

**Barriers to Modularity in the Brazilian Construction Industry and the  
Relationship between Modularity and Supply Chain Integration.**

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## Abstract

Modularity has been recently gaining importance within the construction industry worldwide. Modular solutions might be the key to increasing the industry's efficiency, which did not experience an improvement like the one seen in the manufacturing industry. Under the Brazilian context, nevertheless, the sector is still much smaller than in relation to developed economies. The study investigates why that happen, considering all barriers mentioned in the literature and including impediments particularly related to the Brazilian environment. To do that, an exploratory case study approach was pursued. Other than discovering what limits the use of modular solutions, the relationship between modularity and supply chain integration under this particular environment was assessed.

## Abstract (Italian)

La modularità sta recentemente guadagnando importanza all'interno del settore delle costruzioni in tutto il mondo. Le soluzioni modulari possono essere la chiave per aumentare l'efficienza del settore, che non ha vissuto un miglioramento come quello visto nel settore manifatturiero. Nel contesto brasiliano, tuttavia, il settore è ancora molto più piccolo che in relazione alle economie sviluppate. Lo studio indaga il motivo per cui questo accada, considerando tutte le barriere menzionate nella letteratura e anche impedimenti particolarmente legati all'ambiente brasiliano. Per fare questo, un approccio caso di studio esplorativo (explorative case study) è stato perseguito. Altro che scoprire ciò che limita l'uso di soluzioni modulari, la relazione tra modularità e la integrazione della filiera in questo ambiente particolare è stata valutata.

## Summary

1. Introduction / Motivation .....	6
2. Literature Review .....	8
2.1. Modularity in a General Sense .....	8
2.2. Modularity in the Sense of the Construction Industry.....	11
2.3. Construction Industry Supply Chain .....	15
2.4. Modularity and Supply Chain Integration (Construction Industry).....	17
2.5. Barriers to Modularity .....	19
2.6. The Brazilian Context.....	21
2.7. Literature Review Conclusion .....	26
3. Research Metrics.....	27
3.1. Research Questions and Methodology.....	27
3.2. Assessment of Modularity Level.....	28
3.3. Assessment of Supply Chain Integration .....	28
4. The Case Studies.....	29
4.1. Methodology.....	29
4.2. Case Studies Summary .....	30
4.3. Barriers to Modularity Mentioned in the Literature.....	35
4.4. Barriers to Modularity not Mentioned in the Literature .....	37
4.5. Other Aspects Mentioned by the Market Expert.....	38

4.6. Relationship Between Modularity and Supply Chain Integration .....	39
5. Conclusion .....	42
6. Appendix .....	44
7. Bibliography .....	47

## List of Tables

Table1: Comparison between a Modular and an Integral Product Architecture .....	14
Table 2: Complexity of Operations .....	15
Table 3: References in Literature to Barriers to Construction's Modularization .....	21
Table 4: GDP and GDP per Capita (World Bank) .....	22
Table 5: GINI Index by Country (World Bank) .....	23
Table 6: Overview of the Construction Industry - Comparison between Brazil, USA and EU .....	25
Table 7: Case Studies Summary .....	34
Table 8: Assessment of Supply Chain Integration .....	35
Table 9: Impact of Barriers Mentioned According to the Interviewees .....	37
Table 10: Barriers not Mentioned in the Literature .....	38

## List of Figures

Figure 1: Slot, Bus and Sectional Modularity .....	9
Figure 2: Relationship between Contingent Variables and Modularity .....	19
Figure 3: Gini Index by Country (World Bank) .....	24

## List of Graphs

Graph 1: Relationship Between Degree of Off-site Activity and Supply Chain Integration .....	42
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## 1. Introduction / Motivation

After the industrial revolution, the manufacturing industry has increasingly improved its productivity, achieving new records of efficiency year after year. The introduction of new concepts like lean management and modularity was remarkably important for this achievement.

More specifically, modularity, especially for the manufacturing industry, has been the objective of some studies and its many benefits have been documented. According to (Gershenson, Prasad, & Zhang, 2003), they include:

- Component economies of scale (components are used across different product families);
- Ease of product updating (functional modules);
- Increased product variety from a smaller set of components;
- Decreased order lead-time (fewer components);
- Ease of design and testing (decoupling of product functions)
- Ease of service (differential consumption)

Construction, nevertheless, displays in general a delay in developing towards higher productivity, quality and decreased costs compared to manufacturing (Winch, 1998). The use of modularity has been growing as a mean to decrease this lag. Although modularity in construction is a newer field than it is for manufacturing, it has been studied and some of its benefits have been documented. To the construction industry in particular, benefits include (Pasquire & Connolly, 2002):

- Offsite Benefits:
  - o Reduced labor;
  - o Reduced waste;
  - o Reduced storage requirements;
  - o Reduced welfare facilities provision.
- Programme Benefits:
  - o Bigger upfront commitment (manufacturer / supplier);
  - o Increased quality (factory control system)
  - o Increased efficiency in installation.
- Manufacturing Benefits:

- Better work conditions;
- Increased productivity;
- Better cost / quality performance.

According to (Trkman, Indihar Štemberger, Jaklič, & Groznik, 2007), there is also a positive outcome of product modularity in regards to the development of closer commercial ties with suppliers as a result of increased integration.

(Diekmann, Krewedi, Joshua, Stewart, & Won, 2005) also states that the use of modularity can improve the cost structure, value attitudes and delivery times.

Although there are many benefits related to modularity in the construction industries, it has not been extensively used, specially under the Brazilian environment. Some barriers to modularity and to an improvement in the industry's overall efficiency have been studied in the literature (Des Doran & Giannakis, 2011; Halman, Voordijk, & Reymen, 2008; Höök & Stehn, 2008).

Nevertheless, because the usage of modular solutions is remarkably lower in Brazil than it is when compared to developed countries (ABCIC – Associação Brasileira da Construção Industrializada de Concreto – Brazilian Industrialized Cement Construction Association), there is reason to believe that there are some barriers, inherent to the Brazilian context, that have not been documented in the literature and that is the main motivation for the development of this research.

The first research question is, hence, what are the barriers to modularity in the Brazilian context.

The most recurrent point cited on the literature regards the inefficiency of construction's supply chains. Its lack of cohesion and the adversarial relationships present in construction supply chains have been pointed as one the main barriers to modularity (Bankvall, Bygballe, Dubois, & Jahre, 2010; Rocha, Formoso, & Tzortzopoulos, 2015). That's why, as a complement to the first research question, the relationship between modularity and supply chain integration will be further studied and will become the second research question.

## 2. Literature Review

### 2.1. Modularity in a General Sense

The definition of modularity and modularization lacks consensus. According to (Cigolini and Castellano 2002), it is a broad concept, with various meanings and interpretations across research disciplines and market sector. For example, in the software design field, modularity usually refers to 'tools for the user to build large programs out of pieces' (Chen 1987). It has also been defined under a design engineering perspective by Walz (1980) as 'constructed of standardized units of dimensions for flexibility and Variety in use'. Under the construction industry, modularity can be defined as using sets of units designed to be arranged or joined in a variety of ways (Civil Engineering Research Foundation 1996).

In a general sense, Modularity involves breaking up systems into discrete chunks, which, via standardized interfaces, rules and specifications, communicate with each other (Baldwin and Clark 2000). For (Gershenson et al., 2003), It arises from the decomposition of a product into subassemblies and components.

#### **Product Architecture and Modularization**

According to (Ulrich, 1995), the product architecture can be modular or integral and there are three main decisions in its regards.

- Arrangement of functional elements;
- Mapping from functional elements to physical elements;
- Specification of the interfaces among interacting physical components.

The function-component allocation scheme can be:

- One-to-one
- One-to-many
- Many-to-many



- Many-to-one

A modular architecture has a one-to-one allocation scheme, while all other allocation schemes would belong to an integral architecture.

(Ulrich, 1995) also defines the differences in interface standardization, eliciting 3 possible types:

Slot Modularity: Modules are put together in only one very specific way and there are no particular standards for the assembly.

Bus Modularity: Modules are not connected directly, but communicate via a common bus element

Sectional Modularity: There is a very specific interface standard and every module connect with other modules in arbitrary ways

Figure 1 highlights the differences between the possible interface standardizations:

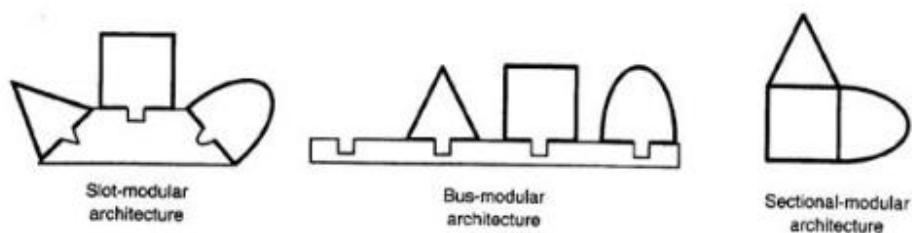


Figure 1: Slot, Bus and Sectional Modularity

### Fine's three-dimensional modularity concept

Fine (1998) claims there is a connection between product, process and supply chain modularity, being the last concept introduced by him. He claims that not only are modular products produced via modular processes, but also by modular supply chains. In order to provide a clear understanding of the aforementioned concepts, we provide a review of Fine's three-dimensional modularity concept.

## **Product Modularity**

Any product can have a more modular or more integral architecture. It depends, basically, on the level of independence of components and interfaces.

Integral products have synchronized components working in close proximity and performing multiple functions. It usually has functions being performed by systems or subsystems, a so called function sharing. That means, for example, that when a function is not being performed as required, it will require a repair that will involve not only one component, but many. It means, in a broader sense, that changes made to one component will usually require changes in other components so that the product works properly.

On the other hand, modular products' components are interchangeable, autonomous, loosely coupled, individually upgradeable and its interfaces are standardized (Fine, 1998). That means that changes made to one component usually don't require changes in other components, providing, therefore, independence to the system as a whole. In a modular product, each component performs only one or a few functions, hence contrasting to integral products.

## **Process Modularity**

To define process modularity, we have basically two dimensions. The first is time and the second, space.

For the time dimension, processes can be fast or slow. Slow means that the process is scattered in time. Fast means, conversely, that the process has a tight time schedule.

For the space dimension, the process can be tight, centralized or, on the contrary, loose and decentralized.

## Supply Chain Modularity

Supply chain modularity can be assessed by rating the level of proximity or non-proximity of some elements. In this case, proximity suggests that the supply chain is more integral while non-proximity implies a more modular supply chain. The elements considered by Fine (1998) are:

- Geographic Proximity
- Organizational Proximity
- Cultural Proximity
- Electronic Proximity

Geographical proximity is the easiest to be measured, via physical distance. Organizational proximity concerns ownership, managerial control and interdependencies. Cultural proximity is more qualitative and can be assessed by language and business mores commonality, as well as ethical standards and, lastly, electronic proximity can be captured by intranets, video-conferencing and, in some cases, commonalities in technological platforms used.

### 2.2. Modularity in the Sense of the Construction Industry

A consensus regarding the definition of modularity in the sense of an Engineer to Order (In E.T.O. environments, differently from what happens in MTS, ATO and MTO environments, customer specifications require unique engineering design and significant customization) industry is even harder to be achieved. In relation to the building industry, there are many terms associated to modularity, as off-site, prefabrication, preassembly, industrialized buildings and modern methods of construction. PPMOF, an acronym which stands for prefabrication, preassembly, modularization and off-site fabrication (Khalili & Chua, 2014)(O'Connor, O'Brien, & Choi, 2014)(Schneider, Buehn, & Montenegro, 2010)(Pan, Gibb, & Dainty, 2012) is an example of how mixed different concepts get and how complicated it is reach a general agreement on what modularity means.

That fact has also been evidenced by (Des Doran & Giannakis, 2011), once, unlike what happens in the automotive sector (Desmond Doran, 2004) suppliers couldn't effectively define modularity, either vaguely defining it or defining it only by its benefits. According to (Des Doran & Giannakis, 2011) construction modularity is "The provision of modular solutions constructed

off-site using modular principles and practices and delivered, installed and commissioned on-site to a pre-determined modular plan.”

(Gosling, Pero, Schoenwitz, Towill, & Cigolini, 2016) makes a distinction on the meaning of modularity during different project phases.

- Planning / Design: Grid Layout, Product Architecture
- Preconstruction Phase: Align hierarchy level with supply chain
- Construction Phase: Physical Manifestation of modules
- Post Construction Phase: Flexibility in use

A definition of a module in the construction industry ambit was then made: “A module is physically manifested as a construction unit that is part of a wider system, which can be integrated through preplanned interfaces. These physical modules are the result of, and can facilitate, modularization in different phases of the project. They may be considered at different hierarchical levels within the overall product architecture, may be manufactured on or off-site, and can be volumetric or nonvolumetric.”

(Rocha et al., 2015) elicits the differences between manufacturing and construction that are relevant for product modularity. The most important one is that, in manufacturing, components have a central role in the definition of the product architecture, while, in construction, the spatial voids are the primary function.

(Voordijk, Meijboom, & de Haan, 2006) Elaborates on the particularities of product, process and supply chain modularity for the construction industry.

For product modularity, the paper highlights the differences between the exterior and interior level and, following (Wolters, 2002), analyses 4 aspects: The modules are constructed off-site, with connections to adjacent units made on-site, they are loosely coupled, the mapping between functions is clear and interfaces between modules are standardized.

In the case of process modularity, the metric is essentially the degree of prefabrication and, for supply chain modularity, he distinguishes into 6 different organizational models. In the first

3, design and execution responsibilities are separated and, in the last three, they are combined. He then argues, that the traditional model, the building team model and the management contracting model are more modular than the ones in which execution responsibilities and design are combined, the Design-And-Build, the General Contracting and the Brochure Plan models.

He concludes that Fine's three-dimensional modularity model also works for the construction industry.

(Des Doran & Giannakis, 2011) suggest a further distinction:

- Pure Modular: Pre-determined architecture and does not accommodate change,
- Hybrid Modular: Combination of aspects of modular (off-site) and traditional (on-site) construction.
- On-site modular: Overcomes some transportation limitations by producing pre-manufactured modules on-site using a flat back approach.

Table 1 presents (Mikkola, 2006) comparison of a modular to an integral product architecture:

	<b>Modular (off-site) product architecture</b>	<b>Integral (on-site) product architecture</b>
Design criteria	Commonality sharing. Customers encouraged to select from a pre-determined range of size options. Such design criteria limit the scope for modular solutions, particularly in terms of wide span requirements	Accommodating exact requirements of client
Component boundaries	Easy identification via standardised sizings and visible fixing columns	Difficult identification since solutions are bespoke
Redesign to architecture	Limited size modification	Without modification
Interfaces	Decoupled. Modules can be added to existing modules with little difficulty since interfaces are standardised	Coupled
Outcome	Economies of scale but limitations in terms of accommodating the wide range of demands from clients	Craftsmanship
Product variants	Generally low and impeded by standardised processes and procedures for manufacture	High
Nature of components	Standardized/generic. This is particularly evident in terms of material supplies to the modular building sector, which are, on the whole, designed for the traditional/integral construction sector	Unique/dedicated
Component outsourcing	Little evidence. This may be due to the fact that the modular building only represents small percentage of the total value of the construction sector. However, this may be area that provides the much needed cost-saving opportunities that are required if this modular building sector is to compete more effectively on price rather than on convenience	Standards exist within the industry
Learning	Localised/dispersed. Very little evidence of supply chain integration activities	Interactive
Synergistic specificity	Low	High
Component substitutability	High	Low
Component recombability	High	Low
Component separability	High. Modules can be detached for refurbishment or onward sale, once renovated	Low
Nature of innovation	Autonomous. Innovation impeded by lack of supply chain integration	Systemic
System design strategy	Decomposition	Integration

**Table1: Comparison between a Modular and an Integral Product Architecture**

(Hofman, Voordijk, & Halman, 2009; Mikkola, 2006; Ulrich, 1995) introduce a hierarchical structure in the context of a house. The house is composed by subcomponents, components and building elements.

- Subcomponents: Beams, pillars
- Components: Wall, floor, roof
- Building Elements: room, entrance, bathroom.

Then, once on-site, the degree of assembly work can be very high or very low, in which case the modules are fitted together via standardized interfaces (Blismas, Pasquire, & Gibb, 2006; Vrijhoef & Koskela, 2000) and (Pan et al. 2012). (Gibb and Isack, 2003) argue that modules can be either volumetric or flat pack.

That shows how modularity can be used at a different level even within the product architecture. (Gosling et al., 2016). Based on the study, a table relating the complexity of the operations (manufacturing complexity, transportation, site integration and handling) for subcomponents, components, elements and the whole building, for modules with low or high % of activities off-site. A summarized version is hereinafter presented at Table 2:

	Implication for Operations		
	Degree of off-site activity	Low Degree	High Degree
Building	Manufacturing Complexity:	Complex	Complex
	Transportation:	Easy	Complex
	Site Integration:	Complex	Easy
	Handling:	Easy	Complex
Element	Manufacturing Complexity:	Complex	Complex
	Transportation:	Easy	Complex
	Site Integration:	Complex	Easy
	Handling:	Easy	Complex
Component	Manufacturing Complexity:	Easy	Easy
	Transportation:	Easy	Easy
	Site Integration:	Medium Complex	Easy
	Handling:	Easy	Easy
Subcomponent	Manufacturing Complexity:	Easy	Easy
	Transportation:	Easy	Easy
	Site Integration:	Medium Complex	Easy
	Handling:	Easy	Easy

Table 2: Complexity of Operations

### 2.3. Construction Industry Supply Chain

Differently from what happens in other sectors, construction's supply chain integration is quite limited. Short term relationships between suppliers and contractors is the norm and companies usually prefer outsourcing strategies rather than to vertically integrate (ILO 2001). (Cherns & Bryant, 1984) argue that, typically, these supply chains only exist for the duration of

the project, remaining theoretically in existence if maintenance services are part of the contract (Reed, 1999).

Big projects usually involve hundreds of different suppliers, be that for materials, components or for a wide range of construction services (Dainty, Millett, & Briscoe, 2001). The reliance on that kind of configuration culminated in the complexity to manage those relations and the industry restructuring, in the mid-1970s, resulted in institutionally embedded low-skill, poorly equipped and labor-intensive sector (Borsh and Philips, 2003).

Outsourcing is remarkably common in the sector and, therefore, the management and coordination functions become notably important. Companies prefer to hire teams in some location than to train their own, this happens partially due to the fact that projects are geographically dispersed, which makes it harder to develop a more integrated supply chain.(Briscoe & Dainty, 2005), (ILO (2001).

(Bankvall et al., 2010) affirms that the Supply Chains have been characterized by a lack of cohesion, adversarial relationships and a one-off project mentality and that those facts together make it harder for the industry to optimize the value creation. (Dubois & Gadde, 2000) argue that there is little evidence of supply chain integration within construction, basically because of the single project focus and the predominance of competitive tendering procedures.

(Trkman et al., 2007) examines the supply chain integration from a process perspective, grading the integration via 5 different levels: At the first, you can see a lack of cohesion, in the second a degree of supply chain process cohesion. Level three shows process cooperation in the supply chain, whilst the two last levels show the achievement of effective supply chain integration practices.

(Briscoe & Dainty, 2005) achieved a consensus in the study, arguing that supply chain integration in construction is rather difficult to be attained. According to the paper, there are many reasons for that to happen, and many different facts that undermine supply chain integration:

**Different concentration of suppliers, contractors and clients:** Usually, suppliers and contractors are much smaller organizations than clients, which increases client's bargaining power and leaves him in a very powerful position in relation to the other



supply chain members. Those clients, which might have long-term relationships and enter in long-term strategic partnerships, are often reluctant to make the same choice regarding construction procurement

- **Historical economic advantage of project basis procurement:** Historically, it was in the client's best interest to treat each construction project as a one-off venture. The norm was to invite competition between tenders, which minimized costs (Borsh and Philips, 2003). The same way of thinking is applied by contractors when dealing with subcontractors and suppliers.
- **Wide geographical spread of construction projects:** The behavior beforehand cited was in part due to the geographical spread of the projects, which usually culminated in the employment of several local teams of suppliers and contractors.
- **Lack of trust and limited knowledge:** When clients have little knowledge on suppliers, it is highly unlikely that they will readily enter in a long-term strategic partnership with them. Earlier unsuccessful attempts also are deemed responsible for the lack of trust present in the industry, mainly with first and second tier suppliers. The same rationale is used by contractors.
- **Cyclical Demand:** The construction sector is characterized by a cyclical behavior. It is, therefore, harder for companies to have long-term partnerships with suppliers, once the volume of projects is deeply variable on time and, therefore, highly uncertain and hard to predict.

Nevertheless, the study found some long-term relationships, mostly informal and only with clients and contractors. This exemplifies the industry's high level of informality, which can be also an explanation for the low level of integration seen in the industry.

#### 2.4. Modularity and Supply Chain Integration (Construction Industry)

Although there have been some studies regarding the implications of modularization to the supply chain, the number sharply decreases when we consider only the particular engineer to order industry. This knowledge gap is one of the motivations for the research.

As previously mentioned, one of the major works connecting modularity and supply chain integration has been conducted by Fine (1998). He argues that product, process and supply chain modularity have a one to one relation, which in practical terms means that as the product modularity increases, so does the process modularity and the supply chain modularity. If,

conversely, the product has a more integral design, the processes tend to be tighter in time and space and the supply chain tends to be more integrated.

That study has been reproduced by (Voordijk et al., 2006) under the construction industry environment. Some adaptations were made to adjust the product, process and supply chain modularity concepts because, as the author states, “Fine’s three-dimensional concept is still very rough in nature and exhibits several shortcomings.”

The conclusion was that Fine’s three-dimensional modularity concept works well to define the alignment between product, process and supply chain modularity, even though one of the cases analyzed wasn’t straightforward and required a more qualitative understanding of the different principles. The research acknowledged its limitations and agrees that more detailed specifications for product, process and supply chain modularity are needed to amplify scientific knowledge.

(Pero, Stlein, & Cigolini, 2015), supported the idea that several contingent variables are likely to affect product modularity, supply chain integration and the relationship between them. They are:

- Customization, measured by the degrees of freedom given to customers in defining product’s specifications. For (Baldwin and Clark, 1997), modularity decreases customization, which is a driver for SC Integration (Pine, 1999) by requiring a higher supplier/customer involvement (Fisher, 1997).
- Innovativeness, which reflects the product novelty for the company. (Caridi, Pero, & Sianesi, 2012) / (Pero & Lamberti, 2013). In other sectors, innovativeness is keen for increasing the supply chain integration.
- Firm size. It is believed that bigger firms have more resources to build factories (increasing product modularity) and integrated IT systems (increasing supply chain integration).
- Product size. The bigger the product, the more complex becomes the management and the supply chain.
- IP protection, measured as the number of patented components in the product (a very modular product can be easily reverse engineered).

The conclusion was as follows:

- ↑ Customization, ↑ Customer Involvement;
- ↑ Customer Involvement, ↓ Product Modularity;
- ↑ Product Customization, ↑ SC Integration;
- ↑ Module Innovativeness, ↓ Product Modularity;
- ↑ SC Integration, ↑ Module Innovativeness;
- ↑ Product Size, ↓ Product Modularity;
- ↑ Number of Patented Modules, ↑ Product Modularity;
- ↑ Product Modularity, ↓ Lead Time;
- ↑ Product Modularity, ↓ Flexibility to Change;
- ↑ Product Modularity, ↓ Cost / Time (During the Building Phase).

A summary of the found relationships is presented at figure 2:

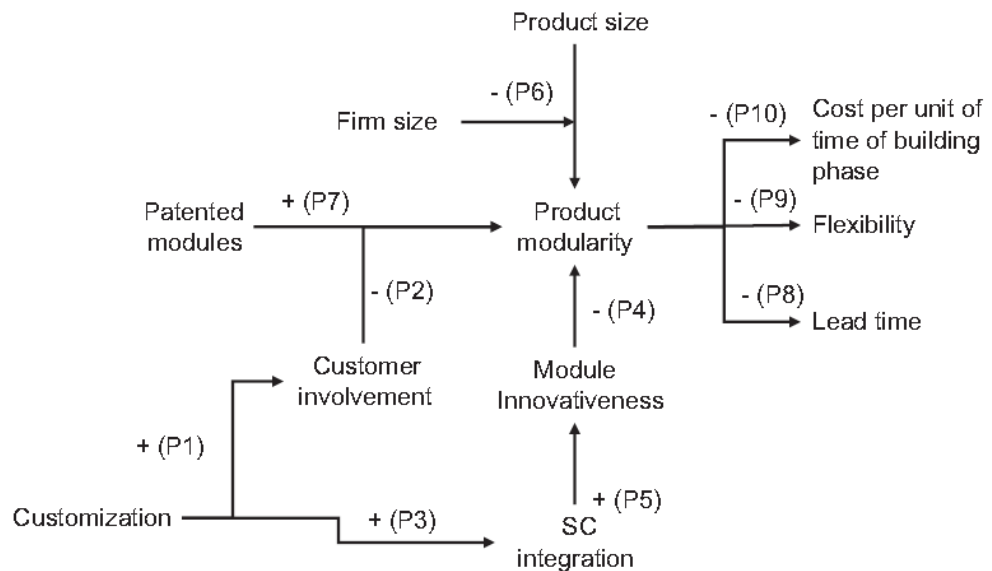


Figure 2: Relationship between Contingent Variables and Modularity

## 2.5. Barriers to Modularity

Using modularity and concepts related to it can, as previously mentioned, bring many benefits to the construction industry: It can drastically reduce lead-times, increase the overall quality by adopting quality management strategies commonly used in the manufacturing industry and remarkably reduce the part of the building activity on site (which means less site disruptions, traffic and an improvement on the overall safety and security).

Nevertheless, the use of prefabrication in the Brazilian construction industry is quite limited and even big companies developing big projects are reluctant to it. Data from the CBIC (Brazilian Chamber of the Construction Industry) states that sales regarding assembly services of prefabricated buildings accounted for less than 0,6% of the whole sales for residential buildings and 1,7% for non-residential buildings in 2014.

Some Barriers for modularity are presented in the literature and help us understand why the sector does not represent a greater part of the industry.

(Rocha et al., 2015) states that one of the difficulties relates to the lack of consensus on the conceptualization of product modularity. There is a large number of different perspectives, languages and definitions coming from different fields of knowledge presented in the literature (Salvador, 2007), as well as no clear measure of product modularity or widely adopted systematic method to help designers to increase the degree of product modularity (Gershenson et al., 2003).

Another difficulty pointed by (Rocha et al., 2015) relates to the differences between the construction and the manufacturing industry, such as on-site production, temporary supply chains, and buildings as one-off-products (Koskela, 2003).

(Des Doran & Giannakis, 2011) also comment on the differences between manufacturing and construction industries, with a special focus on the supply chain. According to them, its general lack of cohesion, the adversarial relationships and the one-off project mentality impede the ability to optimize value creation activity (Bankvall et al., 2010).

(Höök & Stehn, 2008) and (Halman et al., 2008) highlight the importance of the traditional construction culture, which is usually reluctant to change and culminate in low worker motivation and awareness of built-in quality and ad-hoc solutions that are not further analyzed, jeopardizing continuous improvement in the sector (Höök & Stehn, 2008). (Halman et al., 2008) also mentions the heavy amount of regulations undermining the sector.

Modular building solutions also include difficulties associated with complex interfacing between the systems, the inability to unfreeze design decisions, site access constraints and higher capital costs (Pan, Gibb, & Dainty, 2007).

Table 3 is presented highlighting the main barriers to the industry's modularization cited in the literature.

<b>Barrier Mentioned</b>	<b>Reference in Literature</b>
No clear meaning and measures of modularity	Rocha et al., 2015; Salvador, 2007; Gershenson et al., 2003
Adversarial relationships in the supply chain	Rocha et al., 2015; Koskela, 2003; Bankvall et al., 2010
One-off project mentality	Des Doran & Giannakis, 2011; Bankvall et al., 2010
Construction Culture	Höök & Stehn, 2008; Halman, Voordijk, & Reymen, 2008
Design - related difficulties	Pan, Gibb, & Dainty, 2007;
Site access constraints	Pan, Gibb, & Dainty, 2007
Higher capital costs	Pan, Gibb, & Dainty, 2007
Excess of regulation	Halman, Voordijk, & Reymen, 2008

**Table 3: References in Literature to Barriers to Construction's Modularization**

## 2.6. The Brazilian Context

Brazil differs from other countries in many ways. It is important, therefore, to elicit some of its main characteristics, especially at matters that can influence the construction industry and, more specifically, the presence of modularity in the sector and its influence in the supply chain.

According to the World Bank, Brazil is the 5<sup>th</sup> biggest country in the world by both area and population. It is the world's 9<sup>th</sup> economy with a nominal GDP of and was one of the fastest growing economies of the world until the recent recession and political crisis that started at 2014.

Although it is one of the world's largest economies, the outlook can be deceiving, since Brazil ranks at 76<sup>th</sup> for GDP per Capita (when we consider the population). The average Brazilian earns the equivalent of 15.615 dollars in one year, which is a quite low ratio in comparison to European citizens like Italians or Germans, which earn, respectively, an average of 35.708 and 46.893 dollars per year, according to the World Bank.

Table 4 presents data for Gross Domestic Product and Gross Domestic Product Per Capita:

GDP 2015			GDP Per Capita 2015 (PPP)	
Ranking	Economy	(Millions of US dollars)	Ranking	(Int. Dollars)
1	United States	17.946.996	10	55805
2	China	10.866.444	84	14107
3	Japan	4.123.258	27	38054
4	Germany	3.355.772	18	46893
5	United Kingdom	2.848.755	25	41159
6	France	2.421.682	24	41181
7	India	2.073.543	122	6162
8	Italy	1.814.763	31	35708
<b>9</b>	<b>Brazil</b>	<b>1.774.725</b>	<b>76</b>	<b>15615</b>
10	Canada	1.550.537	21	45553

Table 4: GDP and GDP per Capita (World Bank)

Another important distinction to be made refers to the inequality. Brazil is one of the most unequal countries in the world. According to the data from the United Nations, the Brazilian belonging to the richest 10% spends on average 40 times more than the one that belong to the poorest 10%. Using the same logic but changing the threshold from 10% to 20%, the number changes to 22 times.

Another important metric used to assess one country's inequality is the Gini Index. The index ranges from 0 to 100%. A 0% Gini Index would imply that there is complete equality in the country and a 100% index would mean a complete inequality. Brazil holds the 13<sup>th</sup> position for highest Gini Index, which makes it comparable to African countries like Namibia and South Africa.

Table 5 presents data for Country's GINI Index:

GINI Index by Country			
Rank	Country	Value	Year
1	South Africa	63.38	2011
2	Namibia	60.97	2009
3	Haiti	60.79	2012
4	Botswana	60.46	2009
5	Suriname	57.61	1999
6	Central African Republic	56.24	2008
7	Comoros	55.93	2004
8	Zambia	55.62	2010
9	Lesotho	54.18	2010
10	Honduras	53.67	2013
11	Colombia	53.49	2013
12	Belize	53.26	1999
<b>13</b>	<b>Brazil</b>	<b>52.87</b>	<b>2013</b>
14	Guatemala	52.35	2011
15	Panama	51.67	2013
.....			
63	United States	41.06	2013
98	Italy	35.16	2012
133	Germany	30.13	2011

Table 5: GINI Index by Country (World Bank)

As can be seen in the table, European countries like Italy or Germany are considerably more equal than Brazil. As will be further elaborated, this has impacts the composition of companies' cost structure (labor costs x other costs) and can be a sign of different levels of productivity among workers of different countries.

Figure 3 presents a graphic representation of the GINI index:

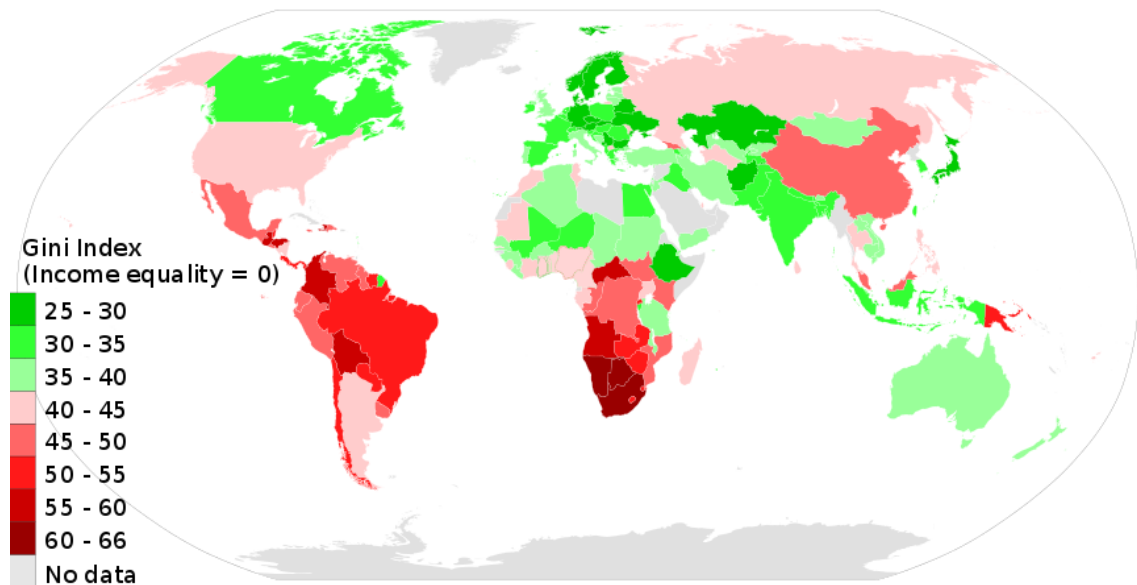


Figure 3: Gini Index by Country (World Bank)

Brazil also suffers from the shadow economy phenomenon. Usually correlated with poverty and sub-development, the informal economy or shadow market represents a substantial amount of Brazil's GDP. This concept is defined by the economic activities, enterprises and workers that are not regulated or protected by the state. This is mainly a way to collect earnings without reporting to tax authorities and to avoid bureaucracies to be able to develop products in a faster and cheaper way.

At a Ranking Developed by (Schneider et al., 2010), Brazil ranks at 105<sup>th</sup> in a list of 151 countries (1<sup>st</sup> is lowest shadow economy and 151<sup>th</sup> is the highest), with the shadow economy representing 39% of the official GDP.

Italy and Germany, for example, are, respectively, at the 51<sup>st</sup> and 18<sup>th</sup> positions, with the shadow economy representing 27% and 16% of the official GDP. The USA come at 2<sup>nd</sup>, with less 9% of the official GDP coming from the informal economy.

This is particularly important to the study, since Brazilian's construction sector is known to have a great participation of informal workers and to be one of the most corrupt sectors of the Brazilian economy.

As could be seen, Brazil differs a lot and in many aspects from more developed countries, such as the European ones. More specifically, focusing on the construction industry



the following table (Table 6), which was translated from the work of Mello & Amorim (2009) is presented:

	Brazil	USA	EU
% of GDP	5,20%	8,47%	10,20%
Revenues	US\$ 40,98 Billion	US\$ 475,6 Billion	US\$ 710 Billion
Number of Companies	105.459	818.000	807.100
Average Revenues / Company	US\$ 388.590	US\$ 581.420	US\$ 879.690
Formal Workers	1.550.000	7.689.000	4.519.000
Formal + Informal Workers	5.170.000	9.589.000	4.519.000
Average Productivity	US\$ 6.177,76 / Worker	US\$ 41.528,00 / Worker	US\$ 31.247,44/ Worker
Rentability	24,35%	67,50%	N. A.
Number of Engineers and Managers	125.420	623.000	550.530
Engineers / Total Labor Force	2,40%	6,50%	12,20%
Engineers / Formal Labor Force	8%	8%	12,20%
Average Instruction Duration (With Degree)	5 Years	5 Years	5-7 Years
Average Instruction Duration (Without Degree)	2 - 3 Years	3 Years	2- 3 Years
Number of Technical Norms	938	N. A.	1.733
Average Lead Time	30 Months	10 Months	14,3 Months
Average Licensing Lead Time	66 Days	30 Days	44 Days

**Table 6: Overview of the Construction Industry - Comparison between Brazil, USA and EU**

The table presents many remarkable insights:

1. The participation of the construction industry in the overall GDP is considerably lower in Brazil than in USA and Europe.
2. The average Brazilian company is smaller than the average American and European country (in terms of revenues).
3. Brazil has 3 times more informal workers in the sector than formal ones, which is quite different from what happens in Europe and in the USA.
4. The average productivity of the Brazilian worker is particularly lower, only 1/5 of the average European worker.
5. The (Engineers / Total Labor Force) ratio is much lower for Brazilian companies.
6. The average lead time for a typical construction in Brazil is 3 times higher than it is in the US and 2 times higher than it is in Europe.

It is important to understand the specificities of the Brazilian context to better analyze the causes and implications of companies' choices. More specifically, it is essential that we understand the big picture to understand certain choices regarding the

level of industrialization of a company (closely related to the level of modularity) and the existent relationships in the construction sector's supply chain.

## 2.7. Literature Review Conclusion

Much has been done in the literature with regards to modularity. The researches comprising the specificities of the E.T.O industries, although newer and in a remarkable smaller number, cover some aspects of the meaning and implications of modularity for these sectors.

The productivity and efficiency in those sectors have been growing in a much smaller pace than what is seen in the manufacturing sector. That is an intriguing fact that calls for research and for findings on what has been delaying the industry's improvement.

The industrialization of the construction industry would allow it to take part in the efficiency improvements that have characterized the manufacturing industry. For that, off-site production is extremely important. Since constructing a whole house or building off-site and then moving it to the site might be, sometimes, impossible, the need to divide the product in discrete chunks is notable.

Modularity becomes, that way, a means to the increase in the industry's efficiency. That is why there has been an increase in the interest of researchers in the modularity with its specificities to the E.T.O. industry and, in particular, to the construction sector.

It was possible to find some barriers to modularity in the construction industry in the literature, such as the design-related difficulties, site access constraints and higher capital costs (Pan et al., 2007), no clear measures of modularity in the sector (Gershenson et al., 2003; Rocha et al., 2015; Salvador, 2007) and the excess of regulation (Halman et al., 2008).

More specifically, the construction industry is perceived as an industry that lacks integration and whose supply chain is characterized by adversarial relationships and one off project procurement. This is, according to some authors (Bankvall et al., 2010; Koskela, 2003; Rocha et al., 2015), one of the main barriers towards modularity in the sector.

Although, as seen, many reasons have been found to be delaying the sector's development worldwide, that delay has been remarkably higher in Brazil. Most of the industry is strange to the meanings and definitions of modularity and its applications are quite rare.

The research was then conducted as to understand what makes the Brazilian construction industry's delay in improving efficiency bigger than the delays experienced by developed economies. Since, as previously mentioned, modularity is a means to improving the overall efficiency and productivity, the main idea was to understand why modular solutions struggle to become more popular under the Brazilian environment.

The supply chain, as well as its integration, has been mentioned by many authors to have importance in changes toward modular solutions and, because of that, the supply chain was also a research target and a connection between product modularity and supply chain integration is pursued.

Section 2.6. provided some knowledge about the Brazilian environment. It is believed that understanding the specificities of the Brazilian environment is keen to understanding the struggles related to the modularization and industrialization of the Brazilian Construction Industry.

### 3. Research Metrics

#### 3.1. Research Questions and Methodology

The study presents two research questions:

1. What the connection between product modularity and supply chain integration in the Brazilian construction industry is.
2. What the main barriers to the industry's growth are.

To answer these questions, an explorative case study was conducted and two different approaches were pursued:

1. Interviews with construction companies' employees or owners with a deep knowledge of the construction process and the supply chain relationships;
2. An interview with a renowned market expert which has more than 40 years of experience in the market.

The companies and their respective projects will be described and, after the interviews, their level of modularity and supply chain integration will be qualitatively assessed. All the companies interviewed were the supply chain owners.

As for the barriers to modularity, there have been contributions from the companies' employees. The market expert was also extremely important in that concern, given that his expertise was keen to provide a wide vision of the industry overall.

### 3.2. Assessment of Modularity Level

The level of modularity of each project will be basically based on the level of off-site activity, using (Des Doran & Giannakis, 2011) concept of modularity as a guidance.

The distinction will go as follows:

- Traditional Methods: Correspond to the lowest level of off-site activity and are, therefore, the least modular solution. The traditional methods are usually connected to craftsmanship, like bricks cemented with mortar.
- Hybrid: Pre-assembled products built off-site but combined with components built on-site.
- Modular: Products are assembled on-site but are built, almost entirely, off-site.

### 3.3. Assessment of Supply Chain Integration

The level of supply chain integration of each firm will be assessed based on Fine's elements of proximity and non proximity:

- Geographic Proximity
- Organizational Proximity
- Cultural Proximity

- Electronic Proximity

Also, the degree of firm's long term relationship and investments made on the relationship will be taken into account. If the firms engage in long-term relationships, that fact will imply a greater supply chain integration.

The distinction will go as follows:

- Low Level of Integration: The firm has shallow connections with their suppliers, with the relationship lasting only for the duration of the project and with low levels of proximity between the firm and the supplier. There have been no investments on the relationship other than those needed for the specific project.
- Medium Level of integration: The level of proximity between the firms is higher and the commercial relationship lasts for more than one project. There have been no significant investments in the relationship.
- High Level of Integration: The firms have a long-term relationship and have high levels of proximity. There have been significant investments in the relationship and the firms work on a cooperative basis.

## 4. The Case Studies

### 4.1. Methodology

The study was based on semi-guided interviews. All interviewees were employees or owners of the companies responsible for the whole supply chain.

The companies were chosen with the purpose to cover all possible levels of modularity encountered in the Brazilian Construction Industry and to assess the difficulties related to the use of modularity according to those that employ modular solution and to those that do not employ them.

The level of supply chain integration was then assessed to allow for a better understanding of the implications of modularity for the supply chain integration in the construction industry under the Brazilian context.

The interviews were conducted at the interviewees' offices and took approximately two hours each. Other than that, some material about the projects was given and data was also gathered from the companies' websites (except for the company of the case 4, which does not own a website).

## 4.2. Case Studies Summary

### Case 1

This interview was conducted with a technical director of a relatively small firm which employs around 150 people. The company delivers, on average, 8 projects per year.

The project's lead time was 8 months, and its cost was 50 million BRL. It was a factory for a large multinational corporation, Nestlé. The total area was twenty-five thousand square meters. The duration of the project was affected by the degree of off-site activity, which was above normal for Brazilian terms. Although in the construction of factory and industrial sites the amount of off-site activity is higher if compared to residential constructions, it is still quite low if compared to other countries.

Nestlé sought the company's services with an already started business and construction plan, and was very involved in the early stages of the project, mainly on the executive project. Therefore, the relationship with the customer was quite intense in the beginning of the project, what was not a major difficulty since the company and Nestlé have worked on 4 other projects before.

On the other hand, dealing with the suppliers was even easier due to the long-term relationship that has been nurtured over time. Given that the Brazilian construction industry is heavily reliant on on-site assembly and production, it is clear that the better your relationships along the value chain are, the better the company will be able to perform. This is also why when the supplier faces a problem the company tries to help in some way, to strengthen even more their business relationship.

Although the suppliers were geographically scattered, as usually happens in São Paulo due to the high land costs, the firm interacted regularly with the main suppliers and the firm's team was quite involved with the main suppliers' teams, not only setting the specifications but also

helping with the processes, sometimes even taking part in some of the supplier's strategic decisions. According to the interviewee, the absence of good suppliers in the market created the need to capacitate them and, therefore, long-term relationships are pursued. That helped to create a cultural synergy between the firms. The company's business mores are connected to delivering the whole solution and that is what they expect from the suppliers they capacitate. On the other hand, the firm and their suppliers did not usually share any specific software for data exchange and much of the interactions are done over phone calls or email exchange.

That, combined, shows a medium-high level of supply chain integrations in comparison to the Brazilian standards, which will be the benchmark for the qualitative assessment of the firm's supply chain integration.

## **Case 2**

The second interview was conducted with a controller and the director of engineering of a company with annual revenues amounting to 250 million BRL. The project was a residential building with 34 units ranging from 40 to 70 square meters and 2 rooftop units with 170 square meters. It was considered innovative in its architecture.

The projects lead time was 18 months for planning and 21 months in construction. The long duration for this project can possibly be explained by the amount of on-site construction that was used, as well as the permission for clients and customers to request customizations, and changes during the project.

The suppliers were geographically scattered, there was low, if any IT integration. If problems came up, the company withheld the suppliers' payment until the error was fixed. These factors could also contribute to the long lead time.

The relationships between the firm and the suppliers only lasted for the duration of the project and the firm's teams were not particularly engaged in helping the suppliers when problems not directly connected to the project aroused. Instead, the strategy used by the firm is to withhold suppliers' payments. That helped create disharmony between the firm's values and beliefs and the suppliers': While the company had a holistic view of the project and was worried with the solution they delivered, the suppliers were usually only worried about doing their part and not being blamed for eventual problems.

That resulted in a low level of integration between the firm and its suppliers when in comparison to the other companies analyzed.

### **Case 3**

The third project was undertaken by a relatively larger firm, with annual income of 500 million BRL, which undertakes about 10 projects every year. It was a Walmart unit and needed to be built fast. Walmart hired the company with an already established construction plan. The cost of this specific project was around 20 million BRL.

Given the short period of time the choice was made for steel frame off-site construction. This would make the assembly easier and faster. The construction lead time of 60 days proves this was the right path to be pursued.

There were long-term relationships with the suppliers, even though the method to handle problems was withholding the payment for the supplier. There was no significant IT integration and most of the data exchange was done via phone or via mail. The suppliers were also geographically scattered and there was, even though not strong, an effort by the firm to help with suppliers' indirect problems that were worsening the quality of the service they delivered.

The interviewee mentioned that the company prefers to work with some specific suppliers because they already know how the firm operates. That, combined with the above, show a medium-low level of supply chain integration.

This interview was conducted with the engineering director of the company.

### **Case 4**

The fourth project analyzed was under Minha Casa Minha Vida, a government program that facilitates the financing for real estate purchases by the poorer population (families with monthly income equal or lower to 6,500 BRL or 1,900 USD) and over 2,5 million families have been beneficiated. The other side of the programme is dealt with by the companies. They must submit the projects for review by the Caixa Economica Federal, which will contact the



constructor and supervise the project, if approved. Some companies have specialized in this type of project and have it as its main, if not only, source of income.

As the buildings were made totally from concrete, including the walls, the same mold could be used to do all the buildings (in this project, the buildings were 6 stories high). This greatly enhanced productivity.

There was no prior relationship with the suppliers and they were geographically scattered. Also, there was no significant IT integration. Most of the data exchange happened on-site, via email or via phone. While the company was worried about the whole project, suppliers were usually worried more worried with not being the one to be blamed when problems arosued than to actually fix the problem, according to the interviewee.

The facts suggest a low level of supply chain integration.

This was the only project this company made in the *Minha Casa Minha Vida* programme and the interview was conducted with the owner of the company.

## **Case 5**

The fifth interview was conducted with the director of engineering of a large company with annual revenues of around 1 billion BRL. The project selected was the construction of a new factory for P&G with a total area of 75 thousand square meters.

The lead time of the project was somewhere around 6 months, and the scope of the project was mounting only. P&G came to the company with construction plan and spent a lot of time debating about the main aspects of the project. This resulted in most of the lead time being spent on planning and not on the construction itself.

The suppliers used were put into three categories A (structure) B (doors, windows, floor, frames, etc) and C. There are few suppliers who work for/with the company and they generally are not prepared to reach the minimum standards required, which is why the company spends about 4 to 6 months training the main suppliers before effectively beginning the business relationship.

The suppliers, although geographically scattered, are in constant contact with the firm's team. The firm is committed to developing the suppliers, always focusing on a long-term relationship with them. The IT integration between the firm and its suppliers is quite low and, according to the interviewee, they are working on enhancing the data exchange methods and creating a more integrated system. This strong relationship shifted the incentives of the suppliers and they are now, according to the interviewee, also worried about the whole project and about creating better solutions to the client, creating, therefore, a cultural synergy with the firm itself.

The facts suggest a high level of supply chain integration.

The customer, P&G, were very strict about job safety and wanted as few people on site as possible, which was a demand that the company had to comply with.

Finally, the interviewee said that the company's intent is to transform the construction sites in production lines.

Table 7 presents a summary of the case studies:

	<b>Case 1</b>	<b>Case 2</b>	<b>Case 3</b>	<b>Case 4</b>	<b>Case 5</b>
<b>Project</b>	<b>Nestlé Factory</b>	<b>Residential Building</b>	<b>Walmart</b>	<b>Minha Casa Minha Vida</b>	<b>P&amp;G Factory</b>
Building Method	Hybrid Modular	Traditional	Hybrid Modular	Traditional	Modular
Activities were mainly held	Off-site / On-site	On-site	Off-site / On-site	On-site	Off-site
Company Revenue (BRL Million)	400	250	500	15	1000
Project Cost (BRL Million)	50	11	50	10	150
Relation with suppliers	Long-term	Short-term	Long-term	Short-term	Long-term
Geographic proximity	Scattered	Scattered	Scattered	Scattered	Scattered
Level of organizational proximity	High	Low	Medium-Low	Low	High
Level of cultural proximity	High	Low	Low	Low	High
Level of electronic proximity	Low	Low	Low	Low	Low

**Table 7: Case Studies Summary**

Table 8 presents a more detailed summary of how the level of integration of the companies was assessed:

	Case 1	Case 2	Case 3	Case 4	Case 5
Relation with suppliers	Long-Term / Focus on Capacitating the Suppliers	Short-term, no focus on capacitating the suppliers	Long-term, small intention of capacitating the suppliers	Short-Term / Relationship only lasted for one project	Long-Term / Strong focus on capacitating the Suppliers
Geographic proximity	Suppliers were geographically scattered	Suppliers were geographically scattered	Suppliers were geographically scattered	Suppliers were geographically scattered	Suppliers were geographically scattered
Level of organizational proximity	Firm's and suppliers' teams work together, firm wants to develop the supplier	The Firm does not participate in the suppliers' company, only project-related discussions	Firm helps suppliers with some improvements, not a strong interaction	The Firm does not participate in the suppliers' company, only project-related discussions	Firm's and suppliers' teams work together, firm wants to develop the supplier
Level of cultural proximity	Firm and suppliers share focus on solving the problem rather than finding who to blame	Suppliers are worried about not being blamed for problems, company is worried about solving them	Suppliers know how the firm operates and try to work accordingly	Suppliers are worried about not being blamed for problems, company is worried about solving them	Firm and suppliers share focus on solving the problem rather than finding who to blame
Level of electronic proximity	Data is shared usually by phone or emails	Data is shared usually by phone or emails	Data is shared usually by phone or emails	Data is shared usually by phone or emails	Data is shared usually by phone or emails, but there is a desire for more IT integration
<b>Level of Supply Chain Integration (Conclusion)</b>	<b>Medium-high</b>	<b>Low</b>	<b>Medium-low</b>	<b>Low</b>	<b>High</b>

**Table 8: Assessment of Supply Chain Integration**

### 4.3. Barriers to Modularity Mentioned in the Literature

The interviewees were asked to give a grade from 1 to 5 on the impact the barriers encountered in the literature have on the use of more modular solutions in the Brazilian construction industry.

According to them, the fact that there are no clear measures of what modularity is and the absence of knowledge on that behalf play an important role on halting the development of the modular construction industry in Brazil.

The adversary relationships in the supply chain are one of the main barriers towards the sector development. According to them, the suppliers are not ready to provide quality modules with the proper specifications and, therefore, training is needed to enable the use of modular solutions. That training is usually made only when there is a long-term relationship, due to the costs associated with it. Therefore, the adversary relationships in the supply chain and specially the lack of trust between agents are the main drivers that impede the industry's development.

The one-off project mentality brings the same impact as the adversary relationships afore mentioned. The companies are not inclined to provide training to suppliers that will only serve them for one project.

The construction culture has received the highest grade by all interviewees. They say the traditional construction culture impede the development of new and better technologies and that changes in culture are much harder to take place than changes in technology.

Design-related difficulties were considered as milder than the previews ones. Apparently, that is not what impedes the modular sector development.

Site access constraints were considered keen to hinder the use of off-site solutions. Indeed, there are some laws that impede the traffic of trucks in some cities during the day, what means that the whole stock for the day must be delivered over night. Since sites in the city are not usually big and the stocking capacity is, therefore, low, those facts might make the building method not viable.

The higher capital costs were seen as a hurdle for companies that do not use off-site solutions. For those that were using off-site and a combination of off-site and on-site methods saw the costs as an advantage for that kind of solution. They argue that, although direct costs are usually higher, the decrease in lead time and in indirect costs overcompensates it, making the solution cost efficient.

The excess of regulation was not seen as a problem at all. All respondents gave the lowest grade possible to that barrier.

The Table 9 shows the interviewees' opinion on how much each of the barriers found in the literature apply to the Brazilian industry and how much they impact the sector. They were asked to grade from 0 (does not apply) to 5 (applies and has a great impact):

Barrier Mentioned	Case 1	Case 2	Case 3	Case 4	Case 5
Project	Industrial Factory (25.000m <sup>2</sup> )	Residential Apartments	Retail Store	Social Housing	Industrial Factory (75.000m <sup>2</sup> )
No clear meaning and measures of modularity	5	2	3	4	4
Adversarial relationships in the supply chain	5	3	3	5	4
One-off project mentality	5	4	4	4	4
Construction Culture	5	5	5	3	5
Design - related difficulties	3	4	3	4	4
Site access constraints	2	4	4	5	5
Higher capital costs	0	4	2	4	0
Excess of regulation	0	0	0	0	0

Table 9: Impact of Barriers Mentioned According to the Interviewees

#### 4.4. Barriers to Modularity not Mentioned in the Literature

The interviewees also mentioned some other barriers that were not present in the literature. Although there are some shared opinions, the views on the barriers change dramatically when we shift from users of off-site solutions to users that are not used to that technology. The market had mentioned all of the barriers mentioned by the interviewees and further elaborated on the impacts of each one of those.

According to those that don't use the technology, the costs are much higher than the benefits. The reason for that is, according to them, that the labor is cheap and the use of industrialized methods would need a more expensive workforce. They acknowledge that modular solutions imply a lower lead time, but say that the reduced time schedule does not compensate the higher costs involved.

One interesting fact is that you need to pay taxes on industrialized products if you produce the components off-site that you do not need to pay if you produce the some components on-site. The IPI (Imposto sobre Produtos Industrializados – Tax on Industrialized Products) is mentioned as one of the factors increasing the costs and, thus, reducing the benefits of using modular solutions.

According to those that already use off-site production, the main reasons why it is so hard to find those solutions in the industry relate to the absence and to the quality of the suppliers.

They mentioned that there are no market standards and that there must be an agreement with the suppliers for the interfaces with other modules. That demands a specific training and capacitation of the supplier. According to the companies, it takes from 6 to 24 months to fully capacitate one supplier.

That involves, therefore, a deeper relationship and a stronger integration in the supply chain. The contractor (supply chain owner) invests time and effort into the capacitation of the suppliers and, as a result, deeper ties are formed in the supply chain. The companies state, nevertheless, that the relationships are only commercial, with no joint-ventures or any kind of equity involvement.

The interviewees mentioned, regardless if they use traditional or more modular solutions, agreed that that kind of method is not viable for some spaces in the city. More specifically, some places have traffic impediments for trucks during certain hours of the day and are not big enough to be able to stock the materials needed for the whole day of activities on-site. That combination limits the applicability of off-site solutions in the inner part of the city, especially if the site is small.

Table 10 presents a summary of the barriers mentioned by the interviewees that were not previously mentioned in the literature.

<b>Barrier Mentioned</b>	<b>Case 1</b>	<b>Case 2</b>	<b>Case 3</b>	<b>Case 4</b>	<b>Case 5</b>	<b>Market Expert</b>
Cheap Labor when Using On-site Solutions		x		x		x
Tax on Industrialized Products (IPI)	x	x		x		x
Absence of Suppliers	x		x		x	x
Bad Quality of Existing Suppliers	x		x		x	x
No Market Standards	x		x		x	x
Traffic and Site Stocking Limitations	x	x	x	x	x	x

**Table 10: Barriers not Mentioned in the Literature**

#### 4.5. Other Aspects Mentioned by the Market Expert

The Design & Construction Managing Director of the Brazilian Branch of Tishman Speyer, one of the main Real Estate companies worldwide, was interviewed. He is also a visiting professor at the Escola Politécnica da Universidade de São Paulo.

He had mentioned the barriers encountered by the companies interviewed and elaborated on some of them. He also highlighted the fragmentation of the industry's supply chain and how that affects any intention of higher modularization.

In Patio da Marítima, one major commercial project with more than 70.000 square meters of leasable space being developed by Tishman Speyer in Rio de Janeiro, there are more than 800 suppliers. The project is supposed to last for 40 months. He states that managing this kind of project is extremely hard and unproductive and the industry is urging for industrialization.

The biggest problem is, according to him, the absence of standards. The fact that there are no market standards make companies need to invest time and effort on capacitating the suppliers. Since not all companies are inclined to do it, due to the lack of thrust inherent to the industry, the result is that modular solutions are not usually seen in the country.

The lack of market standards relates to the fact that there are many small suppliers in the sector and no supplier big enough to develop a standard that will guide the whole industry. There have been some attempts by the academia to develop the standards, but most of them were unsuccessful until now.

The market expert believes that the change will not come from the construction sector and that the manufacturing industry will need to make the change happen. According to him, modularity will only become widespread in Brazil if the industry sector is able to provide the whole solution formulated.

He blames the lack of leadership in the construction industry and the mentality of the agents for the lack of development towards a more industrialized sector in Brazil.

#### 4.6. Relationship Between Modularity and Supply Chain Integration

The Case studies provided some interesting insights.

On the opposite direction of what some studies in the literature suggest (Caridi et al., 2012), (Fine 1998), there seems to be a positive correlation between the use of off-site solutions and supply chain integration, especially concerning the duration of the relationship.

That happens due to the need of investments in the relationship to capacitate suppliers. It usually takes from six to twenty-four months to fully capacitate a supplier, according to the firms interviewed. That process takes plenty of time and effort and companies are not inclined to invest the resources without plans towards a long-term relationship.

In case 5, for example, main suppliers are trained for 4 to 6 months prior to the beginning of the business relationship itself. The idea behind that is to prevent mistakes and to limit the on-site problems to the lowest level possible.

On the contrary, traditional solutions employ suppliers that are characterized by a low-skilled labor force that is used to doing certain things in certain ways. Firms are not inclined to invest on the relationships with these firms and that culminates in a low level of integration between the firms.

The suppliers in the industry are extremely fragmented and it is quite rare to find big suppliers in the market. The company, after choosing a supplier, needs to invest on the relationship by capacitating the supplier so to be able to maintain its quality requirements.

This happens specially when considering off-site solutions. In this case, there is a desire to reduce on-site problems to the minimum and, for that, the parts that will compose the product must be built in a way as to perfectly match the other parts of which the product will be comprised.

In this sense, there is a strong focus on the design phase rather than on the execution phase, and suppliers must comply to the quality standards as a requirement for on-site efficiency.

The absence of market standards make the interface between modules an issue for each different project, making the design phase even more important. This calls for a higher level of integration, since the suppliers must be somehow involved with the project as to develop the modules with the proper interface, so that no problems in the assembly phase arise.

Traditional methods usually employ a work-force that is used to ad-hoc solutions, with a stronger emphasis in the execution phase rather than on the design phase. This kind of thinking brings, on one hand, inefficiencies, but a lower cost and a lower need of integration during the design phase on the other hand.



The absence of big suppliers also makes it harder for the market to accept a common standard. The result is that companies are afraid to comply to the standards provided by a certain supplier due to the risks involved and usually create their own standard, shifting the need to comply to standards from the company to the supplier.

That is extremely harmful to the industry as whole, since economies of scale, which are one of the biggest benefits of modularity, are remarkably limited in that case.

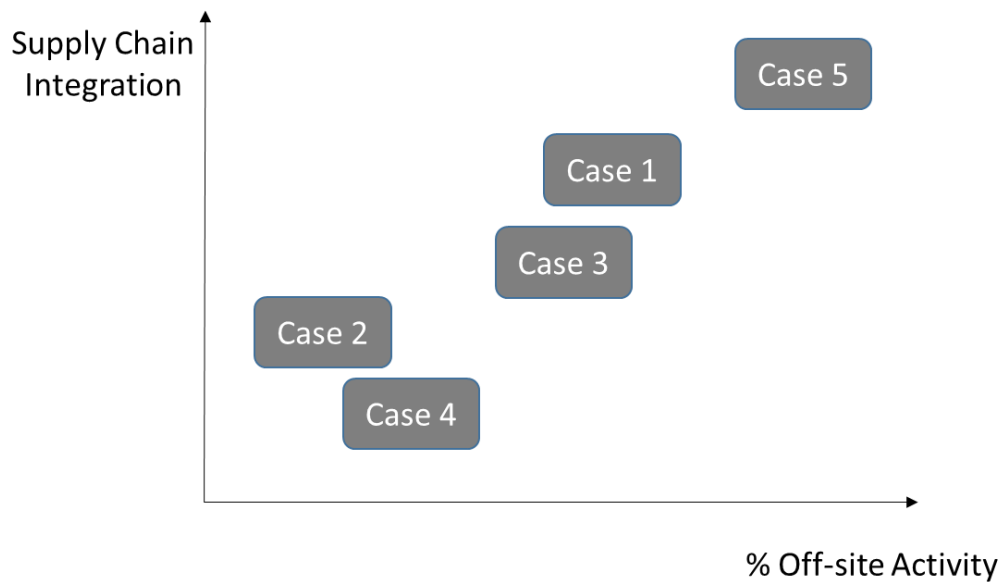
The supplier, instead of making modules that work for all companies, must develop specific interfaces for specific companies. That makes the concept of modularity applicable, even if in a multi-project basis, only to the intra-firm environment.

This might happen because of the small current size of the industry in Brazil. Once market standards are created, as can be the case with the arousal of big suppliers, the level of integration during the design phase will be much lower, since much of the need of this integration is due to the fact that proper interfaces between modules must be created for each different firm.

The market expert, previously mentioned in former sections, believes that, in the stage the Brazilian construction industry is, there is a strong need to develop the suppliers as a way to enable the industrialization of the sector. For him, the adversarial relationships must turn into partnership relationships and the construction supply chain must become a value chain.

As to the results of the study, it is important to highlight that even the firms with the highest levels of supply chain integration are indeed quite poorly integrated in relationship to other industries and that the level of supply chain integration is assessed, in this case, on a comparative basis.

The graph 1 highlights the results of the case study regarding the relationship between the amount of off-site activity (as a way to assess modularity) and supply chain integration:



Graph 1: Relationship Between Degree of Off-site Activity and Supply Chain Integration

## 5. Conclusion

The paper investigated the reasons why modular solutions are not more widely applied in the Brazilian construction sector. There were many barriers found in the literature but none of them could fully explain why there is a gap between the modularization of the Brazilian construction industry when compared to other economies' industries.

The case studies successfully answered this question. Not only do the barriers found in the literature exist under the Brazilian context, there are also many other reasons why the sector struggles to become more industrialized.

One of the main reason is the structure of the industry. There is an enormous number of small suppliers and almost no big suppliers. The implications for that are not only the absence of accepted market standards for the modules provided, but also the need of companies to invest resources into their suppliers to make them capable of delivering a quality service.

The need to make these investments calls for a bigger integration and a focus on long-term relationships. Companies mention that it takes from six to twenty-four months to fully capacitate a supplier. That kind of relationship goes against the industry's norm of one-off project mentality and adversarial relationships in the supply chain.

As a result, there seem to be a positive correlation between the amount of activities done off-site with the level of supply chain integration. Companies only invest on capacitating the suppliers when they can expect longer-term relationships with them. These companies usually work with their suppliers in a quite collaborative way, contrasting with the usual relationships found in the construction industry supply chain.

The characteristics of the city of São Paulo (where the research was conducted) also plays an important role. There are no more large sites in the city's inner part and there are traffic limitations for trucks during certain hours of the day in a great part of the city. That facts combined make it harder to proceed with the On-site activities related to the use of modularity. Modules can only be delivered at night, due to traffic limitations and sites are not big enough to hold the needed stock for a day of On-site assembly.

Moreover, the Brazilian's labor force is remarkably cheap and unqualified. Therefore, traditional solutions, which mainly consist of the use of unqualified labor, have a cost advantage in that regard and, thus, make modular solutions less attractive.

The study is limited to the specific Brazilian environment and to the specific period during which it was conducted. The results are probably connected to the dynamics associated to the changes in the industry and would probably be different if the study were conducted when the off-site sector is more developed.

Also, the absence of fully-modular solutions in the case studies not only reflect the reality of the Brazilian construction industry, but also serves as a limitation to the study itself.

Conducting the same study in other developing countries with similar characteristics can be extremely interesting so to deepen our knowledge about the relationships between supply chain integration and modularity under these circumstances.

Further research should elaborate on these findings and analyze possible solutions to the problems found. In particular, creating market standards in academia would certainly improve the overall efficiency of the industry, creating synergies and making it possible for suppliers to benefit from the economies of scale.

## 6. Appendix

Questionnaire used in the interviews and its translation.

### Questionário

- 1) Descrição da empresa (Nome, número de projetos em um ano, número de empregados, etc)
- 2) Entrevistado
- 3) Descrição do projeto
  - a. Produto do projeto (edifício corporativo, residencial, casa, entre outros)
  - b. O produto final do projeto pode ser decomposto em menores módulos? (elementos estruturais, painéis, etc)
    - i. Os módulos podem ser decompostos ainda mais em módulos menores?
    - ii. Esses módulos podem ser reutilizados?
    - iii. Você enfrenta algum problema quando usa esses módulos? Quais?
    - iv. Eles são comprados no mercado, feitos sob encomenda ou feitos pela própria empresa?
  - c. De acordo com a sua definição, o produto é inovador? Se sim, por quê?
    - i. Se não, ele é customizado?
  - d. Você acredita que a indústria afeta o produto?
  - e. Qual é o lead time e o custo do produto?
- 4) Clientes
  - a. Quantos e quais foram os clientes do projeto?
  - b. Qual o papel de cada um deles no projeto?
  - c. Antes do projeto iniciar, havia um número de reuniões marcadas?
  - d. Durante quais fases eles tem maior influência?
  - e. Qual é a resposta quando um cliente propões uma mudança em um estágio final do projeto?
  - f. Como você lida com demandas muito específicas de clientes?
  - g. Você possui relacionamento de longo prazo com os clientes?
  - h. Quais práticas, se alguma, você utiliza para evitar problema com clientes, seja esse qual for?
- 5) Situação da cadeia de suprimentos

- a. Quais fornecedores foram envolvidos no projeto?
  - i. Qual a localização geográfica deles?
  - ii. Qual o relacionamento com eles?
    - 1. Existe um número pré-determinado de reuniões?
  - iii. Qual a relevância deles para o projeto?
  - iv. Existe alguma integração da tecnologia da informação para facilitar a comunicação?
  - v. Existe um relacionamento de longo prazo com os fornecedores?
  - vi. Existe um, ou mais, encontro(s) entre os fornecedores e os clientes?
  - vii. Os fornecedores participam do design do produto?
  - viii. Existe uma joint venture ou apenas uma relação comercial?
  - ix. Como vocês solucionam problemas, quando esses ocorrem?
  - x. Quais estratégias vocês utilizam para diminuir os riscos de problemas críticos?
- 6) Barreiras em relação à modularidade / pré-fabricados
  - a. Quais são as principais Barreiras que você vê para o uso de pré-fabricados no Brasil?
  - b. Quais são as principais vantagens?
  - c. A empresa já usou pré-fabricados em obras?
    - i. Se sim, como foi a experiência? Pontos fortes e fracos
    - ii. Se não, por quê?
  - d. O quanto cada uma das barreiras abaixo impacta no uso de solução modulares? (de 1 a 5)
    - i. Não existirem medidas nem definição clara do que é modularidade
    - ii. Relações adversárias na cadeia de suprimento
    - iii. Mentalidade voltada somente para um projeto
    - iv. Cultura da construção
    - v. Dificuldades relacionadas ao design
    - vi. Dificuldades relacionadas ao acesso ao canteiro de obra
    - vii. Maior custo
    - viii. Excesso de regulamentação

## Questionnaire

- 1) Company description (name, size, number of employees, etc)

2) Interviewee

3) Project description

- a. Project output (corporate building, house, etc)
- b. Can the output be broken into smaller pieces (modules)?
  - i. Can these modules be broken into even smaller modules?
  - ii. Can these modules be reutilized?
  - iii. Do you face problems when using the modules? If so, which?
  - iv. Are the modules bought, engineered to order, or produced by the company?
- c. According to your definition, is the product innovative?
  - i. If not, is it customized?
- d. Do you believe that the product is affected by the industry?
- e. What is the lead time and the cost of the product?

4) Customers

- a. How many and who were the customers on this project?
- b. What was their role?
- c. Before the project began, was there a set number of meetings?
- d. During which stages do they the most influence?
- e. What is your answer when a customer suggests changes in a late stage of the project?
- f. How do you handle customer specific demands?
- g. Do you have a long-term relationship with the customers?
- h. Do you have any special way to avoid problems with customers, whichever they may be?

5) Supply chain situation

- a. Which were the suppliers in this project?
  - i. What is their geographical location?
  - ii. What is your relationship with them?
    - 1. Is there a set number of meetings?
  - iii. What is their relevance to the project?
  - iv. Is there an IT integration to help with the project?
  - v. Is there a long-term relationship with the suppliers?
  - vi. Are there meetings between customers and suppliers?
  - vii. Do suppliers participate in product design?
  - viii. Is there a joint venture or only a business relationship?

- ix. How do you solve problems when they arise?
  - x. Which strategies do you use to diminish the risk of critical mistakes?
- 6) Barriers related to modularity
- a. What are the main barriers you see related to the use of modular solutions and prefabricated elements?
  - b. What are the main advantages?
  - c. Has the company ever used prefabricated solutions?
    - i. If yes, what were the pros and cons?
    - ii. If no, why?
  - d. What is the impact (from 0 to 5) of each one of those barriers towards the use of modular solution in Brazil?
    - i. No clear measure of what modularity is
    - ii. Adversarial relationships in the supply chain
    - iii. One-off project mentality
    - iv. Construction culture
    - v. Design-related difficulties
    - vi. Site access related difficulties
    - vii. Higher capital costs
    - viii. Excess of regulation

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