility, in which various materials are joined to form a component part of final installation.
>
> -Preassembly. – Preassembly is a process by which various materials prefabricated components, and or/ equipment are joined together at a remote location for subsequent installation as a sub-unit. It is generally focused on a system.
>
> - Module. – A module is a major section of a plant resulting from a series of remote assembly operations and may include portions of many systems. It is usually the largest transportable unit or component of a facility.

However, module has also another meaning. According to the Brazilian technical standard NBR 5706, the module is: “the distance between two consecutive plans of the system that originates the reticulated spatial reference” (ABNT, 1977). Also called base module, the module is universally represented by “M” and is adopted by the majority of the countries, encompassing Brazil and Italy, as having the dimensions of 10cm or 1decimeter. In Brazil, the base module has been adopted since 1950 with the publication of the NB-25R. In the United States the base module is 4 inches. This concept, when used in this research, will be called module in modular coordination, while module will be understood according to the definition of Tatum et. al. (1987).

To complete this subchapter, Modular coordination is defined by The Brazilian Association of Technical Standards (ABNT), in its publication “Modular Coordination Synthesis” defining it as: “the specific implementation of an industrial method by

which it establishes a mutual dependency between components, intermediate products and final products (buildings) by the use of a common unit of measure represented by the module". Another definition for modular coordination is given by Mascaró (1976) as being a mechanism to simplify the inter-relationship of different components of distinct provenance, which must be joined together in the stage of construction (or assembly), with minor modifications or adjustments.

The picture bellow depicts the spatial reticulated reference. (Greven and Baldauf, 2007)

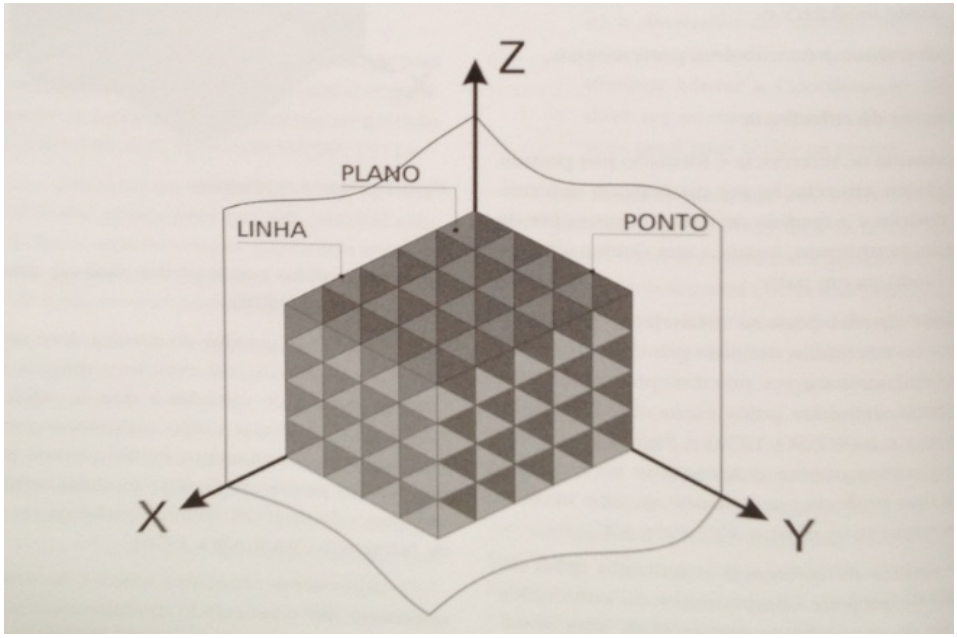

Figure 2: Spatial reticulated reference

2.2 Industrializing the construction industry sector

In the previous subchapter, I presented the definitions of the main concepts presented in this research and I showed how these concepts, particularly the methods, are related to the industrialization of the construction sector.

In this subchapter I will bring a definition regarding industrialization and expand the theme showing that the construction method is not the only way to industrialize the construction sector, that is, increase its productivity and reduce its waste rate.

According to Tatum, Vanegas and Williams (1987) industrialization is:" that aspect of the manufacturing process which by the use of mass production techniques results in an increase in productivity, efficiency, or quality of the product. This results from the creation of new and different products or from new means of production for products similar to the original one. The four general forms of industrialization used in building construction are:

-Rationalized building

-Standardization

-New Technology

-Prefabrication. "

The first one is defined by Rosso (1980) who says rationalization is: "the mental process that governs the action against the waste of time and materials production processes, applying systematic reasoning, free of the emotional flow; is a set of actions that it proposes reforming replace routine practices and resources by conventional methods based on systematic reasoning in order to eliminate randomness in decisions". Another definition of how to implement it is given by Barros (1998): "As regards construction rationalization, the correct procedure would start the execution of the structure; otherwise it is primarily reference to the following parts. However, being the element that supports the entire building, this is one of the subsystems has been receiving more attention by those involved with its production. After the structure, a subsystem that deserves mention is the vertical masonry, consisting of the bricks, the frames and the coating."

Standardization is the oldest form of industrialization and has slowly become standard practice. Modular coordination and standardization provide faster production, lower costs, and more efficient assembly of materials due to uniform dimensions that eliminate costly and time-consuming custom-made applications while still allowing multiple configurations. Depending on how the standardized parts match-up, they are classified into "open" or "closed" systems. In the first, the

manufactured parts can be combined with parts from different sources or suppliers while in the latter; the combination is limited to parts made by the same manufacturer. (Tatum et al., 1987)

The third way of industrializing the construction is new technology that is defined: “The introduction of new technology and equipment also is a form of industrialization. Machines or tools such as “flying” concrete forms speed the construction process. (Tatum et al., 1987)

The last one, pre-fabrication, is the construction method and is already defined in the previous subchapter.

2.3 Supply Chain Management

The term “supply chain management” was introduced by consultants during the 1980s and quickly received attention from academics who wanted to give a structure to supply chain management. The fact of appearing recently allied to the fact that some academics (Fisher, 1997; Lee and Billington, 1992) considered supply chain management not very different from the definition of logistic management used to have in that period contributed to the absence of a unitary definition of supply chain management. The latter reason because the Council of Logistics before defining in 1998 logistic management as the part of supply chain management interest in planning, implementing and controlling the effective flow of goods and service, used to define logistic management with a supply chain orientation when saying “from the point of origin to the point of consumption”.

Using Ganeshan and Harrison`s (2000) definition, a supply chain is “a network of facilities and distributions options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers. Supply chains exist in both service and manufacturing organizations, although the complexity of the chain may vary greatly from industry to industry and firm to firm.”

A more clear definition for the construction industry is given by Kelly, J., Morledge, R. and Wilkinson, S. (2002): “supply chain encompasses all those activities associated with processing from raw materials to the completion of the end-product to the client

or customer. This includes procurement, production scheduling, order processing, inventory management, transport, storage and customer service and all the necessary supporting information systems. The supply chain also includes subcontractors and suppliers as well as the process within business itself." Thus, understanding and developing relationships within and between organizations underpins ability to: optimize "flows"; break down process discontinues; develop networks; make decisions about managing competencies and; optimize the use of power.

2.4 Modularity, outsourcing and the supply chain

Till here, we have seen that industrialization of the construction industry sector is related to the use of modularity principles that are explained in the section 2.1. In this part, I will show how the use of modularity principles affects a certain supply chain.

Gadde and Jellbo (2002) say that increasing modularization thus enables production processes to be decentralized and the use of outsourcing principles normally increases.

Doran et al., 2007; Quinn and Hilmer, 1994; van Weele, 2005) state: "Through the use of outsourcing, modular organizations can concentrate their resources on those activities that provide unique value to their customers while non-core activities are performed by specialist suppliers".

Sturgeon (2006) states: "outsourcing became extremely popular in the United States in the 1990s, and that it was driven by some of the same motivations that exist in Japan: the search for greater flexibility in the face of increased international competition and market volatility through the transfer of fixed assets and inventory to suppliers".

The consequences of outsourcing practices are described by some authors, such as Ernst and Kamrad (2000) who say: "Outsourcing further enables organizations to reduce their fixed costs for assets and adjust more easily to changes. However, as the sub-contractors' margins also have to be accounted for, the variable cost grows"; and Vrijhoef and Koskela (2000) who state that: "By outsourcing activities, temporary organizations can adapt more easily to changing customer requirements and

environments. However, this also results in a less stable and fragmented supply network.

Within outsourcing, there is a special kind of outsourcing called system sourcing that is explained by Gadde and Jelbo (2002) that say: “Using full service suppliers for entire modules and subtasks, instead of a number of component suppliers, is called system sourcing and is based on modularity principles”. The use of the system sourcing in the civil construction industry can be related to more industrialized construction methods that are explained in the section 2.1 in which there are more amount of work being executed away from the construction site.

An advantage of system sourcing is that: it allows an organization to reduce its supplier base. (Arnold, 2000) In addition, instead of spending considerable resources on the management and maintenance of relationships with numerous component suppliers, more effort is spent on a smaller number of system suppliers. The potential improvements that system sourcing can provide can largely be attributed to a higher degree of specialization resulting in economies of scale. Specialization and decomposition of a product or process also increases the adaptability of the overall system, e.g. to changing demands, technologies and contexts, as modules can be substituted. (Sanchez and Mahoney, 1996; Schilling, 2000; Walker, 1997) Furthermore, this allows for a reduction of traditional buffers used by organizations to respond to uncertainties. (Walker, 1997; van Hoek andWeken, 1998)

However, using the construction method called modularization that is seen to be the more industrialized one through the use of system sourcing increase some risks. (Hellstro¨m and Wikstro¨m, 2005) say: “a risk exists with modularization in that an extra tier of module suppliers might have to be added to the supply chain”. (Lau and Yam, 2005) explain this matter stating that: “ This is due to the fact that suppliers who are responsible for delivering full systems to projects often have to rely on a network of service and equipment sub-suppliers to secure sufficient capacity and capabilities”.

2.5 Modularity and the project phase

In this subchapter, using research from reputed academics, I will show that industrializing the construction industry impacts in not just the supply chain, increasing the number of tiers and thus, the degree of integration necessary with certain suppliers, but also in the way the project phase is executed.

In general, general modular construction has the following implications for building projects:

1)-the design approach and process is different for modular and conventional construction;

2)-the organization and selection of the project team is very different and

3)-the use of the modularization has a great impact on construction time and operations. (Tatum, C. B., Vanegas, J.A. and Williams, J.M., 1987)

Prefabrication, preassembly, and modularization, when used for major segments of a project, require earlier project decisions. The earlier decisions include adopting a method, complementing the design based on this method, and placing purchase orders and contracts to implement it. Specials constructions methods increase the interdependency of activities by each of the major disciplines, and therefore require great coordination. With this increased integration, more decisions involve multiple disciplines which require greater involvement of the project manager (Tatum et al., 1987).

2.6 Modularity and other industries

In this subchapter, I will described how the others sectors are trying to increase its productivity through the employment of modularity principles and how it has changed its supply chain.

In the automotive industry, the recent change in the production with the purpose of increasing productivity has been based in the adoption of modularization. A much studied example is the Mercedes-Benz assembly plant in Alabama, United States. Mercedes-Benz structured the vehicle around sets of large production modules, which includes a module for the driver`s cockpit. Within European context, the most

tangible representation of the modular approach to car assembly is the Smart. This collaboration has been developed around modular supply and assembly and draws on the experience of Mercedes-Benz in terms of how modules were defined and assembled for their sport-utility vehicle. Whilst a typical car is likely to necessitate the coordination of around 200 first-tier suppliers, the Smart car collaboration has been engineered and designed using only 25 modular suppliers (Doran, 2003).

Jacob et al. (2007) suggests that one of the positive outcomes of product modularity is the development of closer commercial ties with suppliers as a result of increased integration.

This theme is also explored by Sturgeon (2003), who describes commercial arrangements within a modular supply chain as a “situation where the supplier is given increased control of discrete modules as a process of value-chain modularity, since discrete breaks in the value chain tend to form as points where information regarding product and process can be highly formalized”.

Whilst modular practices and principles have matured within the computing and automotive sectors (Doran, 2004) there is a clear need for the alignment of modular construction sector so that suppliers can effectively respond to the increasingly sophisticated architectural requirements of modular clients (Bankvall et al., 2010; Liao et al., 2010).

3 Research Model

3.1 Research context description

In order to fill the lack of research in the field of construction sector regarding the implications of employing modularity principles, which have already been broadly studied in other fields in order to increase productivity and competitiveness. Hoffman Erwin, Voordik Hans and Johannes Halman (2009) say: “the notions of aligning modular products architectures and buyer-supplier relationships, which have been spread widely through other industrial and retail sectors, have largely bypassed the house-building industry”.

Although there are studies in the field of modular construction and the what would be the bests supply chain practices to obtain the more advantages when employing modular construction, there is a lack of study regarding the supply chain and others degrees of industrialization in construction. In other words, it has already been studied how the supply chain must be in order to implement the most industrialized construction technique, which is the modular construction, but there is missing a research to link the different degrees of industrialization and the different supply chain strategies usually adopted by each.

This research emerges in this context and is particularly adapted to Brazilian reality where the modular construction is unusual. Thus, this research will classify different constructions that have different degrees of industrialization and will analyses how the supply chain reacts to it. Particularly, the focus within the supply chain will be the buyer-supplier relationship. In addition, it will analyze how the increase in industrialization reflects in the complexity when coordinating the project.

Therefore, to summarize and ease the comprehension of the aim of this research, the next subchapter contains three research questions.

3.2 Research Questions

After demonstrating the relevancy of the subject in the previous section, I summarize the research objectives in three questions:

1) How the relationship between the companies in the supply chain construction industry (construction company with subcontractors and suppliers) are influenced by the general degree of industrialization that characterizes a certain construction?

2) How the way to organize the project is influenced by the general degree of industrialization?

3) What are the contingency factors that affect the relationship between the general degree of industrialization that usually characterizes one company developments and the relationships between the actors? And how do they work?

3.3 Theoretical Model

In order to answer the research questions stated above, I propose the construction of a theoretical model presented bellow based primarily on the book “Constructability Improvement Using Prefabrication, Preassembly, and Modularization” from Stanford University. The construction of this model was very important since it provided a framework to guide this research since it leads to a structured manner of gathering information from the case studies, which will be responsible to validate the propositions supported by this model. In addition, it was included the specific characteristics of each contractor since it influences the relationship with subcontractors and suppliers.

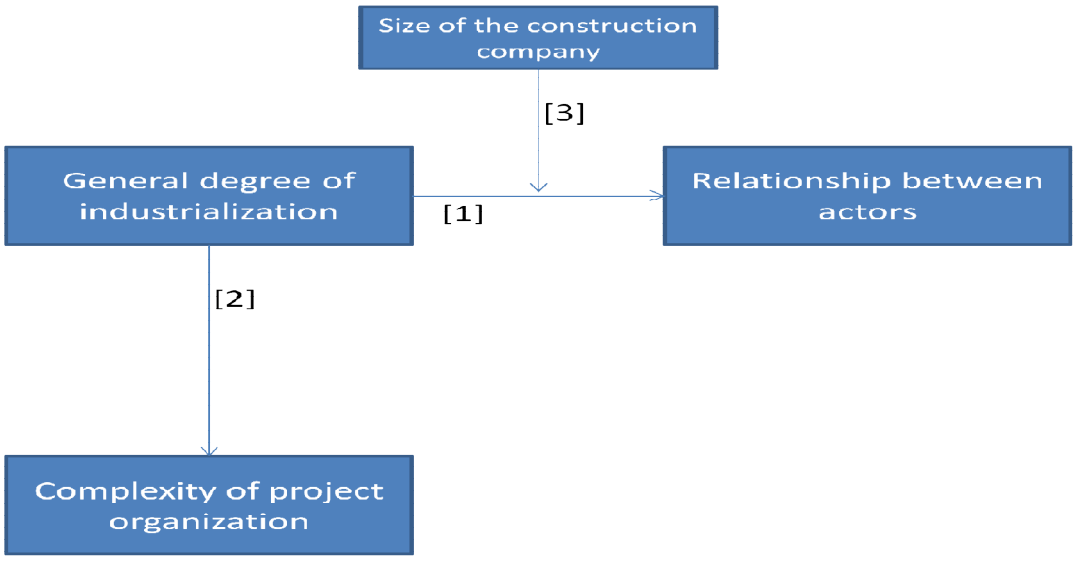

Figure 3: Theoretical model

This chapter is structured in four subchapters where the first three describe the variables presented in the model and the fourth, based on the literature, explains the proposed relationships between the variables. In the first part, the degree of industrialization, the kind of relationship between actors and the complexity of the project organization are explained in order to make possible to understand the relationships proposed between them in the last subchapter.

3.3.1 Degree of construction industrialization

As expressed in the literature review, the industrialization of the civil construction sector is seen, together with partnering strategies, to increase the productivity of the sector.

A good definition for industrialization is given by Tatum, Vanegas and Williams (1987) who say industrialization is:" that aspect of the manufacturing process which by the use of mass production techniques results in an increase in productivity, efficiency, or quality of the product. This results from the creation of new and different products or from new means of production for products similar to the original one. The four general forms of industrialization used in building construction are:

-Rationalized building

-Standardization

-New Technology

-Prefabrication, pre-assembly and modularization"

In this subsection I will explain the construction techniques such as reinforced cast-in-place concrete, prefabrication, preassembly and modular construction. With exception of the first, which is seen to be more traditional, the other three are seen to me more industrialized being the modular construction the more industrialized

among these since it is the one that transfers the great amount of work to factories that base their production on process processes.

To clear what is prefabrication, preassembly and module I will reuse the definition from Tatum, C. B., Vanegas, J.A. and Williams, J.M. (1987):

> -Prefabrication. – Prefabrication is a manufacturing process, generally taking place at a specialized facility, in which various materials are joined to form a component part of final installation.
>
> -Preassembly. – Preassembly is a process by which various materials prefabricated components, and or/ equipment are joined together at a remote location for subsequent installation as a sub-unit. It is generally focused on a system.
>
> - Module. – A module is a major section of a plant resulting from a series of remote assembly operations and may include portions of many systems. It is usually the largest transportable unit or component of a facility.

In order to apply these definitions to the residential building construction in Brazil, I will link the construction techniques usually employed to them.

The major concern regarding the industrialization of the construction is related to the structural and masonry subsystems since are the subsystems that shape the construction as explained by Barros (1998): “As regards construction rationalization, the correct procedure would start the execution of the structure, otherwise it is primarily reference to the following parts. However, being the element that supports the entire building, this is one of the subsystems has been receiving more attention by those involved with its production. After the structure, a subsystem that deserves mention is the vertical masonry, consisting of the bricks, the frames and the coating.”

Starting from the most traditional one, the reinforced cast-in-place concrete produced on site by concrete mixers. This, in contrast with cast-in-place concrete produced on factories and transported to the construction site by specific trucks, is the less industrialized technique of construction. Being the concrete produced on site, it is

more subjected to variations on quality since mistakes are more common when the tasks are executed on site rather than in factories.

The second less industrialized method is similar to the previous depicted above but has a very important difference, that is, the concrete is produced by specialized firms in their factories and are delivered to the construction site according to the demand orders. This increase the construction productivity since the production of the concrete is not subjected to the same degree of mistakes when mixing on site, neither by weather disruptions.

The third one is constructing in structural masonry. In this method precast concrete blocks produced in factories are assembled on site constituting a subsystem that integrates two functions, which are, the structural and the function to close the open spaces.

Next to the structural masonry, there is one technique characterized by the adoption of big precast concrete parts, for example, pillars, slabs panels, wall panels and beams. This technique has an enormous impact in increasing construction speed since it is not more necessary to spend time putting together on site small precast concrete blocks.

The more industrialized technique in construction is called modular construction and is based on modularity principles since it decomposes the whole building in many modules that come constructed totally in a factory away of the construction site. Although it is very hard to see its applications in residential buildings, it is more common in types of constructions in which there is a repetition of spaces, such as, schools and hospitals. According to Doran et al. (2007), the use of modularity principles have gathered distinguished pace during the last decade and especially dominate those industries that produce highly complex products to satisfy constantly changing consumer demands.

Even if the technique of construction employed is very important for industrializing the construction, it is not the only one form of doing so, being just a starting point. In other words, two different constructions which use the same construction technique can have a different degree of industrialization since, according to C. B., Vanegas,

J.A. and Williams, J.M. (1987), there are four manners for industrializing the construction: standardization, new technology, rationalization and pre-fabrication, pre-assembly and modularization. The construction techniques described above correspond to the latter, being possible having different degrees for the other three aspects implicating in a possible difference of the general degree of industrialization for two different constructions that employ the same technique. For example, two different undertakings being constructed in reinforced cast-in-place concrete can have a different general degree of industrialization if one of them uses more new technologic equipments which boost the construction productivity.

3.3.2 Relationship between actors

In this subchapter the aim is to describe the possibilities of relationship between the contractors and subcontractors or suppliers. With this objective, I will adapt the range of relationships styles described by Cooper (1993) despite of the fact he has done this classification for the logistic field because even if the area changes, the range of relationship styles don`t. He describes the range of relationships styles as being a continuum going from Arm`s length relationship style to full vertical integration, as you can see in the picture bellow. In order to make his classification more clear for the construction industry, I substituted the kinds of relationships called by him as typical small account relationships and national account relationships by a common practice in the construction sector that lies between the arm`s length and the strategic alliance, that is, the rationalization of the supplier base.

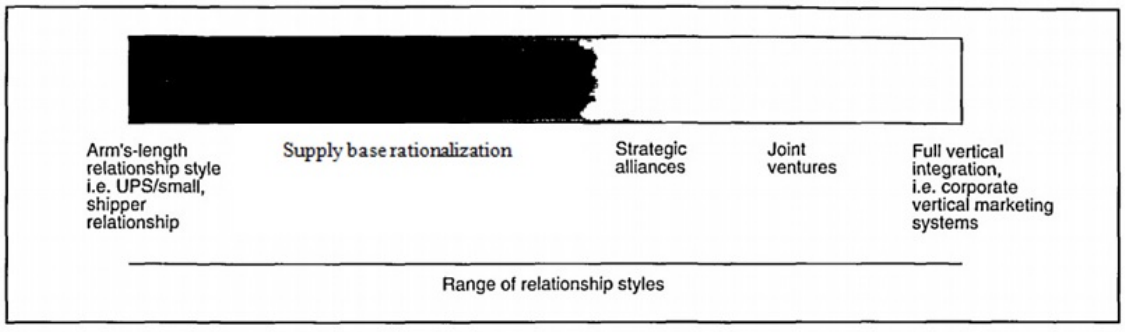

Figure 4: Range of relationship styles

The arm`s length relationship style is characterized as being a kind of relationship in which neither party involved expects future transactions. Even if the suppliers hopes for further sales, but there are many buyers and sellers in the marketplace. The buyer need not consider any inter-organization ties beyond the transaction level of interaction. This is the most traditional strategy regarding purchasing and is characterized by the buyer searching the price of many suppliers prior to engage one for the task.

This kind of relationship has received critics from academics who seen the lack of integration as a reason for many construction sector problems. Moreover, it implies on implicitly costs that must be added to the one given by the supplier once the buyer has to take into account the costs brought by dealing with many uncertainties such as the costs of maintaining a safety stock and the extended delivery time (Abdel-Malek et al., 2005). In addition to these implicitly costs, adopting the arm` length relationship also implies on possible delays on the schedule since the time taken by negotiation is not very predictabl (Sarkar and Mohapatra, 2006).

The supply base means the rationalization of costs of purchasing programs through the reduction of the supply base (Dubois, 2003). It consists of two phases: (1) Determination of the optimum size of the supply base and (2) recognition of those who should constitute this base (Christopher and Juttner, 2000). Furthermore, Christophe and Juttner (2000) claim that a supply base reduction may also be viewed as a one-time selection of one or a small group of suppliers so as to reduce transitional costs and purchasing complexity. Therefore, contrasting this approach with the arm`s length described above it is possible to evidence that the negotiations costs is decreased since there is no need to contact all suppliers available in the market. In addition, it provides the base to establish partnerships with key suppliers.

Making use of Cooper`s (1993) definition, a strategic alliance is a contractual relationship formed between two independent entities to achieve objectives and benefits. This range of relationship called by cooper as strategic alliance can be seen also as partnerships, which is defended by Egan (1998) in his study promoted by the UK government with the aim of improving construction quality and efficiency. As defined by Cooper (1993), partnership is:

-A relationship that attempts to build interdependence, enhance co-ordination, improve market position focus (by broadening or deepening), or to achieve other shared goals.

- A relationship that entails sharing benefits and burdens over some agreed time horizon.

In my adaptation of Cooper`s range of relationships, following strategic alliances there is joint ventures. Joint ventures are relationships that involve some form of equity or ownership. They may be formed as mean of achieving market power, synergies in information sharing or economies of scale (Harrigan, 1985).

In order to finish this subchapter, I will describe the most integrated kind of relationship, that is, the vertical integration. The vertical integration is when more than one company belonging to the same supply chain has a common owner.

3.3.3 Complexity of project organization

The project of a whole building is very complex since there are many subsystems to be projected such as foundation, structure, hydraulic, electric, architecture, masonry and so on. Being each project usually designed by a specific design office since each project involves the need for specific knowledge implying the need to join all projects.
Carliss and al. (1997) speak of building a complex product or process from smaller subsystem that can be designed independently yet function together as a whole.

The industrialization of the construction has had an enormous impact on the design of the buildings since the industrialization means the adoption of components of standard dimensions instead of producing them on site or ordering customized components. In this context of construction industrialization, emerged the need of standardizing the dimensions of the components produced since different producers used to produce them in different dimensions. In this scenario, the technical standards have had a key role in determining the components dimensions to be produced.

With the industrialization of the construction emerges the modular coordination that is defined by Mascaró (1976) as being a mechanism to simplify the inter-relationship

of different components of distinct provenance, which must be joined together in the stage of construction (or assembly), with minor modifications or adjustments.

The Brazilian Association of Technical Standards (ABNT), in its publication “Modular Coordination Synthesis” defines it as: “the specific implementation of an industrial method by which it establishes a mutual dependency between components, intermediate products and final products (buildings) by the use of a common unit of measure represented by the module”.

Therefore the complexity in the project organization seems to increase with the industrialization because components become bigger and come already assembled to the construction site, for example, precast concrete blocks. In this way, for example, another non principal project, such as, water and electric facilities have to be adapted for the constraints imposed by the structure imposing an additional challenge for the designers who have to take into account the dimension and the spaces provided by the main projects to make their project fit. Thus, the complexity of project coordination increases with the number of constraints imposed by other projects. In addition to the constraints, the complexity of project organization increases with the number of specific design offices working together in a certain development because there are more projects that need to be integrated to complete the whole project.

3.3.4 Links between the variables

The motivation behind the arrow [1] and [2] was found in literature in the book “Constructability improvement using prefabrication, preassembly and, modularization”. It claims that adopting the most industrialized construction technique that is modularization has the following implications for building projects:

1) The design approach and process is different for modular and conventional construction;

2) The organization and selection of the project team is very different and

3) The use of the modularization has a great impact on construction time and operations.

However, it is not just the modularization that has an implication on the complexity of the project organization. The arrow [2] also is supported by the literature found in the same book from Stanford University “Prefabrication, preassembly, and modularization, when used for major segments of a project, require earlier project decisions. The earlier decisions include adopting a method, complementing the design based on this method, and placing purchase orders and contracts to implement it. Specials constructions methods increase the interdependency of activities by each of the major disciplines, and therefore require great coordination. With this increased integration, more decisions involve multiple disciplines which require greater involvement of the project manager.”

Moreover, the motivation for the arrow [1] was found in literature which says: the use of prefabrication, preassembly, and modularization also influences nearly all of the functional activities on a project, such as, procurement operations and construction operations, changing the division of responsibility. (Tatum et. Al 1987)

The motivation behind arrow [3] emerges from Erwin Hoffman (2009) who claims that: “the alignment between product modules and contractor – supplier relationship is found to be contingent in four driver: the degree of variety in customer demand, the extent of the required supplier investment, the extent of dependence on supplier knowledge, and the intentions of both the supplier and the buyer in a relationship.” In other words, a small construction firm with a small number of projects going on at the same time doesn`t have a wide range of activities going on at the same time since in each project the activities start and ends, so it makes the demand for a certain service very irregular hampering the partnerships. In contrast, a large construction firm has several projects going on at the same time and almost always has demand for a certain type of service rendering favorable the implementation of possible partnerships.

4 Case Studies / Interviews

In order to validate the model suggested in the previous chapter a few construction works going on were analyzed in the respective aspects: size of the construction, size of the work under construction, specialized knowledge of subcontractors, relationship with suppliers, relationship with subcontractors and the design phase. The information was obtained by contacting people working in the construction industry sector, encompassing enterprise partner, consultant and site engineers. In addition to providing data, they were asked about their opinions regarding the strategic choices chosen by their enterprises in the fields of outsourcing the design, outsourcing the execution, supply management. The goal of the research, thus, also became exploratory and explanatory. This made it suitable to use qualitative case studies as they can provide deeper and richer data than quantitative methods. (Ellram, 1996; Stuart et al., 2002)

The table in the next page summarizes the people interviewed and encompasses some information about each construction going on, such as, name of the company, company focus, role in the supply chain, revenue, size of the company and role of the contact.

Table 1: Case studies

Undertaking	Company	Company focus	Role in the supply chain	Revenue (euro)	Company`s size	Role of the person interviewed
Residencial Hikari Garden	Evaldo Paes Barreto ltda.	Residential	Contractor and principal	*	Small [2]	Managing shareholder
Jardins do Brasil – Abrolhos	Construtora Adolpho Lindenberg	Residential	Contractor	12.546.718,15	Medium	Engineer
Belo Monte Dam	CCBM (led by Andrade Gutierrez)	Infrastructure	Contractor	511.587.644,79 [1]	Large	Intern
Consulting in Residencial Hikari Garden	Métrica Ases. E Consultoria	Consulting in construction	Superintendent	*	Small	Managing partner
Extension of the metropolitan line 5	Galvão Engenharia	Infrastructure	Contractor	821.621.621,62	Large	Intern

[1]: The revenue is from Andrade Gutierrez, CCBM leading company

[2]: The company was classified as small because it was running just one undertaking at the time

The people contacted don`t have the same status within its enterprise but the data provided by them are reliable because they are part of the author`s personal network. However, their opinions towards the strategic choices taken by their firms may be subjective and hard to compare. Although it would be better to contact persons with the same status inside the construction firms, it is not easy that unknown persons provide private information from their firms.

When choosing the new developments that would be studied, it was a concern to find different types of works in order to allow the comparison of the implications brought from their characteristics, such as, different construction techniques (structural masonry and reinforce cast-in-place concrete), different size of the new developments and different size of construction companies. The motivation behind this was to obtain a broad data allowing the identification of the motivation behind each strategic choice such as partnering with subcontractors or suppliers.

The first case studied is a development of two residential buildings in the countryside of Brazil, built in structural masonry by a small firm acting as the constructor as the developer. The second is also a development of two residential building in a neighboring city of Sao Paulo but built in reinforced cast-in-place concrete by a large renowned civil construction company. The third case, in contrast with both firsts, is the construction a hydroelectric power plant, The Belo Monte dam, taking place in the state of Para in the north part of Brazil. The fourth contact, differing from the first three, instead of providing data from a specific new development, explained the linkages between the firms and the suppliers of pre-cast concrete blocks in the design phase and then, in the deliveries. The fifth case study is the construction of the extension of the line 5 of the Sao Paulo metropolitan network being, in conjunction with the Belo Monte dam, the two infrastructures projects analyzed.

The cases following were written based on recorded interviews and translated answered questionnaires sent by e-mail. In addition to providing data, they expressed their personal opinion about their firms partnering strategy and the outsourcing strategy of the design to different specialized offices.

4.1 Residencial Hikari Garden, São Carlos, SP, Brazil

Figure 5: Residencial Hikari Garden

Description:

This new development consists of two residential towers built in structural masonry by Evaldo Paes Barreto ltda., a small developer company based in São Paulo that usually develops its projects in the countryside. This particular business in São Carlos consists of 96 apartments, divided in two towers of fourteen floors each. The total revenue of this business is expected to be approximately 8.5 million euros.

The company was founded in 1947. By the time of the interview with the enterprise's partner Jomázio Avelar, it was developing just one business.

Position in the supply chain:

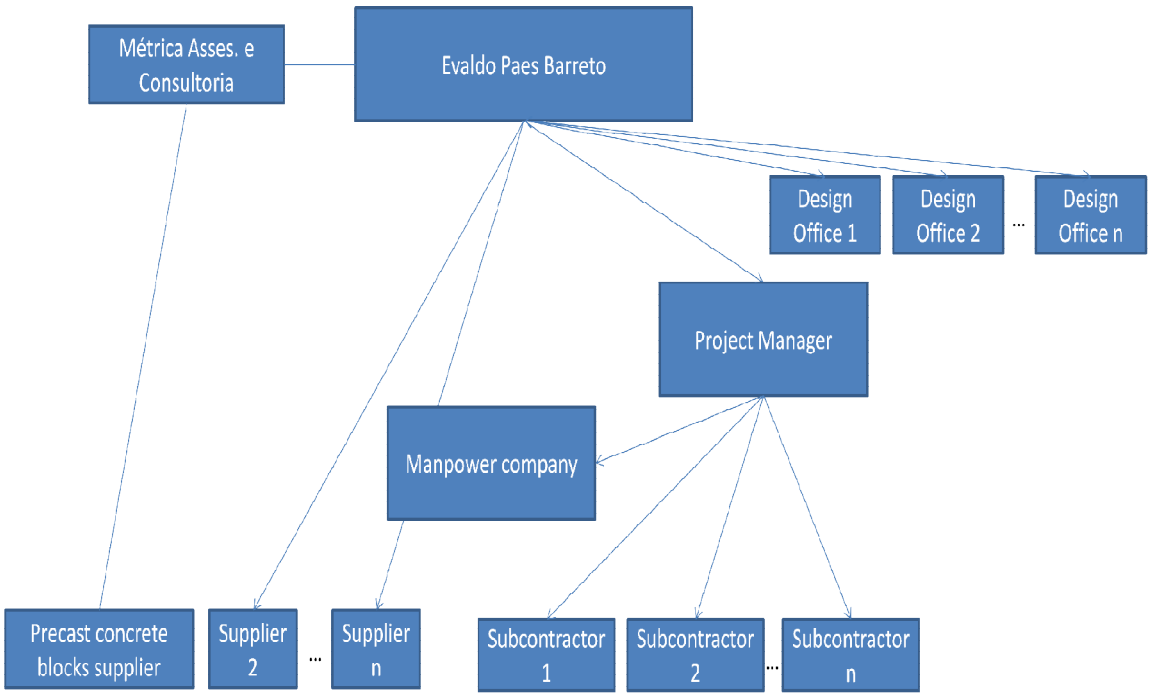

Figure 6: Supply chain network of Evaldo Paes Barreto

Defining the site:

The search of the land occurs with a few partners going to the countryside cities. There, they go to a few real state agencies to see the lands for sale. In conjunction with each real state agency, that knows very well their lands neighborhood, is discussed what type of project can be developed in each land. Also, the characteristics of the project are supposed by the agencies, as for example, the apartment`s size, the number of rooms and the building quality. After, the partners with their experience make a first analysis to see which projects are feasible. This relationship between the agency and the developer enterprise is not a long-term relationship and the agencies can be easily substituted without any loss. However, the support given by them is given without fees as a strategy to sell the land and the possible the future apartments. In this case study particularly, the owner of the land agreed to let the developer construct on it in exchange for future apartments in the building.

Design phase:

After setting the site and the building characteristics, the owners contact several project offices, each one for a specific task, for example, an architecture office, a structure office, a foundation office and a building system office. Often the offices are located in the city of the business or nearby as a measure to facilitate possible future intervention and to decrease the total project cost as the offices in the countryside are less expensive. This relationship between the project offices and the developer is not a long-term relationship and the choice of the offices is made in a cost base. However, not all the offices are taken into account as a possible choice, just those one known for designing good projects. Usually, the offices owned by university professors are seen as a good option.

Consulting:

The company Evaldo Paes Barreto ltda. usually receives advices from Carlos Alberto Tauil, a specialist consultant in structural masonry and precast concrete. The adoption of structural masonry in the Residential Hikari Garden was defined by the owners together with Carlos Alberto and the architecture office as a way to reduce costs and increase construction speed. Using structural masonry implies on a need to use the modular coordination in the design phase as the concrete pre cast blocks are 20cm long.

The fact of always hire the same consultant provide a great benefit for the company since this advisor, knowing well precast concrete blocks suppliers, can ensure the contracted will be reliable. Even if there are many suppliers producing 20cm good quality blocks, it was chosen just one to supply all the business need as a way to increase bargaining power and reduce costs. Therefore adopting just one supplier, the log-term relationship with Carlos Alberto proved to be very beneficial since he can guarantee the supplier adopted delivers on time and a good quality material. In this case specifically, being the building built in masonry structure, a delay on deliveries would impact on the critical path, delaying the rising of the building and thus, increasing the total implementation time.

Project Manager:

The choice of the project manager is seen as very decisive for the success of the project, specifically the developer company Evaldo Paes Barreto ltda. relies on its knowledge of the site environment. Particularly, its knowledge of local construction enterprises that could participate in E.P.B project is crucial for the choice of the right subcontractors for each specific task. Therefore, the subcontractors are chosen not just in a price base but taking into account their service quality and their commitment to complete the services on time. In order to align the project manager interests to those of the company, his income is set in a way that depends totally of the total profit of the business he is managing.

Workforce:

The task of hiring workers to construct the building is outsourced for just one company. The benefits on this strategy are: a better total labor cost and the assurance that the workers employed are able for their jobs. The payment for the workforce company is made in a mix way, comprising a fixed and a variable quota.

Subcontractors:

The subcontracted companies are suggested by the project manager. The relationship with each one of them is short-term for Evaldo Paes Barreto ltda., and in some cases, it is not for the project manager that may have already worked with some. The subcontractors are paid in a service base way, that is, they are paid according to the service realized, that is, measured by the developer company. In the Residential Hikary Gardens case, the outsourced services were foundation and covering.

Suppliers:

The choice of the suppliers is made according to different procedures depending on the type of the material.

For example, the supplier of the pumping concrete for all the slabs was chosen according to price among the two available in São Carlos because the quality of both is similar. Two slabs are made per month. Also, the supplier of the welded meshes,

for the slabs was selected based on price among three available. However in both cases, the reliability of both selected was taken into account once late deliveries would imply on delay of the building completion, being very harmful for the success of this project. This happens because one of the benefits of the industrialization of the construction is the increase in productivity and thus, the construction speed.

However, the suppliers for other components that are not produced by a small number of large firms are chosen with project manager advice as the subcontractors.

4.2 Jardins do Brasil – Abrolhos, Osasco, SP, Brazil

Description:

The Jardins do Brasil Abrolhos is a new development consisting of two residential towers under construction in Osasco, the neighboring city of São Paulo. The construction is being performed by Construtora Adolfo Lindenberg, a renowned enterprise known for constructing high quality buildings for more than 50 years in Sao Paulo area. The company has already delivered more than 450 developments and since 2004, actuates together in a strong relationship with Lindencorp, an investor who contracts the Construtora Lindenberg to construct its business.

While the smaller tower will reach 18 floors, the higher will have 23, both encompassing floors of 3, 4 or 6 apartments. Together both towers will have in total 498 apartments of different sizes, ranging from 67 m2 to 120 m2. In addition, there will be constructed leisure facilities, such as, sports courts, swimming pool and gym.

Figure 7: Jardins do Brasil – Abrolhos

The structure of the towers are being constructed in reinforced cast-in-place concrete cast by pumps and the masonry is made up of ceramic bricks has just the function of shutting the spaces.

Position in the supply chain:

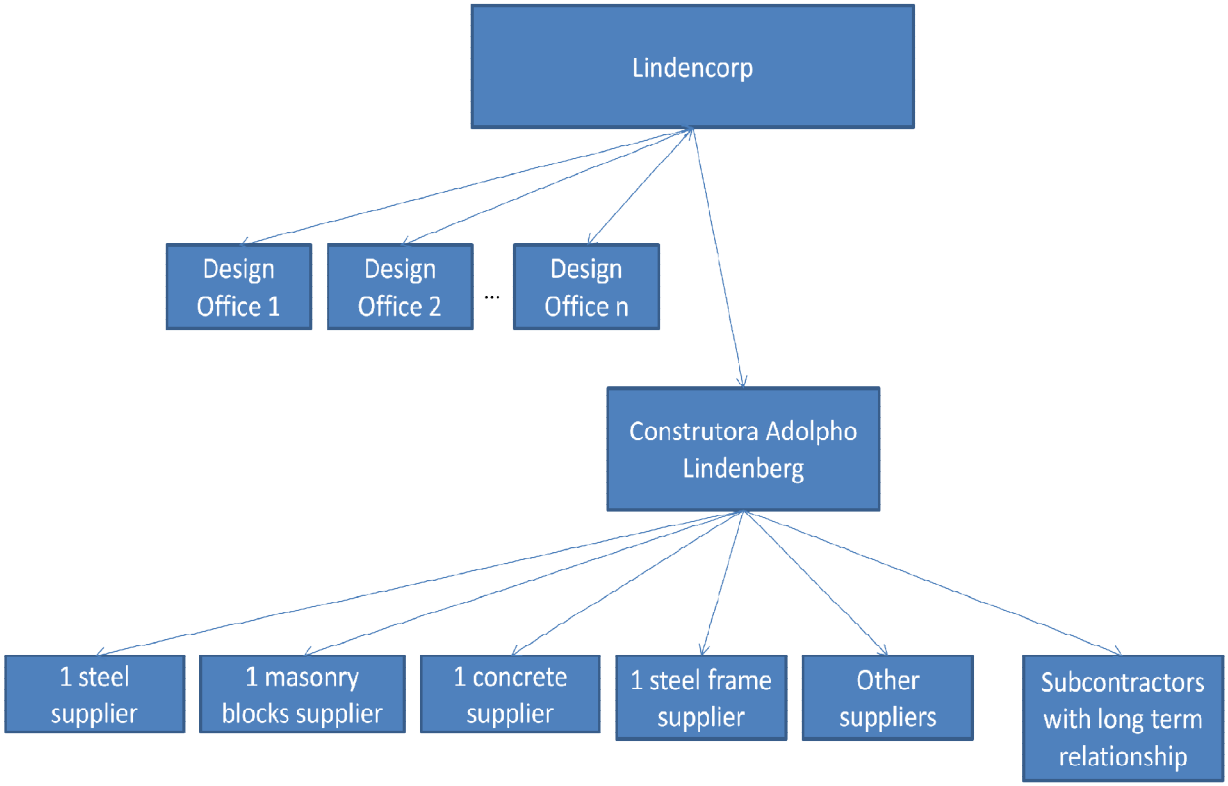

Figure 8: Supply chain network Adolfo Lindenberg

Defining the site:

The site of the development was defined by the investor, Lindencorp, who has contracted the Construtora Lindenberg to carry out the construction.

Design phase:

The whole building is divided into sub systems that are projected independently. In other words, the project of the building is decomposed in several projects in order to facilitate the task. The Jardins do Brasil Abrolhos project encompasses 20 different

projects, each one done by different design offices specialized in the respective project. The projects are:

1) Masonry	2) Architecture	3) Air conditioning
4) Drain	5) Facilities (Eletropaulo)	6) Electrical
7) Window Frames	8) Structure	9) Frames
10) Foundation	11) Hydraulic	12) Waterproofing
13) Fire / Firefighter	14) Interior	15) Landscaping
16) Hall	17) Facilities (Sabesp)	18) Survey
19) Earthwork	20) Topography	

Subcontractors and Workforce:

Almost all of the work is done by subcontractors, being just the management done by company`s employees working on construction site that are (engineers, work supervisors, administrative staff, storekeepers, interns). The reason behind this strategy was the possibility to hire a specialized firm for each task. Furthermore, with the large number of works the company has today, it would be difficult to perform all services with own workforce.

The Construtora Adolpho Lindenberg has partnerships with its subcontractors but if one of them is not doing its job well, the quality department studies other firms with the purpose of substituting the poor one. In case of approving a new subcontractor, the supplying planning department registers the company in order to be contracted.

Suppliers:

The company Adolpho Lindenberg has a partnership with the steel supplier and only one company provides steel for all our works. For concrete, masonry, concrete and steel frames Adolpho Lindenberg has partner suppliers with a long-term relationship. The construction company not only evaluates suppliers by price but also, tries to see the set so that they can meet in the best way possible. For example, when hiring a concrete company, the construction company sees the local plant of each company

and how the company is serving the other buildings. The advantage of having partner companies is they already know contractor`s procedures and they know the way the contractor likes to work.

4.3 Belo Monte Dam, Altamira, Para, Brazil

Description:

The Belo Monte dam is a hydroelectric power plant under construction on the Xingu River in the north part of Brazil. It is supposed to be the second larger by installed capacity (11233 MW) when it starts to operate in 2015, being surpassed just by the Three Gorges Dam (20300 MW) in China. However, because of design changes that have reduced the lake area due to environmentalists pressures, the plant will be able to generate around just 39% of its installed capacity. Being a government project, the government has run an auction to search which enterprises would be responsible for the implementation of the dam. The capable enterprises and interested to participate in this business have organized themselves in two groups being the Norte Energia the winner of the auction with a price of R$ 77,00/MW (around 29 €/MW), acting as an investor. The cost for the construction of this huge dam is estimated in R$ 26 billion (around € 10 billions). Even being part of the looser group, the company Andrade Gutierrez was chosen by the winner group to manage the construction consortium, a consortium that was created for the purpose of constructing the dam, acting as an enterprise with a lifetime equal to the project one (Marcelo).

This project differs from the others hydroelectric plants where the dam, the powerhouse and the spillway are all together. This project particularly, consists of multiple dams, reaching 33 in total, and has the main spillway and the main powerhouse separated for almost 40 kilometers. Even if each dam and each powerhouse can be constructed independently, to generate electricity power all the dams have to be completed.

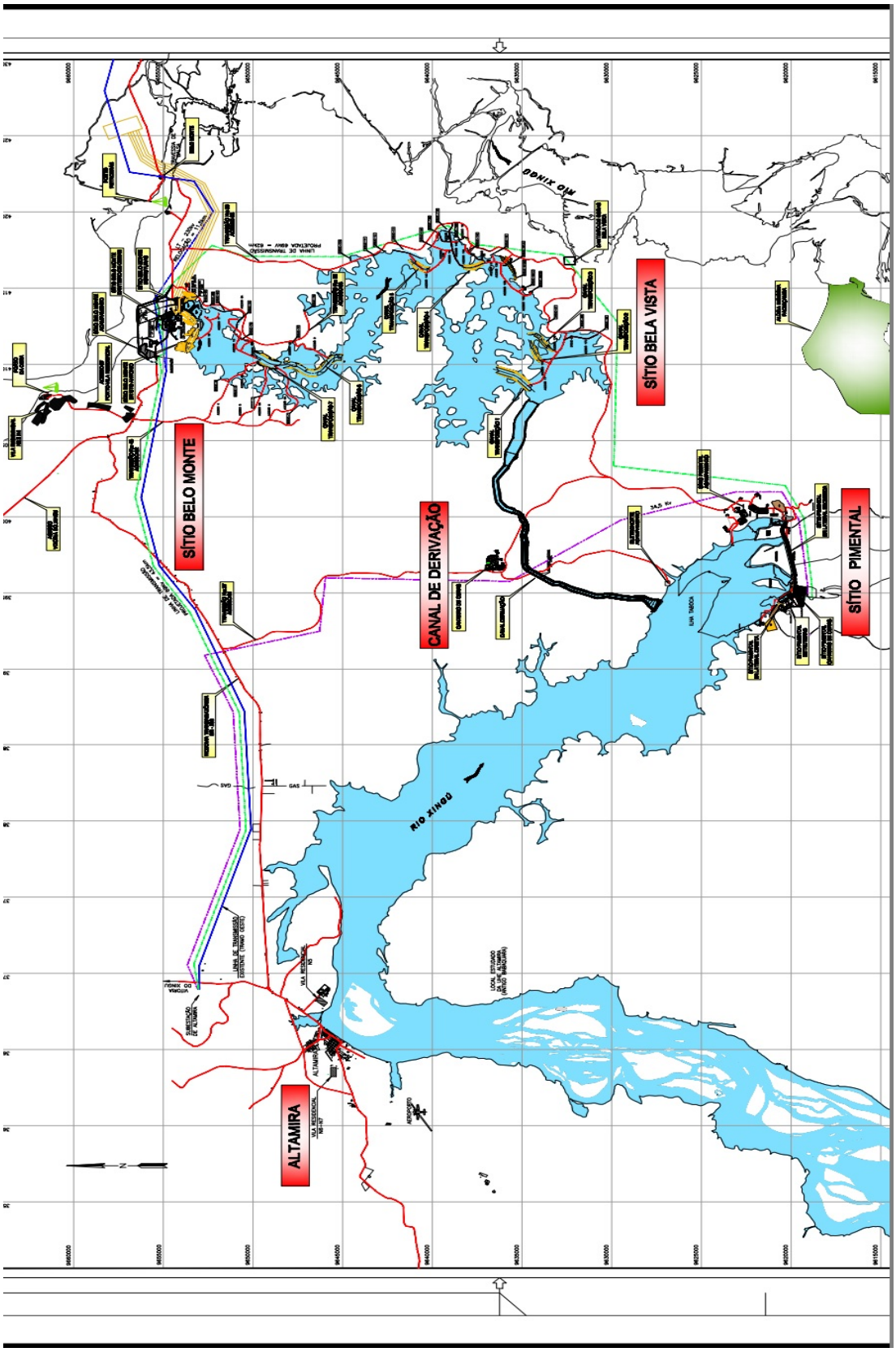
SÍTIO BELO MONTE
CANAL DE DERIVAÇÃO
SÍTIO BELA VISTA
SÍTIO PIMENTAL
ALTAMIRA
RIO XINGU

Figure 9: Plan of the Belo Monte hydroelectric power plant

Contact:

The interview to understand the relationship between the enterprises involved in the construction of this dam was realized with Marcelo Raphe Matar, an Andrade Gutierrez civil intern that has been on the construction site for two months.

Position in the supply chain:

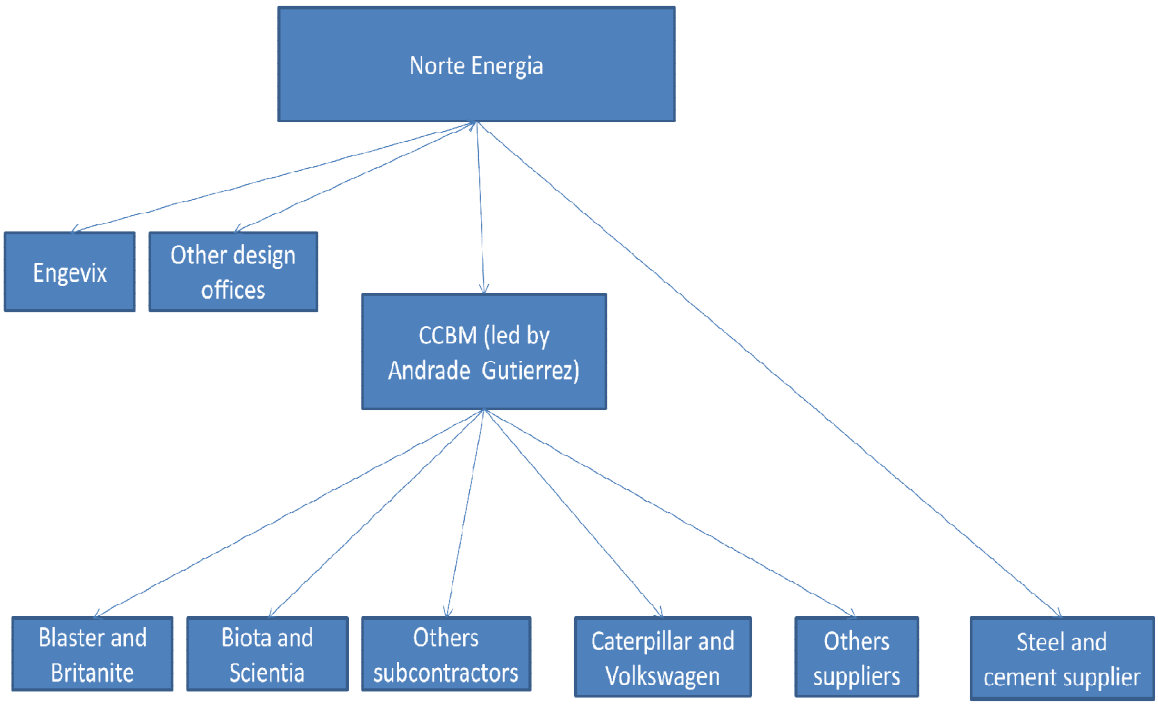

Figure 10: Supply chain network CCBM

Design phase:

The investor has contracted a few design offices to make the project such as Engevix. However, the design of the site and the production project, that is, how the construction consortium constructs what was designed by the offices is done by him. This was a motivation for complains by the construction managers because of two main reasons, that are, the design offices sometimes doesn`t take into account the particularities linked to the production environment of this dam and in case of need to

make some modifications in the project implies on a large bureaucracy, contacting every time the people who have designed.

In addition to the hydroelectric plant project, there are also infrastructure projects. These infrastructures projects, such as the bridge, the port and the road, can exit independently from the dam but their projects are limited by the lake level.

Subcontractors:

Being a very huge project, there are many activities and amount of work to be executed. Also, the amount of work is not fixed during all the project lifetime implicating in periods of high amount of work being executed at the same time and in periods with less amount. Therefore, the strategy of outsourcing some works is a good options once the construction consortium doesn`t have to buy all the equipments and have all the manpower for the whole project time. Furthermore, in some specific works, the subcontractor has an absolute advantage on executing them.

The service quality of subcontractors is heterogeneous, existing companies realizing a very good service and subcontractors, mostly local, executing low quality services. Therefore, the quality control of the services realized by subcontractors is very strict, done by the subcontractor`s audit, by the construction consortium and by the Norte Energia audit. In addition to the quality matters, the local subcontractors re sometimes also not reliable in a matter of meeting deadlines, for example, their equipments breakdown and they don`t know how to fix it.

The relationship between the construction consortium and subcontractors are not long-term because the consortium is temporary. However, some subcontractors have a relationship with a few managers who work for the consortium and are indicated by them to work for CCBM (Belo Monte Construction Consortium). Then, these subcontractors are managed directly by the consortium subcontractors departments, exiting one for each construction site. Also, these departments are responsible to measures subcontractor`s production and pay them accordingly. A list of all the subcontractors can be seen in the picture bellow, in which they were listed with the purpose of controlling their service.

Figure 11: Subcontractors of CCBM (Belo Monte construction consortium)

Soil Excavation:

Being a task with a high volume of work to be executed at the start of the construction, the strategy opted by the construction consortium was to work together with a few subcontractor in this task. In other words, to make the earthmoving, it was decided that the construction consortium would employ his staff and equipments together with rented equipments being conducted by his staff and a few subcontractors, being large or small. The motivation behind this strategy was to size the company`s staff and equipments for the average rate of work, being the peaks executed by the subcontractors.

Rock excavation:

For this task, there are two companies working in Belo Monte, called Blaster and Britanite. They usually works in almost every dam`s construction since they are the

only capable to excavate rocks in such huge dimension. For example, the amount of work to be excavated in Pimental site can be compared to that one of the Panama Canal.

Figure 12: Rock excavation in Belo Monte

Sustainability:

To mitigate the dam`s environmental impact, it was subcontracted some companies specialized in some tasks. For example, Biota was subcontracted to safe the fauna from the flooding. In addition, an archaeological company, called Scientia, was subcontracted to do the archeological survey.

Figure 13: Xingu river landscape

Logistic:

Even though the logistic is very complex, the consortium decided to take care of that, becoming responsible for planning all the deliveries. The products with low added value, such as, sand and crushed stone are available at the local and just have to be transported to the concrete batcher, constructed in the local by the consortium just for the dam`s construction. The industrialized products are transported by sea from the southeast part of Brazil till Belem, and then it is transported by smaller boats till the dam`s port according to Marcelo who says: “the majority of the industrialized stuff come from the southeast part of the country, the major parts with greatest value that will be totally produced off site and will come ready to install on site will be the hydro turbines and the pieces, such as, floodgates and hydraulic jacks come all assembled since doesn`t exist factories for such thing nearby”

Figure 14: River transport in Xingu river

Suppliers:

Steel and cement:

All the steel and cement used in the dam`s construction are bought by Norte Energia, as established by the contract in which the investor contracted the construction consortium. The investor, Norte Energia, engaged just one supplier for each material to supply the entire project. This may be seen as an way to decrease project implementation cost as the steel and cement are seen as high added value products and correspond to a great part of construction cost.

Cars and machines:

Some partnerships were created to supply the CCBM necessity of tractors and cars, being all the tractors bought from Caterpillar and the cars from Volkswagen. This partnership was established in order to reduce costs and was based in supplier`s

quality and cost. In addition, the fact of choosing just one supplier facilitates the maintenance. For example, all the caterpillar`s machines have their maintenance done by Sotreq, the caterpillar official dealer. However, the subcontractor`s equipments can be from every brand.

Figure 15: Caterpillar machines in Belo Monte

Hydro turbines:

The turbines are going to be pre-assembled off-site and just going to be installed in their respective places.

4.4 Interview with Carlos Alberto Tauil, managing partner of Metrica Assessoria, a consultant company in architecture and construction

He supports the industrialization of the construction, that is, the transfer of tasks generally executed on site to factories, as way of increasing productivity, decreasing waste and also fostering the development of technical solutions. For example, the precast slab panels can be designed and easily fabricated with empty holes inside in order to reduce the slab weight and thus, the mechanical loads on beams and on pillars. In addition, it fosters an increase in slab load capability once it can increase

easily the slab height, and thus the bending moment resistance. An example of this kind of precast concrete slab, called hollow core slab, is shown in the figure bellow.

Figure 16: Reinforced precast concrete slabs

Besides the technical development fostered by the industrialization, transferring the tasks from the site to factories, that are more controlled places with structured processes conducting the fabrication of the precast pieces. These processes together with skilled manpower are responsible for decreasing the waste rate while constructing a building from 30% up to 5%, according to the Associaçao Brasileira de Cimento Portaland (Brazilian Association of Portland Cement). Furthermore, it provides the assurance that the precast parts are good quality.

In spite of all benefits listed before, being Brazil a country where traditional construction methods prevail; there is an opposition to the adoption of industrialized methods. There are several explanations for this opposition. Some sceptics claim that more industrialized methods implies on design rigidity once the components tend to be larger resulting in the necessity of the use of the modular coordination.

This argument is countered by Carlos Alberto Tauil who affirms that the modular coordination helps the design phase because it allows the designers to overcome many dimensions issues easily, decreasing the design phase overall time. In addition, he affirms that in case the market doesn`t have the precast parts in the exact dimensions the architectures want, it is possible that the problem can be overcome by the integration between the supplier and the project responsible resulting in a fabrication of special elements as the customer demands. Another critic that was countered by Carlos was the high difference on quality of the industrialized components provided by a great number of suppliers. He argues that this issue is no more a problem these days since there are trustful associations to classify the suppliers, such as Associação Brasileira de Industrializados de Concreto (Brazilian Association of Precast Concrete). This association, towards a seal of excellence, classifies the producers of precast concrete according to three levels, depending on the process verifications focusing on the final quality that is realized in each producer`s factory.

According to Carlos Alberto, the employment of precast concrete is associated with the real estate market, being more used for residential construction in periods of high demand. Also, the number of suppliers also varies accordingly to the demand because its easiness to open and close. However, it is always a very good option for industrial and commercial constructions once it increases the construction speed, and thus anticipates the start of operations in the building. The fact that explains why the employment of precast concrete is not always convenient for residential buildings is because the components that are pre-assembly in factories pay more tax than the services realized on site, being 12% the fee for the state (ICMS) paid for components production in factories and 5% the fee paid for the county (ISS).

Design phases of a regular project in structural masonry:

The design office engaged by the customer studies the feasibility of the structural masonry method comparing it to the traditional one. Then, if the more industrialized is chosen, the basic project is done taking into account of the precast concrete dimensions available in the market. After concluded the basic project, the precast concrete suppliers are contacted in order to request the budget. In this phase, the

suppliers try to give ideas to enhance the basic project for the purpose of making the sale. This can be explained as a strategy of the suppliers actuating in a competitive market once they propose project improvements without being sure they will make the sale but the customer realizes the supplier trusts him and ends up buying from the same supplier that gave the best solution. The suppliers contacted usually belong to the same regional area and the deliveries are stipulated using a contract according to the construction schedule.

Interaction between the precast supplier and the other companies:

Usually the foundations are done by another company specialized in this task. So, the latter has to finish all the work in order to the assembly of the precast concrete start. In turn, when the precast concrete company ends its work, the companies responsible to finish the building come on site. The management of this interaction between the enterprises is done by the project manager which sets the deadlines and the starting dates with the companies according to their capability. The figure bellow illustrates this issue.

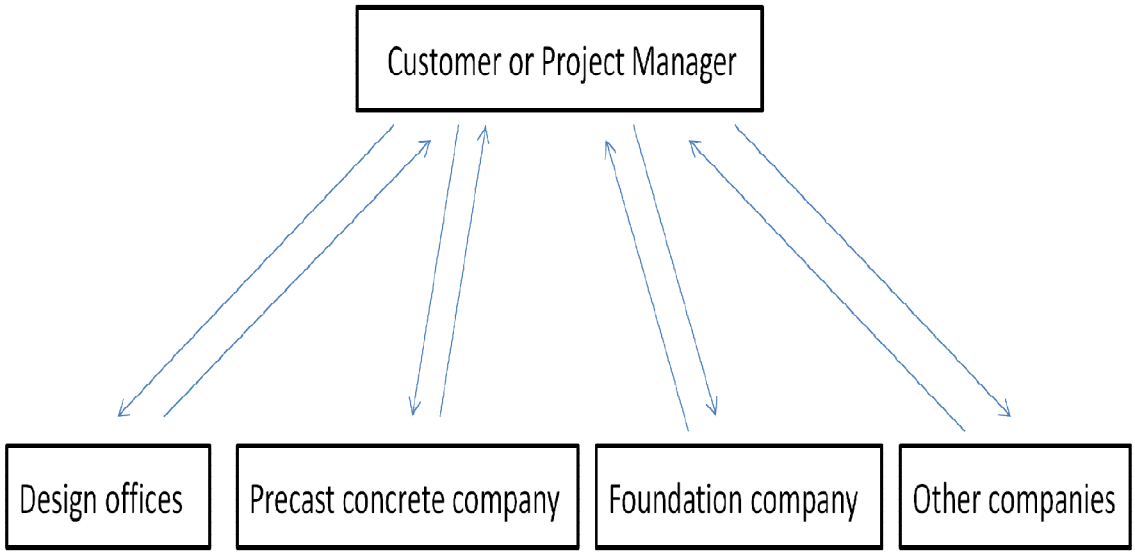

Figure 17: Project manager network

4.5 Extension of the metropolitan line 5, Sao Paulo, Brazil

Description:

The expansion of the metropolitan line 5 “lilaz” of the Sao Paulo metropolitan network encompasses the construction of 11 stations and the tunnels liking them increasing the total extension of the line from 6 to 17 stations. The line 5, which starts in the “Capao Redondo”, will be extended from “Largo Treze” station to “Chacara Klabin” station. The state controlled “Companhia do Metropolitano de São Paulo”, which is the responsible company for the planning, design, construction and operation of the metropolitan transport system in the Sao Paulo metropolitan area, has run two auctions in order to extend the metropolitan line 5. The first one was for choosing who would be the design office based on the company`s request and the second for choosing who will execute the construction.

Figure 18: The map of the line 5, still under construction

Position in the supply chain:

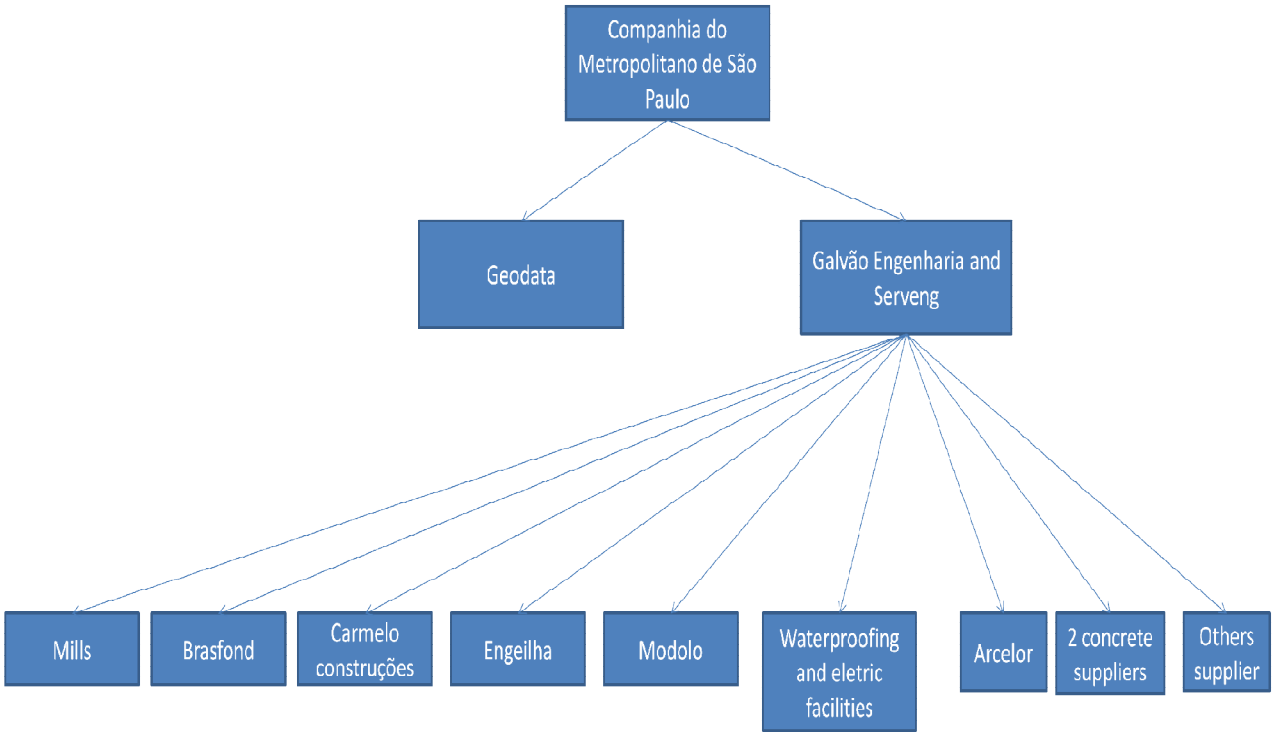

Figure 19: Supply chain network of Galvao Engenharia

Design phase:

After setting the specifications of the extension of the line, the company has run an auction to choose the design office that would be responsible to project the line extension. The winner was an Italian company based in Turin called Geodata S.p.A., which is specialized in projecting metropolitan lines but was its first time doing business in Brazil. This brought some problems because Geodata used in the project some technologies that the people in Brazil are not used to. Therefore, to realize the project they took into account different machine dimensions. According to Mariana: “The biggest problem occurred because they considered when doing the project that the diaphragm walls would be excavated with a machine that can excavate just 1, 80 meters once and the construction company would like to use a larger machine available in Brazil that can excavate 2, 40 meters once to increase

productivity. This succeeded because they did not know that the better equipment was available in Brazil and when they researched from Italy, they thought that just the small one was available." To deal with the situation, the construction company asked to change the project taking into account the more efficient equipment but it could just be done for the other stations, being the first one, Alto da Boa Vista, constructed with the old machines. However, the changes brought other problems to the placement of the steel reinforcement that became difficult its placement inside the excavated walls. This was a reason for more misunderstandings between the construction company and the design office that end up with the construction company doing the necessary adjustments since Geodata was covered by the contracts that they were not obligated to redesign in this situation. Even if the constructor doesn`t have a design department inside, it is able to make some project adjustments with its engineers but in this situation Galvao was not able to do it itself and was necessary to engage another design office just to size the new steel reinforcement. Engaging this new office opened space for more discussions to see who would pay for this design office.

Therefore, it is clear that the fact of engaging a foreigner design office resulted in some problems since the latter was not able to take into account correctly the equipment available in Sao Paulo.

However, the project of the electrical facilities will be done by another office specialized in this task

Construction Consortium:

The next phase was to assign the task of constructing what was projected by Geodata. In order to find the more appropriate company, the "Companhia do Metropolitano de São Paulo" has run an auction with restrictions to participate and the winner consortium was formed by Serveng and Galvao Engenharia. Although this is the first time the firm Galvao Engenharia is working for "Companhia do Metropolitano de São Paulo", Galvao has already participated in infrastructure constructions for the "Companhia Paulista de Trens Metropolitanos (CPTM)" (The regional trains company). According to Mariana Linhares is not a great difference

from working to Metro and CPTM as she said: “because both companies are controlled by the state government and the work is quite similar”.

Subcontractors:

In order to execute the construction, the firm Galvao Engenharia has relied on a few subcontractors. However, there is a limit imposed by the “Companhia do Metropolitano de São Paulo” of subcontractors that the construction consortium can have with aim of avoiding a company to just manage the construction instead of building it itself. The Galvao has a department called commercial department to manage the subcontractor being in charge of the contracts. “They have a lot of partners in Sao Paulo state and they usually work with the same people”

Diaphragm wall:

This is one of the first tasks that has to be executed and consists of excavation of the site perimeter till the bottom of the future station and after filling it with concrete. The reason of doing this is to contain the soil around the station in order to permit the excavation of the whole site. The excavation is done by parts each 2,40m due to the equipment`s capability. After the excavation, the hole is filled with a special liquid that permits the placement of the steel reinforcement and avoid the soil to fall inside. Then the concrete is cast inside from the bottom and the special liquid is collected in the surface. Being a very important task encompassing many specific and complex activities, such as, the excavation with the specific equipment (clamshell), filling the excavation with the polymer liquid and the precision when placing the steel reinforcement, it was decided to rely on an expert subcontractor called Brasfond, which is an enterprise specialized in doing diaphragm walls and has already worked for Galvao. The subcontractor is known by being a large firm doing this task and because of that has also worked in other stations. “They have already worked with Galvao, they are large and were them who were doing this tasks in the other stations”. In turn, Brasfond also had a subcontractor responsible for the liquid polymer.

Figure 20: Hydraulic clamshell in Borba Gato station

Steel Assembly:

For this task, it was engaged a small subcontractor called Carmelo Construções who was responsible to assembly the steel bars in order to leave them ready for the placement inside the diaphragm walls. The firm was based only on the owner and its employees who assembled the steel cages. “It was a very small firm that had a person and his employees”.

Ventilation shaft:

Between two stations there was one ventilation shaft with 13 meters diameter. For its excavation it was engaged a subcontractor called Engeilha that had the equipment and the staff necessary for this task.

Dump trucks:

For the task of removing the soil from the construction site, it was decided to engage just one firm called Modolo who usually works with the construction company Galvao. This enterprise was responsible to remove all the soil resulted from all excavation works. However, even having worked with Modolo many times, there was space for conflict interests since Modolo was paid by each truck trip. This left a reason for disagreements since they wanted to not fill all the truck`s capability in

order to earn more money. For solving this issue, Galvao judged necessary to allocate an employee to check if the dump trucks were leaving the site full. “With this company, Galvao has already worked with them for a long time”. The concern about this task can be understood once it was a critical task as claimed by Mariana: “It was also a critical path to remove the soil since if you could not remove it, you could not continue excavating”

Concrete forms

The firm Mills was responsible for supplying all the forms in this and in others Galvao constructions. Moreover, its employees were responsible for assembling it on site in order to be possible to cast the concrete.

Waterproofing and electrical facilities:

There will be a subcontractor responsible for the waterproofing and another one for the electrical facilities but they had not begun to work yet. The waterproofing subcontractor, as the forms subcontractors, is always the same in all Galvao constructions.

Suppliers:

Concrete:

To meet the concrete needs of the construction, it was decided to have two suppliers at the same time, Engemix and Supermix. The reason behind this strategic choice was that both suppliers were working with high demand and were not able to supply the entire amount needed due to a lot of constructions going on around the construction site. In addition, there is a technical standard that forbids leaving the steel cage immersed in the polymer liquid for a long time, so the delays on the concrete deliveries could not be tolerated since it was a critical path. “So they preferred to have two concrete suppliers because it was a critical path, and also, being a huge amount demanded it was necessary ordering from both”. The estimates of the need of the concrete were done weekly since it was not possible to know how much of diaphragm wall would be excavated in the week because being it

42 meters leaves not possible to predict with certainty what would be found even existing a soil survey.

With the concrete suppliers succeeded the same problem with the dump truck`s firm, they were not using all the trucks capability delivering less concrete at a time since they are paid each concrete truck. In order to solve this situation, was installed a scale for weighting the trucks when they arrived.

Figure 21: One of the concrete supplier`s trucks

Steel:

All the steel used in the construction was from just one supplier, called ArcelorMittal. The responsible for ordering was the company Galvao Engenharia.

Workforce:

The company Galvao was responsible to excavate all the stations with its own equipment and personal. In addition, the structure is done by Galvao using its own staff using the forms from Mills. Therefore, Galvao employed its employees to execute the general tasks leaving to subcontractors more specific tasks.

5 Case Study Analyses

This chapter starts with two subchapters where there is presented the results obtained with a brief explanation for them. The first one regards the implication of the industrialization in the relationship between actors while the second regards its impact in the complexity of project coordination. Following these first two, there is a deep analyses of each case study where there are explained the specific matters of each construction going on in order to make possible to validate the model proposed.

5.1 Implications of the construction industrialization in the relationship between actors:

In order to start to analyse the implications of the industrialization of the construction in the relationship between actors of the supply chain and in the complexity of project organization, respectively corresponding to the arrow [1] and [2] of the theoretical model presented in the research model chapter, I will briefly bring the main issues necessary to understand the analysis from the Research Model chapter.

According to the model proposed in the chapter Research Model, the industrialization of the construction depends primarily on the construction technique employed that is related to the degree of work executed away from the construction site (pre-fabrication) and to the other three forms of industrialization that are rationalized building, standardization and new technology.

Using the data brought from the five interviews I will indentify the general forms of industrialization presented in each construction and see how they impact in the degree of integration among the supply chain and the complexity of the project organization. Moreover, I will show how the modularity is correlated to the industrialization in each case study. In this way, the model presented in this work, which says the increase in industrialization of the construction implies in an increase in the integration with the subcontractors and suppliers and in an increase in the project organization complexity, can be tested.

Before starting to describe the analysis of each case study with its specific issues regarding the general degree of industrialization in construction and its implication in

the degree of integration between actors involved in each development, I will summarize first in the table below the results obtained when analysing the cases studies regarding the implication of the industrialization in the relationship between actors. Following the table there is brief explanation for the conclusions but the to understand better each case study is better to look at the deeper analyses of the each specific case study that follows these two first subchapters.

Table 2: Results of the industrialization in the degree of integration between actors

	Technique employed	Degree of industrialization of the technique employed	Main industrialization form	General degree of industrialization	Average integration between actors
Residencial Hikari Garden	Precast concrete blocks and steel reinforcement made up by ready to install welded meshes	High	Prefabrication of main components	High	Low (arm`s length)
Jardins do Brasil – Abrolhos	Cast-in-place concrete fabricated in one factory and steel reinforcement made up by bars cut, bended and assembled on site	Low	Rationalized building	Medium	High (strategic alliances)
Belo Monte Dam	Cast-in-place concrete fabricated by a concrete central on site and the steel reinforcement	Very low	Rationalized building	Low	Low (arm`s length)
Extension of the metropolitan line 5	Cast-in-place concrete fabricated in two factories and the steel reinforcement made up by bars cut, bended and assembled on site	Low	New Technology	Low to Medium	Medium (supply base rationalization and strategic alliances)

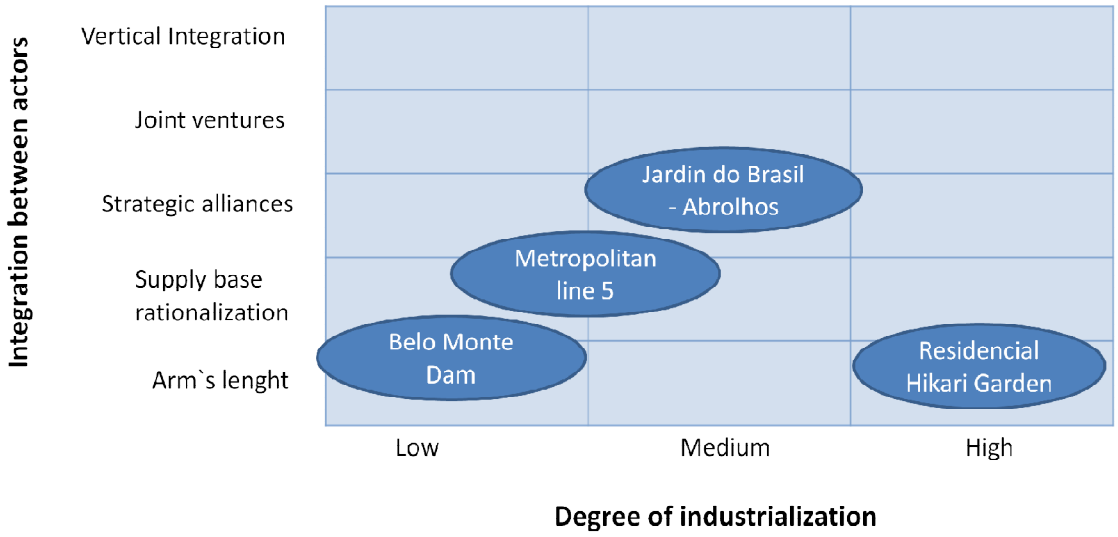

Figure 22: Matrix linking the degree of industrialization and the integration between actors

The construction of the two towers encompassing the Residencial Hikari Garden is the most industrialized among the four cases studies analysed because is the one that has the most amount of work transferred from the site to factories as can be evidenced by the use of pre-cast concrete blocks and steel welded meshes. However, it is not the more industrialized technique of construction possible that is the modularization in which the modules come to the construction site ready to be installed. The case study analysed is characterized by pre-fabrication of the main components that belong to the critical path. For example, the structure and the shutting of the building is made up by precast concrete blocks fabricated in a factory, the steel reinforcement is made up by steel meshes that come to the construction site already welded ready for being put in place. Even being the most industrialized of the cases studies, it was not the one that has the most integration on average in the relationship between the actors involved in its execution contradicting what was expected by the model. However, the relationship with the superintendent is a long-term relationship since he always gives advices for the company Evaldo Paes Barreto, particularly in the choice of the suppliers of the industrialized components that belong to the critical path where the delays in deliveries are not tolerated.

Contrasting the Residencial Hikari Gardens, the construction of the Jardins do Brasil – Abrolhos is constructed in the conventional way, far away from the technique called modularization, with the main components employed in the structure and for shutting the building worked on site. This undertaking is characterized by reinforced cast-in-place concrete with the steel reinforcement made up by bars cut, bended and assembled on site. However, despite of the low industrialization characterizing the buildings construction technique, there is a high concern about industrializing the construction that is tried to be achieved by the building rationalization that is one of the four forms of industrializing construction which are described in the beginning of this chapter and are: pre-fabrication, rationalization, standardization and new technology. Rosso (1980) says rationalization is: “the mental process that governs the action against the waste of time and materials production processes, applying systematic reasoning, free of the emotional flow; is a set of actions that it proposes reforming replace routine practices and resources by conventional methods based on systematic reasoning in order to eliminate randomness in decisions” and in this undertaking, the rationalization is achieved by having many different subcontractors that are specialized in their tasks in order to increase productivity and reduce waste when constructing, leaving just the task of managing the subcontractors for the construction company.

Regarding the relationship between actors, it is very integrated with the company Adolpho Lindenberg, which is the contractor, having a long-term relationship with all its subcontractors that are defended by the engineer Christiana Braga as she claims: “is the best way for avoiding fitting problems when constructing once the subcontractors already know how the firm Adolpho Lindenbeg likes to work”.

The construction of the hydroelectric power plant characterized by having a low degree of industrialization since the main activities encompassing its construction are labor intensive encompassing a huge amount of earthmoving and compacting a huge amount of concrete. However, there are many complex components that come already ready to install in its place that were fabricated in factories far away from the construction site. In accordance with the model, a construction with a low general degree of industrialization would have a low integration with the subcontractors and

this is evidenced when studying the relationship with them, which are characterized by short-term relationships.

The construction of the extension of the metro line 5 of Sao Paulo`s network is characterized by a moderate degree of industrialization. Even employing reinforced concrete cast-in-place to do the diaphragm walls, there is evidenced an increase in productivity comparing to other constructions that employs cast-in-place concrete with the steel reinforcement being shaped on site. This moderate industrialization was achieved since was employed a new equipment to excavate a larger wall module that is an activity belonging to the critical path. The increase in the module excavation was increased from 1,50m to 2,40m, allowed by the new equipment that is excavated almost in the same time it was if it were being used the old equipment, providing an increase of 60% in productivity.

Regarding the relationship between actors, it is evidenced that the contractor, Galvao Engenharia, relies on strategic alliances with some subcontractors and have a supply base rationalization for others.

The rationalized building approach seems to be boosted by the use of specialized subcontractors once the fact that they are executing a specific task all the times gives them the advantage in seeking more efficient ways of doing the same task, that is what the definition of the approach says: “It includes the study of organizations, management, and process of construction to seek more efficient ways of doing the same tasks. It may involve on site or off-site production techniques”.

5.2 Implications of the construction industrialization in the complexity of project organization

Table 3: Implications of the construction industrialization in the complexity of project organization

	General degree of industrialization	Degree of complexity of project organization	Motivation
Residencial Hikari Garden	High	High	Industrialized technique (structural masonry)
Jardins do Brasil – Abrolhos	Medium	High	High rationalization
Belo Monte Dam	Low	-	
Extension of the metropolitan line 5	Low to Medium	Medium	One main project office involved

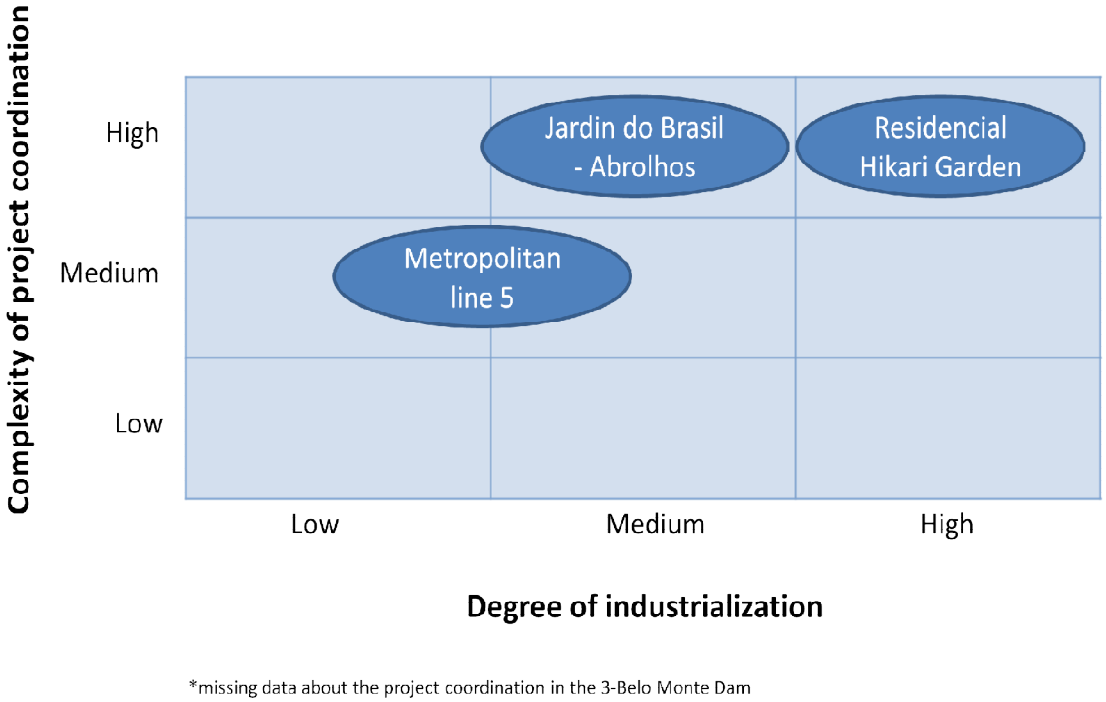

Figure 23: Matrix linking the degree of industrialization and the complexity of project coordination

In order to make possible employing such industrialized technique of construction that uses large main prefabricated components was necessary to rely on the modularity when designing the building once there was the need of making the components fit together in a dimension that could be repeated. For example, the module for the structural masonry wall is the 20 cm, encompassing the block that has in average 19 cm plus 1cm that is filled by the joint. According to Penteado (1980), the modular coordination is defined as “the achievement of the dimension coordination though the use of the module”. Therefore, the industrialization resulted in the need of using the modular coordination to make the components fit in a certain dimension that could be repeated, making possible to manage complex projects coordination since, for example, the water and electric facilities designs need to fit the limits imposed by the structural masonry technique.

Even if the technique employed is not very industrialized, leaving a substantial amount of work to be executed on site, the projects coordination can be not simple because in order to increase productivity and reduce waste the construction company can adopt rationalization measures as a way of achieving a certain degree of industrialization. For example, in the construction of these two building which encompass the undertaking Residencial do Brasil – Abrolhos there were 20 different design offices whose projects were put together making it a complex activity. Engaging many different design offices, one for each specific task in order to increase productivity and reduce waste when constructing, can be seen as a way of industrialize the construction as it was described in the implications of the industrialization in the relationship between actors. Therefore, the increase in the industrialization though rationalization by engaging many specific project offices increases the complexity of project organization.

The complexity of project organization of the construction of the extension of the line number 5 of the Sao Paulo network is simple when comparing to the others case studies analysed since there was one main design office who made the project and the technique employed was cast-in-place concrete produced in concrete factories with the steed reinforcement being cut, bended and assembled on site. However, there were many problems involving this project because the design office was Geodata S.p.A, a specialized Italian firm based in Turin, who did not know the local

availability of new technologic equipments capable to excavate the diaphragm walls each 2,40m instead of 1,5m. It brought the problems since the company made the whole project using the module of 1,5m meters what made the construction low productive since the old equipment had to be used once was the only that could fit the project specifications.

5.3 Analysis of the Residencial Hikari Garden, São Carlos, SP, Brazil

To analyse the implications of the industrialization of the construction predicted by the arrow [1] and [2] of the model suggested, which say respectively that an increase in the industrialization of the construction provides an increase the proximity with the subcontractors and suppliers involved in the project and an increase in the complexity in the project organization.

In order to proceed with the analysis, I will start making clear the industrialized aspects presented in the construction of the residential Hikari Gardens. First of all, as described in the case studies, the development of this two construction towers is realized using a construction technique called structural masonry, in which the precast concrete blocks are produced in factories by external suppliers and just assembled on site. Employing this more industrialized technique, implies on putting together two normally distinct subsystem that are the structural one once the precast concrete blocks substitute the function of the pillars constructed traditionally in cast-in-place concrete and the function of closing and dividing the building spaces. In addition, the projects of the electric and water facilities have to take into account that the buildings are being constructed in structural masonry to size and allocate the conduits in appropriate places avoiding the task of tearing the wall later.

The first picture bellow shows the tears in the wall usually done in the traditional masonry while the second illustrates how the facilities interact with the precast concrete blocks.

Figure 24: Tears in the wall for placing electric ducts

Figure 25: Electric ducts passing through precast concrete blocks roles

The book called Alvenaria Estrutural from Tauil and Nese (2010) supports the arguments presented in the previous paragraph, which claims that the structural masonry needs more integration and coordination between the actors involved in the project design, since there is a comparison between the project phases in the traditional technique and in the structural masonry technique. In order to depict the main differences that occurs in two of the five phases, I am going first to clarify all phases. In the traditional construction technique five phases of the project development are: project program, preliminary study, legal project, preliminary draft and the executive project. In turn, in the structural masonry construction technique the project phases coincident are: project scope, study and preliminary draft, legal project, pre executive project and executive project or production project. The table presented bellow easies the way to understand how the phases are correlated.

Table 4: Structural masonry and traditional technique differences

Traditional Technique	Structural Masonry
Project program	Project scope
Preliminary study	Study and preliminary draft
Legal project	Legal project
Preliminary draft	Pre executive project
Executive project	Executive project or production project

The main difference was found in the preliminary study phase that is suggested to be called study and preliminary draft in the structural masonry technique is employed, in which, according to Tauil (2010), he claims that the structural masonry calls for an integration between disciplines as can be extracted from his book “with the current tools of research and drawing production, develop a preliminary study with the

characteristics of the preliminary draft phase is absolutely common, the availability of information and the production speed makes necessary the unification of many steps, including all disciplines, structure, electrical and water facilities, surrounding project etc."

In addition, another great difference was found between the preliminary draft and the correspondent pre executive project because in the first there is no discussion before about putting together the different disciplines, which can be called also subsystem, such as structures and electrical facilities, water facilities and surrounding project making this phase difficult ending up with bad solutions. In turn, regarding the structural masonry technique in the pre executive phase starts the task of sizing the subsystem in a time in which the modulation is closed, and ending the zoom that showed the constructive interferences (Tauil, 2010). The whole table explaining all the phases in both traditional and structural masonry is from the book Alvenaria Estrutural (2010).

Therefore is largely explained in the theory the implications in the project phase brought from the degree of industrialization of the construction. As shown in the previous paragraphs, when changing from the traditional cast in place concrete with the masonry in traditional bricks to the structural masonry construction technique, in which the pre cast concrete blocks are produced in factories from many inputs, there is an increase in the complexity of project organization.

Comparing the theory depicted above to the case study of the construction of the Residential Hikari Gardens in structural masonry, it is evidenced that the matters pointed by the theory respecting the design phase occurs in the project of the construction of the two towers since as written in the chapter of the case study. It affirms that there is a prior phase of valuation of the construction method which involves the consultant, the principal and the architecture office as the text part demonstrates: "since defined by the owners together, the consultant and the architecture office as a way to reduce costs and increase construction speed". After that, there is a coordinated organization of the other project offices to design their subsystems taking into account the constraints brought from the technique employed.

After having explained the implications of the increase in the degree of the industrialization through the adoption of pre fabricated pre cast concrete blocks in the project coordination, I will demonstrate its impact in the supply chain, specifically in the difference in the relationship with the suppliers/subcontractors.

Since the main input when changing from the traditional method to that one in structural masonry is the pre cast concrete blocks we would expect an increased concern about the supplier of this input. In fact, it is evidenced in the supply management of the Hikari Gardens once that the reliability of this supplier is very important for completing the construction on time avoiding extra costs resulted by the delay in the deliveries of the apartments to the final customers. In this case study, this is ensured by having a long-term relationship with a consulting firm specialized in constructions in structural masonry which know very well the suppliers of pre cast concrete blocks as can be evidenced by the passage in the case studies chapter: “The fact of always hiring the same consultant provide a great benefit for the company since this advisor, knowing well precast concrete blocks suppliers, can ensure the contracted will be reliable.” This is supported by the fact of when comparing the traditional made up by normal bricks; in which if there is a delay, the building continue rising having the delay of the bricks no impact in the rising of the structure, since the bricks have just the function of one subsystem; to the method using pre fabricated concrete blocks, in which the delay of the supplier impacts negatively in the rising of the building increasing the time of the whole construction.

In addition to the use of pre fabricated concrete blocks, characterizing the industrialization through the last of the four general forms to industrialize the construction, evidenced by Tatum, C. B., Vanegas, J.A. and Williams (1987), that are rationalization, standardization, new technology and pre fabrication, explained in the start of this chapter called pre fabrication, there is the use of steel welded meshes, which come assembled from the supplier, instead of assembling the mashes on site from steel bars using manpower. As well as happens with the supplier of the precast concrete blocks, with the steel welded meshes there is also a concern about having the input arriving according to schedule because it impacts in the critical path since the meshes belong to the structural subsystem, that is the one which impacts the rising of the tower. However, being the supplier who delivers the bars the same as

the one who delivers the ready steel welded meshes and being the steel suppliers very big respecting the Evaldo Paes Barreto precludes a higher integration in the relationship with the supplier. Nonetheless, the reliability of the delivers is guaranteed since the steel suppliers are large and structured companies.

5.4 Analysis of the Jardins do Brasil – Abrolhos, Osasco, SP, Brazil

As has been done in the analysis of the model for the others case studies in the previous sections, I will start the analysis of the Jardins do Brasil - Abrolhos by indicating the aspects of the construction of the two residential towers.

Starting from the construction technique aspects, it seems to be less industrialized when comparing to the Residential Hikari Gardens since it uses less prefabricated components leaving more amount of work to be executed on site instead of executing more components in factories. Continuing this comparison, instead of using pre fabricated concrete blocks for shutting the building and also supporting the loads since it comprises the structure subsystem in the Residential Hikari Gardens, in the construction of the Jardins do Brasil – Abrolhos, the structure subsystem is comprised by steel reinforced cast in place concrete and the masonry is made up by traditional bricks. However, in a way of implementing the rationalization of the masonry subsystem in order to reduce the waste rate, there was used a specific project for that subsystem. Two definitions of rationalization are given in the next two paragraphs.

According to Rosso (1980), rationalization is: “the mental process that governs the action against the waste of time and materials production processes, applying systematic reasoning, free of the emotional flow; is a set of actions that it proposes reforming replace routine practices and resources by conventional methods based on systematic reasoning in order to eliminate randomness in decisions”.

Tatum, C. B., Vanegas, J.A. and Williams, J.M. (1987) define rationalized building as: “the approach that applies the knowledge of industrial production methods and techniques to construction. It includes the study of organization, management, and

process of construction to seek more efficient ways of doing the same tasks. It may involve on site or off-site production techniques”.

The rationalization applied in the development of the Jardins do Brasil – Abrolhos, in addition to the fact of having a specific project for the masonry even being made up by traditional bricks, is evidenced by the fact of having 20 different specific project offices involved in the design phase, each one designing its specific part. A picture of a traditional brick is illustrated bellow:

Figure 26: Traditional brick with roles, called in portuguese "tijolo baiano"

The routine practices pointed above of having many specific design offices to project the whole building is a way of improving the company`s competitiveness as it is, in other words, a way of rationalization the construction that is supported by Rocha Lima Jr. (1993) as a way of staying in the sector while it is becoming more competitive. Rocha Lima claimed that who wanted to continue in the sector needed to tread routine business action guided by a vector of modernity based in the adequacy of methods of administration and management, the ability to understand the relationship market-entrepreneur in all its dimensions and in conditioning the processes of production technology that resulted in an improvement in the level of losses through rationalization.

The 20 projects encompassing these two buildings as depicted in the case studies chapters are:

1) Masonry	2) Architecture	3) Air conditioning
4) Drain	5) Facilities (Eletropaulo)	6) Electrical
7) Window Frames	8) Structure	9) Frames
10) Foundation	11) Hydraulic	12) Waterproofing
13) Fire / Firefighter	14) Interior	15) Landscaping
16) Hall	17) Facilities (Sabesp)	18) Survey
19) Earthwork	20) Topography	

5.5 Analysis of the hydroelectric power plant of Belo Monte, Altamira, Pará, Brazil

In this section, I start the analysis of the model regarding its arrow number [1], which says that the industrialization of the construction has an impact in the relationship between actors involved in the construction. In a general way of viewing, the industrialization changes the supply chain characteristics, not just the relationship between the actors.

The construction of the Belo Monte dam is a particular type of construction once its size and complexity makes its study very important for this work. Since the construction of a hydroelectric power plant involves a large number of specific tasks, not just the main tasks of constructing residential building that are casting concrete or rising brick walls, it needs the execution of such amount of tasks that the contractor has to rely on many subcontractors.

In the literature, the industrialization of the construction is achieved by four general forms that are rationalization, new technology, standardization and pre fabrication (Tatum, C. B., Vanegas, J.A. and Williams (1987).

Starting by analyzing the employment of new technologies in the construction of a hydroelectric power plant is essential to reduce costs since using the more recent specific equipments can increase the construction speed and reduce the manpower employed on site, in other words, reduce the total costs. What succeeds in this type of construction is that some specific assets capable to reduce the total cost are very expensive and do not worth it to the construction consortium buy all them by itself since not just because the consortium has a limited life time, but also because the employment of specific technologic assets are usually used in just a small period of the lifetime of dam`s construction.

Following this thinking of the previous paragraph, we can explain the fact of the construction of the hydroelectric power plant of Belo Monte has more than 70 subcontractors working together in order to help the construction consortium. For example, the task of excavating rocks has specific issues involved to its exaction that are: the firm has to have a license to manipulate explosives once this materials can be bought and employed just with this license and the professionals who are capable to manipulate dynamites are a few and usually works in specific firms that have a more flat demand for this task. This can be evidenced by the passage written in the Case Studies chapter: “For this task, there are two companies working in Belo Monte, called Blaster and Britanite. They usually works in almost every dam`s construction since they are the only capable to excavate rocks in such huge dimension”. Thus it is easier for the consortium to subcontract instead of excavating rocks, increasing a tier in the supply chain.

In addition to subcontracting the firms for the task of rock excavation, it was also decided to subcontract firms for dealing with sustainability with the aim of mitigating the environmental impact. The strategy motivation behind this choice was that the firms are specialized in doing these tasks and would be worse for the consortium to hire people who have never worked together than subcontract a specialized firm that have the assets already organized.

According to Hall (1983), the number of components a company has to handle implies in carrying an onerous administrative burden. Following this thinking, in addition to the fact of choosing to subcontract instead of executing some tasks since

buying some required assets do not worth it, Hall explain that when you reduce the companies you have to handle facilitates the management of them reducing administrative costs. Although his study was based on research carried out at automotive industry, the principles are generically applicable, and have subsequently been applied across a wide array of sectors. In fact, Mariana Linhares interview showed that her company Galvao Engenharia also found in subcontracting a good option for enhancing the supply chain performance.

Therefore, the strategic choice of subcontracting was essential since it permitted to reduce the complexity in managing the suppliers once the subcontractors became responsible for managing the components supply of their services. Doing so, it approximates to the Japanese organizations in which the companies usually deal with a much less number of suppliers as can be evidenced by Hall (1983) “For any given tier it seemed that Western organizations tended to maintain relationships with far more suppliers than did their Japanese counterparts. Moreover, Japanese companies had more levels spanning raw materials to finished goods in their supply chains than did those in the West. In short, Japanese tiers were far more pyramidal in structure. The difference can be seen in the figure bellow took from Hall (1983) where it is depicted in the left a common supply network in Japan and in the right a common supply network in the West.

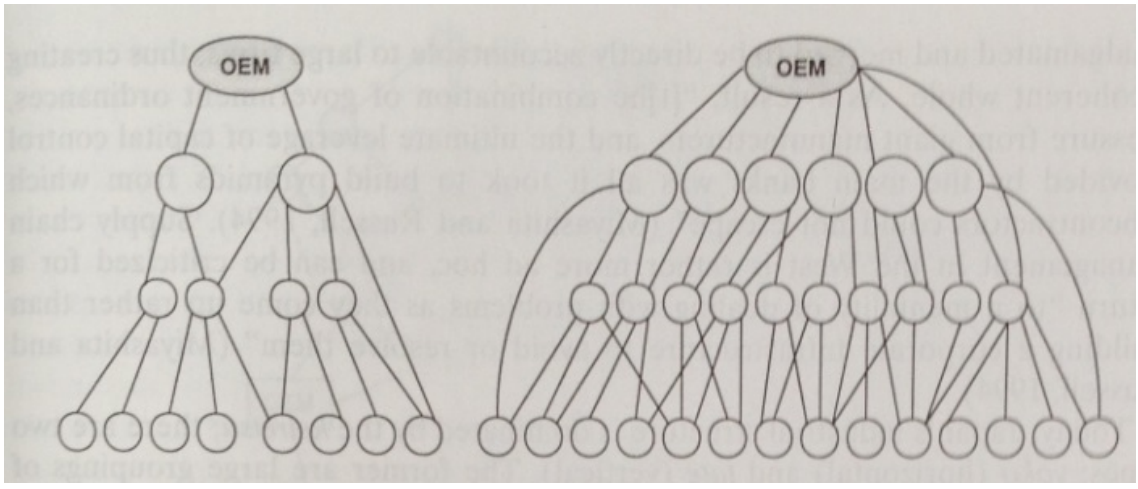

Figure 27: Common supply network in Japan in the left and in the right a common supply network in the West.

Therefore, subcontracting fosters the integration between the actors presented in the same supply chain since there are less suppliers to manage but their role has an increased importance since they execute the services managing the material suppliers. However, being the construction consortium a company with limited lifetime, it is not possible to evidence the integration between the parts by the fact of working always together in more projects. Moreover, since the dimensions of the dam`s construction when the subcontractors were chosen, there were a huge necessity for them in every sector that almost every local company had been employed in the hydroelectric power plant of Belo Monte.

Regarding the influence of the industrialization in the complexity of project organization, there was not enough data brought from the contact person, Marcelo Matar, in order to make it possible to analyze in a deep perspective the correspondent arrow [2], which claims that an increase in the industrialization of the construction impacts in a major complexity in the project coordination. However, Marcelo Matar explained that there were more than one large office firms from the southeast region of Brazil working together, which is the more industrialized part of the country. This fact contrasts the choice of the company Evaldo Paes Barreto who preferred to hire project offices from the region where the construction was taking place. A very good explanation for this difference is the fact that the complexity of the dam`s execution is so great that are no capable project offices in the north part of Brazil to project the power plant. Thus, it can be seen as the industrialized aspects provided by the new technology adopted in the dam`s construction, which are explained in the beginning of this subsection, increased the complexity of project coordination being reflected by the necessity of hiring skillful project offices from a region far away from the construction site.

5.6 Analysis of the metropolitan line 5, Sao Paulo, Brazil:

In the construction of the metro line 5, even if the concrete is cast-in-place to do the diaphragm walls, there is an increase in productivity comparing to other constructions of this kind. It was mainly possible because the employment of a new equipment to excavate a larger wall module that is an activity belonging to the critical path. Increasing the construction speed is related to the increase in productivity once the same amount of time spent by the new technological equipment produces a

higher rate of work. For example, the increase in the module excavation was increased from 1,50m to 2,40m, allowed by the new equipment that is excavated almost in the same time it was if it were being used the old equipment, providing an increase of 60% in productivity.

According to the book “Constructability improvements in construction using prefabrication, preassembly and, modularization” (1987), new technology in the equipments, in addition to new construction techniques, standardization and rationalization; is also a form to industrialize the construction industry. Therefore, it is rational that the employment of the new equipment would have the impacts in the supply chain and in the complexity of project organization.

Being the new equipment responsible for increasing the module dimension of the diaphragm walls that represents the limits of the future station, it changes the possible dimensions that the station can have varying from multiples of 1,50m prior to multiples of 2,40m. According to the Brazilian technical standard NBR 5706, the module is: “the distance between two consecutive plans of the system that originates the reticulated spatial reference” (ABNT, 1977). Also called base module, the module is universally represented by “M” and is adopted by the majority of the countries, encompassing Brazil and Italy, as having the dimensions of 10cm or 1decimeter. In Brazil, the base module has been adopted since 1950 with the publication of the NB-25R. In the United States the base module is 4 inches.

According to the AEP (1962), the module has three essential functions:

1) Is the common denominator of all ordered measures
2) Is the unit increase of any modular dimension with the aim that addiction or the subtraction of two modular dimensions is also a modular dimension
3) Is a numerical factor, expressed in units of the adopted dimension system or multiple of a progression (Greven and Baldauf, 2007)

The picture bellows from Greven and Baldauf (2007) depicts the components location in the reticulated spatial reference.

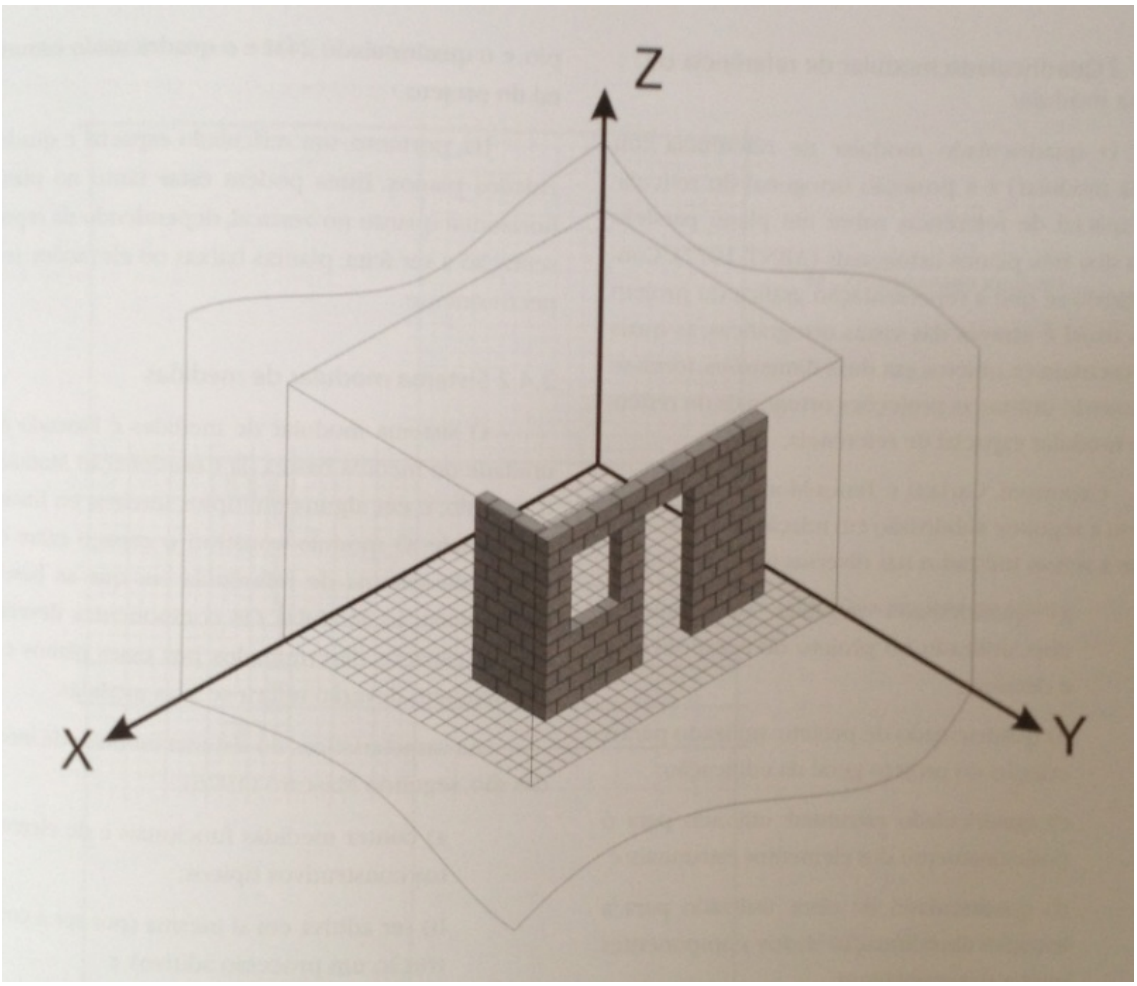

Figure 28: Components location in the reticulated spatial reference

In addition to the existence of the base module defined above, there are the sub modules and the multi modules where the multi modules dimension are dictated by n X M (being n an integer) and the sub modules by M / n (being n an integer).

Therefore, the adoption of the new excavation equipment which delineates the possible station dimensions changes it from 15M to 24M.

In order to analyze the implications of this change, I will remind what was described in the case studies chapter. The design office charged to project the new stations of the metro line 5 extension was the firm called Geodata S.p.A, a Turin based firm specialized in the geotechnical field, as the firm claims in its website: “Our deep experience in the underground, as witnessed by the works carried out in all the

world, qualifies us as full partners to accept this challenge of modernity geotechnical". However, even if this company has won the bid for projecting the stations, the output was problematic once the firm, not belonging to the Brazilian reality, supposed wrong that the only equipment available in Sao Paulo was the old one with low productivity since its exaction capability is 1,50m. After this wrong assumption, the project has been done with Geodata using 15M as the multi module for delineating the external dimensions of the stations. This brought huge costs for the construction of the extension of metro line 5 of the Sao Paulo network once using the low productivity old equipment implied in spending much more than if the new technologic excavation equipment was employed. After constructing the first station as described in the project from Geodata with the old equipment, it became clear that the old equipment would have to be substituted to the new one in order to reduce the construction costs. The problem brought from this change was that the new one could not excavate in the same multi module as designed by Geodata of 15M, bringing the necessity of redesigning a great part of the project in order to make the project fit to the new equipment. A discussion between Geodata and Galvao Engenharia started in order to see who would be responsible for the extra costs in the project, ending up with Galvao Engenharia paying itself the extra cost since it was more economic than continue constructing with the low productivity equipment.

Therefore, the increase in the industrialization of the construction though the new technology, in the case represented by the new excavation equipment, implies in an increase in the complexity of the project organization since the designers has to take into account a broad range of things while designing, such as the suppliers of the equipments to see what is available.

Following the analysis of the impact of the industrialization in the complexity of the project organization, we will analyze the impact of the industrialization in the relationship between actors. In this field, in addition to the complexity brought from the new technology that is the third general form of industrialization in construction, I will focus on analyzing the impact of the first form of the industrialization in the construction that is the rationalized building. The rationalized building approach implies the knowledge of industrial production methods and techniques to

construction. It includes the study of organizations, management, and process of construction to seek more efficient ways of doing the same tasks. It may involve on-site or off-site production line techniques (Tatum, Vanegas and Williams, 1987).

The rationalized building approach seems to be boosted by the use of specialized subcontractors once the fact that they are executing a specific task all the times gives them the advantage in seeking more efficient ways of doing the same task, that is what the definition of the approach says: “It includes the study of organizations, management, and process of construction to seek more efficient ways of doing the same tasks”.

Applying the definition of rationalized building described to the construction of the extension of the metro line 5 of the Sao Paulo network, I can evidence the presence of few specialized subcontractors that are: Carmelo Construções, the steel assembly firm; Mills, the concrete forms company; Brasfond, the company specialized in foundations owner of the new equipment described above as being responsible for its impact in project organization; Modolo, the firm responsible for removing the excavated soli from the site and; the firms responsible for waterproofing and electric facilities.

Following this path, in which a higher degree of the industrialization of the construction is achieved though the using of the rationalized building approach, we can conclude that the higher the industrialization, higher is the number of specialized subcontractors working on a single project.

5.7 Contingent factors

Implications of the construction company`s size in the relationship between actors:

To verify the arrow number [3] of my model which says the supplier – buyer relationship is affected by the size of the construction company we will analyse first how the suppliers of the same materials relate to each company.

Prior to start linking the relationship with key materials suppliers such as steel and concrete ones to company`s dimensions I will start giving an idea of the size of each company through their sales revenue that is depicted in the table below.

Table 5: Revenue of the companies studied

Name	Revenue (brazilian real)	Revenue (euro)	Year
Evaldo Paes Barreto	*	*	*
Construtora Adoplho Lindenber	32.496.000,00	12.546.718,15	2012
Andrade Gutierrez (CCBM)	1.325.012.000,00	511.587.644,79	2012
Galvao Engenharia	2.128.000.000,00	821.621.621,62	2011

In order to facilitate the analysis, it was decided to classify the companies in a qualitative scale (small, medium and large) since there is no data about Evaldo Paes Barretto revenue. The companies are sort in the table below according to its size. For the firm Evaldo Paes Barretto, even if there is no data about its revenue, it was classified as being a small firm since it has just two building under construction by the moment.

Table 6: Size of the companies studied

Name	Company`s Size
Evaldo Paes Barreto	Small
Construtora Adoplho Lindenber	Medium
Andrade Gutierrez (CCBM)	Large
Galvao Engenharia	Large

5.7.1 Relationship with concrete suppliers:

It is depicted below in a matrix the size influence on the relationship with concrete suppliers, in which the companies are disposed according to their size and their relationship with them. The relationships types were segmented from Cooper`s (1993) article, which is described in the Research Model chapter. Some modifications were made in order to adapt to the concrete supplier relationships shown in the previous chapter that are: the strategic alliance was divided in two, an alliance made just for the construction of a given project and an alliance for all

construction the company executes; and the joint venture was suppressed since it was not encounter in the case studies.

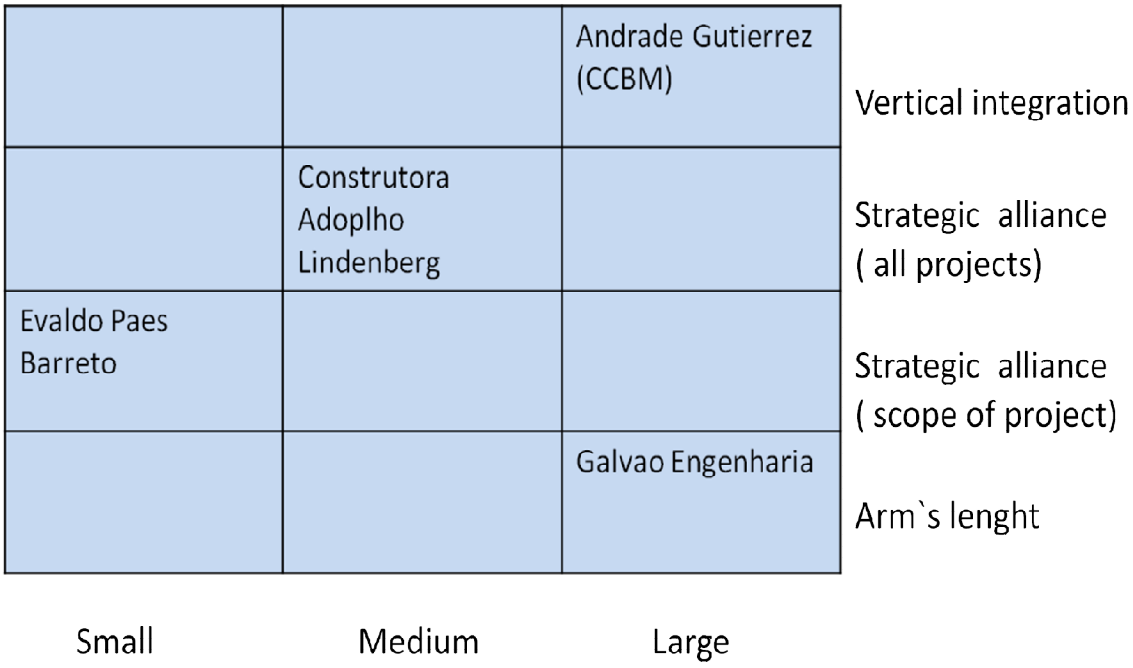

Figure 29: Kind of relationship with concrete suppliers

The idea presumed by the model was that larger companies would be disposed in the strategic alliance for all projects with their concrete supplier while for smaller ones would be more difficult to start a partnership due to their small size. The abnormalities encountered in the matrix for the company constructing Belo Monte, Andrade Gutierrez, and the company Galvao Engenharia can be explained by the project characteristics.

According to Mariana Linhares, Galvao Engenharia has chosen for buying concrete from two different suppliers because of the high demand for concrete in the construction site region, which has left the suppliers not able to deliver every time the company needed. In addition to this context, the regulation laws for the underground construction were strict leaving it impossible to stop the construction of the diaphragm walls once the steel reinforcement had been placed inside the excavated

walls. From the previous chapter, Mariana says: “So they preferred to have two concrete suppliers because it was a critical path, and also, being a huge amount demanded it was necessary ordering from both”. Therefore, due to the projects characteristics the Galvao Engenharia is encountered in the arm`s length line.

Also, the company Andrade Gutierrez is encountered in a strange position because since it decided to have a concrete central on site, shown in the picture below.

Figure 30: Concrete production in Belo Monte

The reason behind this strategy was also due to specific project characteristics. In this case, the lack of concrete suppliers near the construction site capable to supply enough concrete and the huge amount of concrete needed to construct all the dams belonging to the Belo Monte hydroelectric power plant made necessary the construction of this huge concrete central.

5.7.2 Relationship with steel suppliers:

As was done with the concrete suppliers in the previous part, in this part, the same matrix linking the size of the construction companies with their relationship with the steel suppliers will be constructed. However, since none of the case studies presented its own production of steel I decided to simplify the matrix taking out the vertical integration as a type of relationship. It has occurred because the knowledge and assets necessary to produce steel is very specific and just big companies are capable to produce this material. The matrix presented bellow depicts the relationship of the construction company with their suppliers. However, the CCBM (with Andrade Gutierrez management) is not presented since who buys the steel for the construction of the Belo Monte dam is the consortium Norte Energia, the investor behind the dam`s construction.

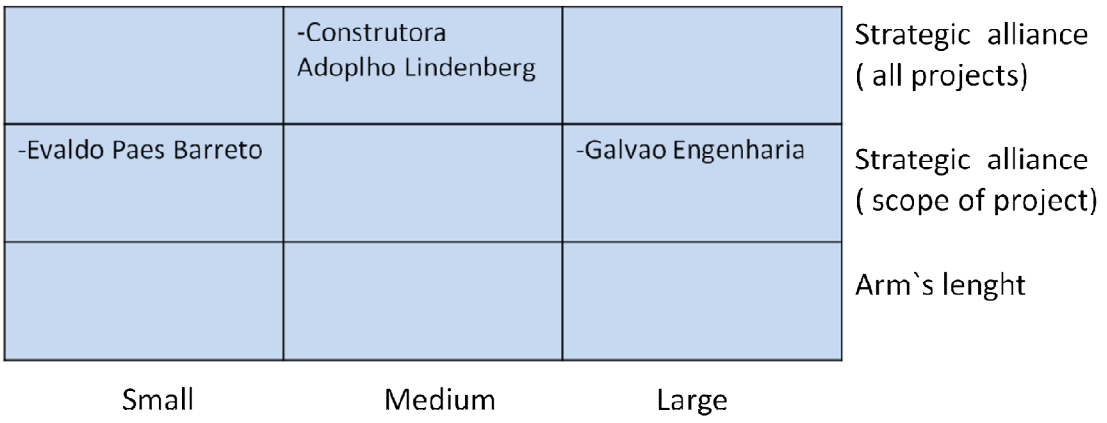

Figure 31: Kind of relationship with steel suppliers

***CCBM is not present because who buys the steel is Norte Energia (principal), the power plant investor consortium**

The possible reason for the strange fact that both large companies find themselves with a relationship with steel suppliers characterized by partnership just for the scope of a singular project contrasting the medium company which has a strategic alliance with its steel supplier may be explained by the fact that both large firms don`t have all its project in the same geographical area. For example, Galvao Engenharia

constructs all over Brazil and depending on the site, it has to take into account different steel suppliers once their production plant location may impact in their prices since the logistic costs increase for plants located away from the construction site.

Therefore it is possible to see that the medium construction company has stronger ties with its steel supplier than the small local company since as predicted by the model based on Erwin Hoffman (2009) which explained the demand irregularity as an obstacle to getting in partnerships. On the other hand the large companies, even having a more regular demand for steel since it is constructing more projects at the same time, their projects are spread all over Brazil making convenient buying from different suppliers instead of partnering with just one.

5.7.3 Relationship with subcontractors:

In this part, there will be analysed if the construction company`s size impacts in their relationships with subcontractors presented on site.

As evidenced by the case studies, the choice of involving third parts on the construction site is common for small to large construction companies although they may be boosted by different reasons going from necessity in the case of just the subcontractor is able to execute the specific task since it may need some specific knowledge to the easiness of managing subcontractors instead of doing the job itself.

Evaldo Paes Barreto: Relies on subcontractors because the company usually develops projects in different cities in the countryside, being impossible to execute all the tasks with its own manpower. In this case, even if there may be not necessarily a specific knowledge for executing a task, the fact of having its constructions spread forces the company to subcontract.

CCBM: According to Marcelo Matar, relies on subcontractors because the amount of work is not fixed during all the project lifetime implicating in periods of high amount of work being executed at the same time and in periods with less amount. Therefore, the strategy of outsourcing some works is a good options once the construction consortium doesn`t have to buy all the equipments and have all the manpower for

the whole project time. However, in some cases, there is a necessity in outsourcing the service because it is very specific. For example, for the tasks of rock excavation and sustainability, the construction consortium has subcontracted two firms for each field area that are respectively, Blaster and Britanite; and Scientia and Biota.

Construtora Adolpho Lindenberg: According to Christiana Furtado, the Construtora Adoplpho Lindenberg relies on subcontractor because of the easiness of managing other companies instead of executing a lot of tasks itself. This, associated with the fact that they have a lot of constructions going on at the same time makes the strategy of involving subcontractors the best option. Almost all the construction is executed by subcontractors; being just engineers, work supervisors, administrative staff, storekeepers and interns, the Adolpho Lindenberg employees present on site.

Galvao Engenharia: The construction company primarily relies on subcontractors just for specialized tasks, when there is a need of having specific assets in order to execute them. This was the case of subcontracting Brasfond, which owns the specific equipment to make the diaphragm walls; Modolo, which owns the trucks to remove the soil from the excavation; Engeilha; and the subcontractors of waterproofing and electric facilities. However, Galvao also relied on subcontractors for tasks they could do in order to not to have to allocate more private assets in the construction.

Therefore, even if the reason behind the choice of subcontracting a task may differ, it can be seen that the degree of integration with each subcontractors is in general impacted by the company`s size. The figure bellow, using the relationship between actors described in the model from Cooper (1993), depicts the average relationship with subcontractors depending on the size of the construction company.

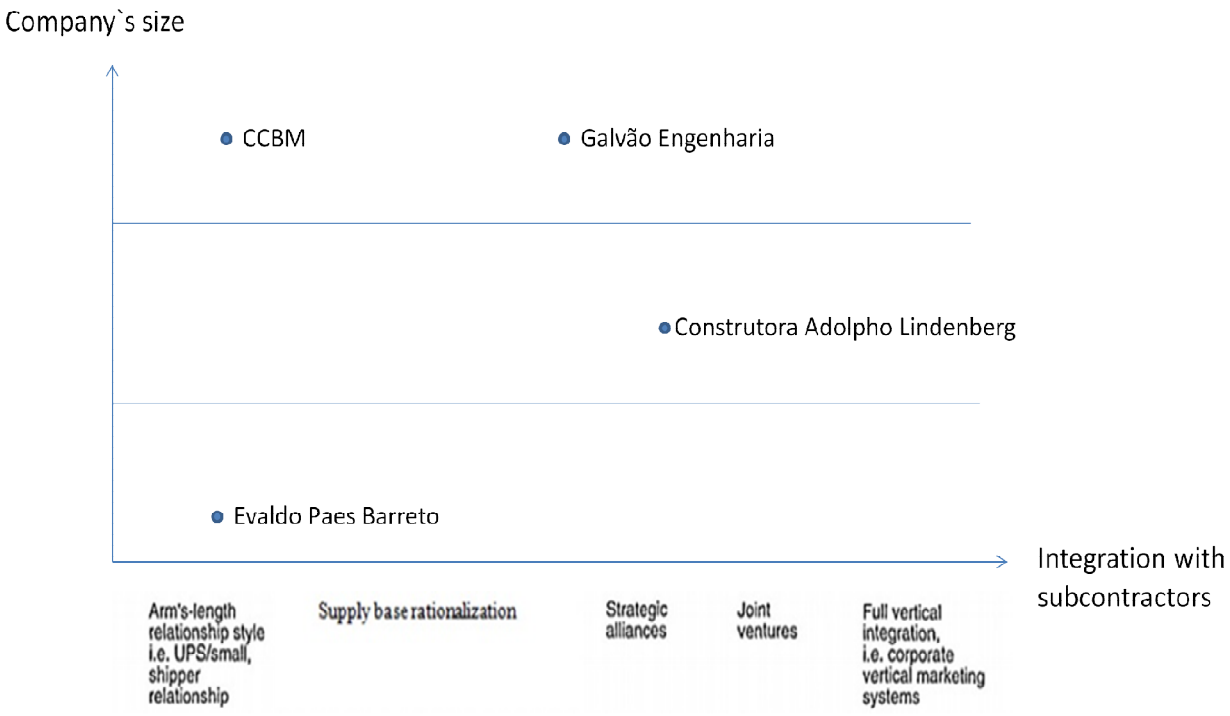

Figure 32: Average kind of relationship with subcontractors

Analysing the figure, it was expected that the medium company, Construtora Adolpho Lindenberg, would have more integrated subcontractors than the small one, Evaldo Paes Barreto; since, according to Erwin Hoffman (2009), the demand irregularity for services of a certain subcontractor hampers the integration with subcontractors. Knowing that the demand irregularity increases as the company`s size decreases, it was expected that the medium company had more integrated subcontractors. However, it is also evidenced in the figure above that the large company has less integrated subcontractors than the medium one. The explanation is different for each large company: the first one is for CCBM arm`s length relationship is because the construction consortium has a finite lifetime making no sense strategic alliances with subcontractors; and the reason for Galvao Engenharia having less integrated subcontractor than Lindenberg may be the fact of: as Galvao works with infrastructure all over the country it has more demand irregularity for a certain task in a certain geographic area.

6 Conclusions

In this chapter, first, there is presented a concise synthesis of the analyses of the objectives proposed and the description of the context that they emerge. Afterwards, there is the presentation of the results obtained through the case studies and the confrontation with the initially proposed model. In addition, the research questions that guided this research are answered. To complete the chapter there is a small critical analysis of this research and path suggestions for future research.

6.2 Research synthesis and context

The aim of this research was to understand the civil construction industry, particularly, its aspects that are related to the possibility of increasing the sector`s productivity that is seem to be low productive when comparing to other industries. This work emerges in a period in which the government of different countries, such as the UK, started to promote research in the field with the aim of understand the sector`s low productivity and try to solve this issue. As a result of these researches, arises that the sector characteristics of one-off projects, competitive behavior and the lack of partnership was the reason behind its low productivity rates. Egan (1998) supports: that an increase in partnership would solve this problem.

Furthermore, the sector is in constant evolution since the industrial revolution in which moved a great amount of work that was usually executed on site to factories. It brought an increase in productivity, the less need of specialized craftsmen and the necessity of standardizing components dimensions. In this way, arises the modular coordination around the 1950`s with the aim of easing the problems of fitting components to the project. Recently, the modularity ideas that appeared in others industries, such as, automotive and electronic, as a manner of increasing further the productivity has also emerged in the construction sector being called modular construction that is the most industrialized manner of constructing since is the technique that transfers the most amount of work to factories.

However, the modular construction in Brazil is still not very usual due to the countries characteristics such as the labor cost not as high as in the countries where it has had emerged, such as, Netherlands, United Kingdom and Japan. Meanwhile, others

construction techniques not as industrialized as the modular construction has emerged in the country as a way of increasing sector`s productivity such as the structural masonry. Moreover, arose also an increase concern in rationalizing the construction industry as a way of reducing its high waste rate and increase sector`s productivity that even if it is not a construction technique it is a way of industrializing the construction and increase its productivity (Tatum et. al., 1987).

Therefore, this research motivated by studies in the others industries regarding the employment of modularity principles and its impact in the supply chain and also; in studies regarding modular construction and its necessity of partnership, has the aim of establish a linking between different constructions with different degrees of industrialization and how the supply chain reacts to it, particularly, the integration between actors. In addition, it is also the goal of this research to see the impact of constructions with different degree of industrialization in the project phase.

6.2 Final Analysis

In the subchapter number three, with the aim of guide the research and focus in certain aspects that are responsible for the construction sector`s productivity, I placed three questions that will be answered here.

1) How the relationship between the companies in the supply chain construction industry (construction company with subcontractors and suppliers) are influenced by the general degree of industrialization that characterizes a certain construction?

In accordance with the model proposed in the chapter Research Model, the industrialization of the construction depends primarily on the construction technique employed that is related to the degree of work executed away from the construction site (pre-fabrication) and to the other three forms of industrializing construction that are rationalized building, standardization and new technology.

The relationship between the companies within a supply chain was found to have an increase in integration when there is an increase in the average general industrialization. As it was explained in the analyses case studies, this succeeds because much more the company industrialize its developments, more it has to rely on external suppliers. Thus, the integration seems to be the best option since the

success of its developments depends more in the external suppliers performance. This also in accordance with the literature review that says: “to employ the modularization, the most industrialized construction technique where the modules come ready to be assembled on site, the companies need to change their way to work as it requires greater coordination. Tatum, C. B., Vanegas, J.A. and Williams, J.M. (1987) says “[…For example, these methods can alter the project organization, change planning and monitoring, require great coordination, and alter project results. They can also add new activities and change conventional operations.]”

The graphic bellow summarizes the results obtained from the case studies.

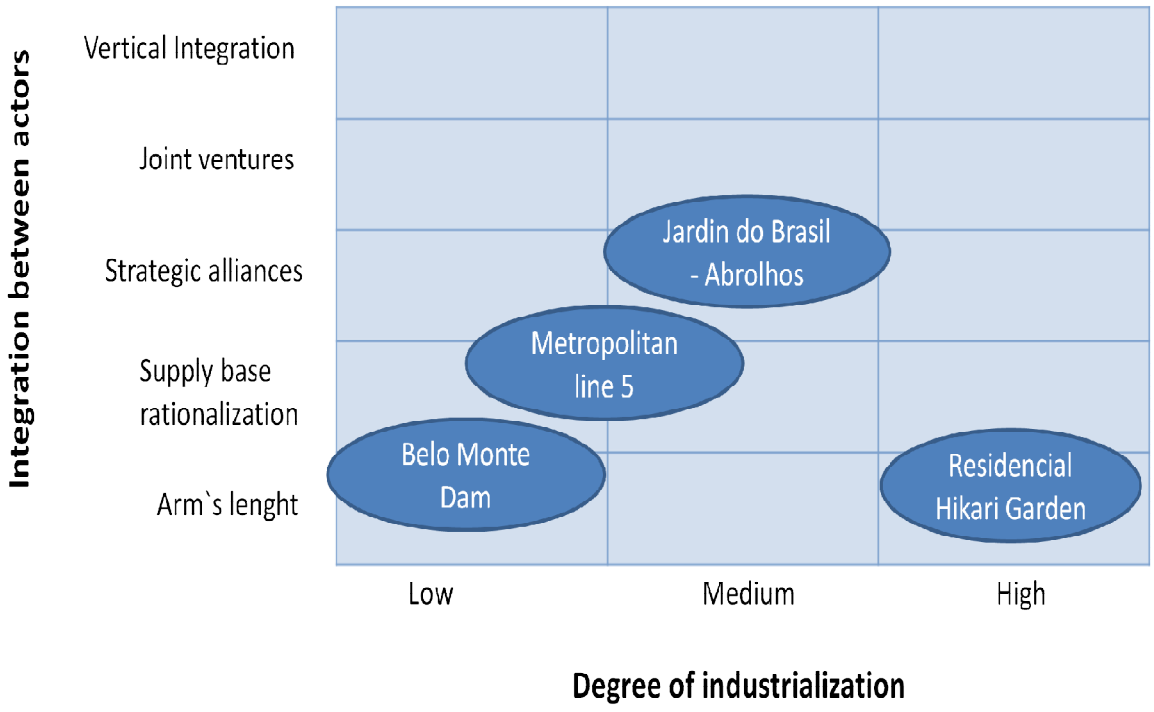

Figure 33: Matrix linking the degree of industrialization and the integration between actors

The fact of the point one is not in accordance with what was explained above can be explained by the contingent factors that are better discussed in the answer of the question three.

2) How the way to organize the project is influenced by the general degree of industrialization?

As the general degree of industrialization in construction increases the complexity in coordinating the project seems also to increase. The increase in the degree of industrialization in construction either by the employment of new construction techniques, such as, pre-fabrication and modularization or by the increasing in industrialization due to the employment of rationalization principles, new technological equipment or standardization seem all of having the impact in the project phase, leaving it more complicated. First of all, the more industrialized construction techniques that transfer more amount of work to factories, implies that the designers responsible for different subjects, for example, structure, architecture, electric facilities and water facilities work closer and have to respect more constraints imposed from the others increasing the coordination complexity of the project phase. This was the case of the Residential Hikari Gardens where the structural masonry was employed.

In addition to the technique, the other matters also implicate in a higher complexity in the project phase since, for example, the rationalization that means “the mental process that governs the action against the waste of time and materials production processes, applying systematic reasoning, free of the emotional flow; is a set of actions that it proposes reforming replace routine practices and resources by conventional methods based on systematic reasoning in order to eliminate randomness in decisions” (Rosso, 1980) and this implicates in a greater concern in the project phase, usually evidenced by the engagement of more project design offices that increase the project coordination that was the case of one of the case studies, the Residencial do Brasil – Abrolhos. Moreover, the possible employment of new technological equipment increases the project phase complexity since the designers have to take into account different possibilities in order to reach the best solution and make the final project for that.

The graphic bellow summarizes the results obtained.

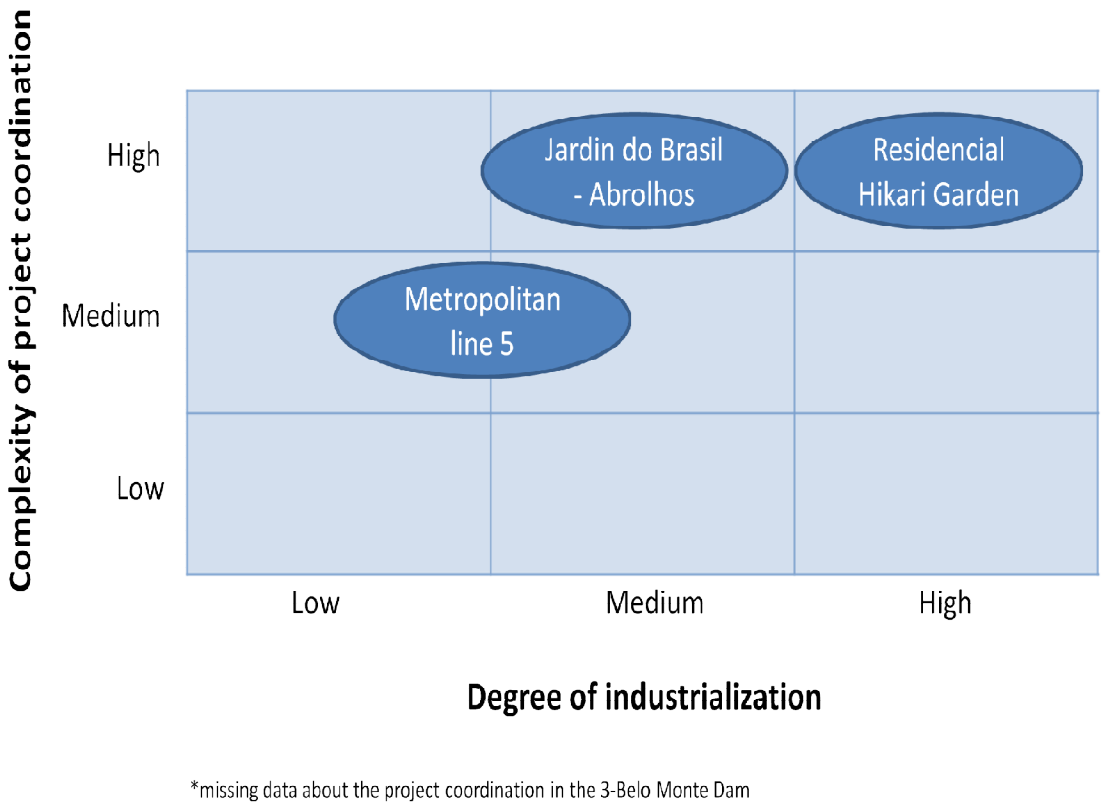

Figure 34: Matrix linking the degree of industrialization and the complexity of project coordination

3) What are the contingency factors that affect the relationship between the general degree of industrialization that usually characterizes one company developments and the relationships between the actors? And how do they work?

In addition to the industrialization in construction that was seen in the answer of the question 1) to affect directly in the relationship between the actors within a certain supply chain, there is a contingent factor that impacts the possibilities of two companies getting into a partnership. Erwin Hoffman (2009) who claims that: "the alignment between product modules and contractor – supplier relationship is found to be contingent in four driver: the degree of variety in customer demand, the extent of the required supplier investment, the extent of dependence on supplier knowledge, and the intentions of both the supplier and the buyer in a relationship."

Based in this statement, it is possible to make the reasoning: a small construction company will have a small number or one project going go at the same time, this implies that the demand for a certain activity varies greatly being in a certain period of demanding the task and in the following not. For example, the execution of the foundations, which is usually executed by a subcontractor, will just be demanded when the construction is starting. Therefore, applying Erwin Hoffman (2009), the smaller the construction company is less likely that it will get in a relationship with suppliers or subcontractors.

The case studies proved this statement since the more industrialized construction going on, the Residential Hikari Gardens that is being developed by a small company showed to be the one with the average less integrated relationship with suppliers and subcontractors. The graphic bellow depicts the encountered situation.

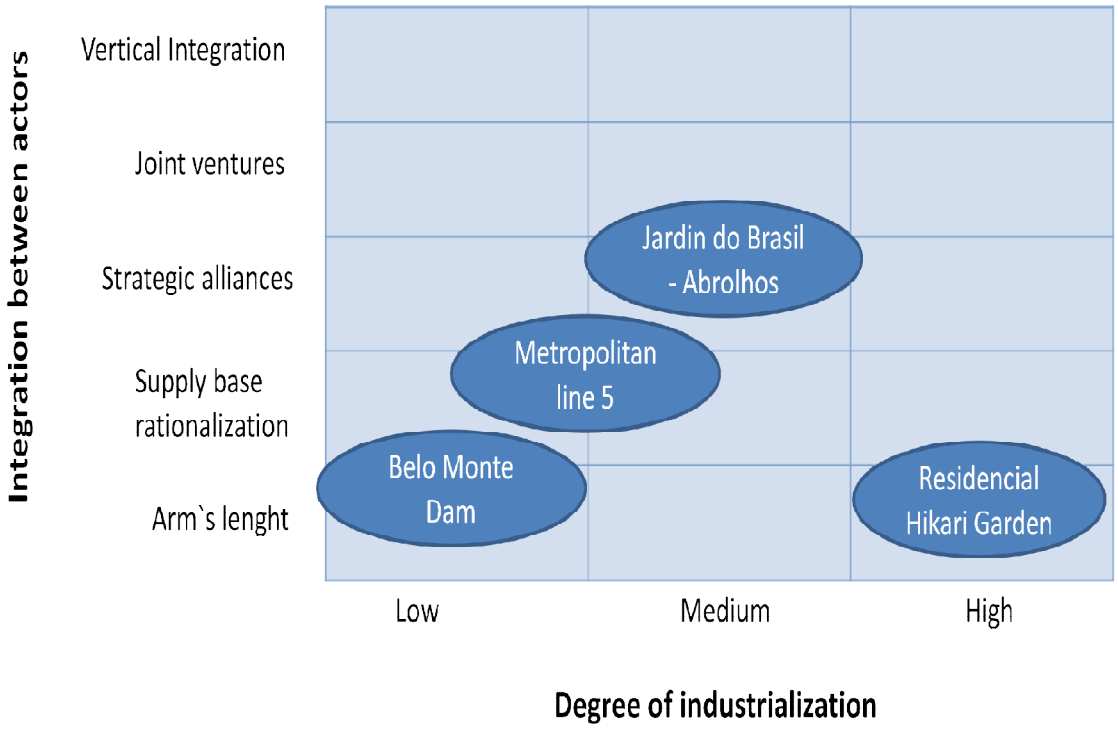

Figure 35: Matrix linking the degree of industrialization and the integration between actors

6.3 Critical analysis

This research started with the idea of applying a questionnaire to persons who work in the civil construction sector regarding what they thought modularity is, if they could indentify modules in their respective constructions, the benefits they thought were brought from applying modularity principles. However, due to divergent answers and due to the fact that sometimes the people have never heard about the theme, was hard to continue in that way. This may have happened because in Brazil, where the research took place, the theme “modularity in construction” is not very known.

So, based in the literature, particularly in the book “Constructability Improvement Using Prefabrication, Preassembly, and Modularization”, where it says that the modularization would be the most industrialized way regarding construction and for that is necessary that the relationship with suppliers is integrated since the construction company depends more on them because they execute a greater amount of work, emerged the idea of link constructions with different degrees of industrialization to how their supply chain is, particularly, the relationship between actors. Then, during the interview phase emerged the fact that different degrees of industrialization have also an important in impact in the complexity of the project phase that showed to be relevant and was added to the work.

6.4 Suggestions for future research

Being the theme discussed very important and very current discussed with the aim of increasing civil construction sector productivity as it was shown by Latham (1994) and Egan (1998), I suggest that the research between supply chain and modularization in construction should continue in order to not leave the sector lag behind the others industries.

A good path to follow would be extend this analysis, including more industrialized constructions going on that employ modularization techniques that are harder to find in Brazil. In addition, a broad analysis with more companies would be good to prove the links found.

Bibliografy

Abdel-Malek, L., Montanari, R. (2005) – “On the multi-product newsvendor problem with two constraints”, Computers and Operations Research, 32 (8), pp. 2095–2116.

Arnold, U. (2000) - “New dimensions of outsourcing:a combination of transaction cost economics and the core competencies concept”, European Journal of Purchasing &Supply Management, Vol. 6 No. 1, pp. 23-9.

Barros, M. (1998), - “O desafio da implantação de inovações tecnológicas no sistema produtivo das empresas construtoras”, Seminário Tecnologia e Gestão na Produção de Edifícios: Vedações Verticais, São Paulo.

Bankvall, L., Bygballe, L., Dubois, A., Jahre, M. (2010) - “Interdependence in supply chains and projects in construction”, Supply Chain Management: An International Journal, Vol.15 No.5, pp. 385-93.

Carliss, Y., Baldwin, C.Y., Clark, K.B. (1997) - “Managing in the age of modularity”, Harvard Business Review, Vol. 75 No. 5, pp. 84-93.

Camuffo, A. (2000) - “Rolling out a ‘World Car’: globalization, outsourcing and modularity in the auto industry”, IMVP working paper.

Christopher, M., Jüttner, U. (2000) - “Developing strategic partnerships in the supply chain: a practitioner perspective”, European Journal of Purchasing and Supply Chain Management, Vol. 2 No. 6, pp 117-127.

Cooper, M.C., Gardner, J.T. (1993) - “Building good business relationships – more than just partnering or strategic alliances?, International Journal of Physical Distribution & Logistic Management, Vol. 23 No.6, pp. 14-26.

Cooper, M.C., Lambert D.M, Janus, D.P. (1997) - “Supply chain management: more than a new name for logistics”, the international Journal of Logistics Management.

Doran, D. (2003) - “Supply chain implications of modularization”, International Journal of Operations and Production Management, Vol.23 No.3, pp. 498-509.

Doran, D. (2004) - “Rethinking the supply chain: an automotive perspective”, Supply Chain Management: An International Journal, Vol. 9 No. 1, pp. 102-9.

Doran, D., Hill, A., Hwang, K., Jacobs, G. (2007) - “Supply chain modularization: cases from the French automobile industry”, International Journal of Production Economics, Vol. 106 No.1, pp 2-11.

Egan, J. S. (1998) - “Rethinking Construction”, Department of the Environment, Transport and the Regions, London.

Elram, L.M. (1996) - “The use of the case study method in logistic research”, Journal of Business Logistics”, Vol. 17 No.2, pp. 93-118.

Ernst, R., Kamrad, B. (2000) - “Evaluation of supply chain structures through modularization and postponement”, European Journal of Operational Research, 124, 495–510.

Fisher, M.L. (1997) - “What`s the right supply chain for your product”, Harvard Business Review, Vol. 75 No.2, pp. 105-116

Gadde, L. E., Jelbo, O. (2002) - “System sourcing – opportunities and problems”, European Journal of Purchasing & Supply Management, Vol. 8 No. 1, pp. 43-52.

Hall, R. (1983) - “Zero inventories”, Dow Jones-Irwin, Homewood, IL.

Helper, S., MacDuffie, J.P., Pil, F, Sako, M., Takeishi, A., Warburton, M. (1999) - “Project report: modularization and outsourcing: implications for the future of automotive assembly”, paper presented at the IMVP Annual Forum, MIT, Boston.

Hellström, M., Wikström, K. (2005a) - “Benchmarking survey on modularity in land-based industries”, Laboratory for Industrial Management.

Hellström, M., Wikström, K. (2005b) - “Project business concepts based on Modularity”, International Journal of Project Management, 23, pp. 392-397.

Hofman, E., Voordijk, H., Halman, J. (2009) - " Matching supply networks to a modular product architecture in the house-building industry", Building Research & Information, 37 (1). pp. 31-42.

Jacobs, M., Vickery, S.K., Droge, C. (2007) - "The effects of product modularity on competitive performance: do integration strategies mediate the relationship?", International Journal of Operations & Production Management, Vol. 27 No. 10, pp.1046-68.

Langlois, R. (2002) - "Modularity in technology and organization", Journal of Economic Behavior & Organization, Vol. 49, pp 19-37.

Lau, A.K.W., Yam, R.C.M. (2005) - "A case study of product modularization on supply chain design and coordination in Hong Kong and China", Journal of Manufacturing Technology Management, Vol. 16, pp.432 – 446.

Lee, H.L., Billington, C. (1992) - "Managing supply chain inventory: pitfalls and opportunities", Sloan Management Review, Vol. 33 No. 3.

Liao, K., Tu, Q., Marsillac, E. (2010) - "The role of modularity and integration in enhancing manufacturing performance: an absorptive capacity perspective", Journal of Manufacturing Technology Management, Vol.21 No.7, pp. 818-38.

Mascaró, L.E.R. (1976) - "Cordinación modular? Que es?", Summa, Buenos Aires, n.103, pp 20-21

Pasquire, C., Connolly, G. (2002) - "Leaner construction through off-site manufacturing", Proceedings IGLC, Gramado, Brazil.

Quinn, J., Hilmer, F. (1994) - "Strategic Outsourcing, Sloan Management Review.

Rocha Lima, J. (1993) - "Qualidade na construção civil Conceitos e Referências", Boletim técnico da Escola Politécnica da USP.

Rosso, T. (1976) - "Teoria e prática da coordenação modular", Fau-USP, São Paulo.

Rosso, T. (1980) - "Racionalização da construção", Fau-USP, São Paulo.

Sarkar, A., Mohapatra, P.K.J. (2006) – “Evaluation of Supplier Capability and Performance: A Method for Supply Base Reduction”, Journal of Purchasing & Supply Management, 12 PP 148-163.

Sako, M., Murray, F. (1999) - “Modular strategies in cars and computers”, Financial Times.

Salvador, F., Forza, C., Rungtusanatham, M. (2002) – “Modularity, product variety, production volume, and component sourcing: theorizing beyond generic prescriptions”, Journal of Operations Management 20, 549-575.

Sanchez, R., Mahoney, J. (1996) - “Modularity, Flexibility, and Knowledge Management in Product and Organization Design”, Strategic Management Journal, Vol. 17, pp. 63-76.

Schilling, M.A. (2000) - “Towards a general modular systems theory and its application to inter-firm product modularity”, Academy of Management Review, Vol 25, pp. 312–334.

Stuart et al. (2002) - “Effective case research in operations management: a process perspective”, Journal of Operation Management, Vol. 20 No.5, pp. 419-33.

Sturgeon, Timothy J. (2003) - “Exploring the benefits, risks and evolution of supply chain modularity in product level electronics”, MIT publications, Cambridge, MA.

Sturgeon, Timothy J. (2006) - “Modular Production`s Impact in Japan`s Electronic Industry”, Industry Studies Working Paper.

Van Weele, A.J. (2005) - “Purchasing strategies and Supply Chain Management: Analysis, Strategy, Planning and Practice”, Thomson International, London.

Van Hoek, R.I., Weken, H.A.M. (1998) - “Integrating the supply chain using modular production”, Inetnational Journal of Logistics; Research and Application, Vol. 1 No.1.

Vrijhoef, L., Koskela, L. (2000) - “The four roles of supply chain management in construction”, European Journal of Purchasing and Supply Chain Management, Vol. 6, No 3-4, pp. 169-178.

Books:

Brewer, A.M., Button, K.J., Hensher, D.A. (2001) - “Handbook of Logistic and Supply-Chain Management”, Emerald Group Pub Limited.

Greven, H., Baudalf, A. (2007) - “Introdução à coordenação modular da construção no Brasil”.

Kelly, J., Morledge, R., Wilkinson, S. (2002) - “Best Value for Construction”.

Santos, A., Jungles, A. (2010) - “Como gerenciar as compras na construção civil”, Pini.

Tatum, C. B., Vanegas, J.A., Williams, J.M. (1987) - “Constructability Improvement Using Prefabrication, Preassembly, and Modularization”.

Tauil, C.A., Nese, F.J.M. (2010) - “Alvenaria Estrutural”, Pini.

Technical standard:

ABNT (1977) – “NBR 5706: Coordenação modular da construção”.

Thesis:

Freire, A (2006). - “Coordenação modular de projetos como ferramenta para racionalização da construção”, thesis presented to Escola Politécnica, São Paulo.

Moratti, T. (2010) - “Diretrizes para a implantação estratégica de suprimentos em empresas construtoras”, thesis presented to Escola Politécnica, São Paulo.

Penteado, A.F. (1980) - “Coordenação Modular”, thesis presented to Escola Politécnica, São Paulo.