MODULAR SUPPLY CHAIN OPTIMIZATION IN THE CONSTRUCTION INDUSTRY

Pedro Manuel Bairrão Aranha Rijo
Department of Civil Engineering, Architecture and Georesources, Instituto Superior Técnico, Av. Rovisco Pais, 1, 1049-001 Lisbon, Portugal

Abstract

Nowadays, the construction industry is going through an unprecedented crisis. The number of companies going bankrupt is alarming. According to COSEC, approximately one third of the nearly 5000 bankruptcies in Portugal in 2011 correspond to construction companies [1]. It is, therefore, suitable to look at the industry and try to find solutions.

The industry needs a change. The proof of that is that the number of homes sold is reaching record lows, while the number of homeless is constantly increasing. Europe has a demand for cheap homes that greatly exceeds the supply.

Customer satisfaction with the construction product and the working conditions, are also distant from what is standard in other industries.

However, even in the presence of these facts, the industry continues to invest little in research, and that investment is decreasing. This is a result of low profit margins, due to the fact that clients select the designers and constructors almost exclusively on the basis of tendered price.

In Portugal, the industry is also turning increasingly to foreign markets. However the product of construction is not the easiest to export due to its nature.

In this paper we analyze the solutions found by other industries to improve them selves, and discuss the possibility of being applied to the construction. The concepts of modern supply chain management and industrialization will be applied to construction and their benefits will be discussed.

A fictitious case study was created to help understand this concepts. Then, it's supply chain was optimized by a mathematical model developed for that purpose.

Objectives and hypotheses

As a guideline for this paper, the following hypotheses were formulated:

Hypothesis 1 - The construction can learn from other industries and improve the construction processes;

Hypothesis 2 - Better management of the supply chain, together with the use of industrialized construction and the most advanced information technologies, can help the industry to become more agile in terms of its internationalization.

Then, from this hypothesis, were set out the objectives below:
Objective 1 - Identify ways in which the construction industry can improve and what it can learn from other industries;

Objective 1.1 - Characterize the construction industry and identify problems;

Objective 1.2 - Understand how other industries have surpassed similar problems;

Objective 1.3 - Understand the differences between the construction industry and others and the reasons why there may be difficulties in implementing improvements.

Objective 2 - Verify the feasibility of the use of industrialized construction, using a global supply chain and the latest information technologies, to perform work across borders;

Objective 2.1 - Develop a fictitious case study of a construction company with international projects;

Objective 2.2 - Develop a mathematical model that calculates the costs along the supply chain;

Objective 2.3 - Create various scenarios, the most representative of reality as possible, to understand how the supply chain behaves with the variation of different parameters and what is the optimal solution for each case;

Objective 2.4 - Analyze the feasibility of the use of industrialized construction in the case study;

Objective 2.5 - Assess the importance of optimization in the decision making process.

Objective 3 - Analyze the feasibility of implementing these concepts in a real case and what are the main differentiating aspects to consider.

Characterization of the construction industry

This sector is one of the biggest employers in the European Union and Portugal. According to the Monthly Bulletin of the Portuguese Economy of November 2010 [2], the construction sector in 2007 employed 540,000 individuals, representing 12.2% of total employment in the economy. In the European Union, 11.8 million (7.1%) are employed in the sector, while 26 million have their job very dependent on the construction industry [3].

Despite the high number of jobs that depend on this industry, in 2007 53% of the companies employed fewer than four employees, 79% less than ten and only 2.1% more than fifty workers, showing that the majority of the companies were small [2]. In the remaining EU the picture is again similar, with 96% of businesses having small or medium size [3].

In this context, the construction sector shows to be very important for the country and the European Union, and in 2007 accounted for 10.7% of national GDP [2] and 9.8% of GDP in 2005 of the European Union [3].

The high number of SMEs is due to the fact that the industry rely heavily on subcontracting. This means that there is no continuity of teams, which is essential to an efficient work. The project is seen as a sequence of operations performed by several different teams that can not see the product as a whole and that are only interested in the quality of their part, instead of the final product.
This means that there are short term relationships between teams and suppliers. For a good performance, a long term relationship is required. A team that doesn’t remain together doesn’t have a learning capacity and has no possibility to make improvements over time, to increase the quality and productivity.

Need for a change

Despite the number of properties sold is reaching historic lows, the number of homeless is growing every year. When looking at these data, quickly is concluded that it is necessary to create a market for cheap homes and that the supply isn’t aligned with demand [4]. This demand cannot be met using the traditional method of construction, because the costs associated with construction are too high, which is partly due to the fact that almost all new buildings are being planned and built from scratch.

The current crisis also increases the need for internationalization of companies, yet the sector is far from being competitive in this field. The product of the construction is not the easiest to export, due to having to be implemented on site. The current solution consists is the expatriation of skilled personnel to the site in question and hiring unskilled labor directly on site. However this solution is not ideal because the expatriation of qualified staff have very high costs and hiring local labor is often unpredictable in developing countries. Absenteeism is present in the mindset of many local people and complicates the logistics of the work, bringing in personnel management problems and may lead to a delay of the work [5].

But the men power is not the only difficulty. There is also all the complicated paperwork, the fact that the company has all the equipment in the country of origin, the existence of different standards, different products with different names, types and different areas, among others.

Furthermore, there are too few people being trained to replace the aging skilled workforce, poor working conditions and the customer dissatisfaction with the end product of construction. The projects are seen as unpredictable in terms of delivery within the stipulated time, within budget and within the parameters of desirable quality. In summary, the construction fails to meet the requirements of a modern business that rarely offers the best value to customers and taxpayers.

Tools for a change

There are a number of promising developments that emerged in the construction industry that can lead to improvements [6]. Among them are:

- Best components, materials and construction methods, including standardization and prefabrication;
- Increased use of new technologies such as BIM (Building Information Model), global positioning systems (GPS), commerce platforms that enable a more efficient procurement (eCommerce), technologies to better manage the supply chain (ERP), among others;
- Tools to mitigate fragmentation, such as partnerships, which are becoming increasingly used by the best companies instead of the traditional contract procurement;
- Growing interest in tools and techniques to improve efficiency and quality learned in other industries, including benchmarking, value management, team working, Just-In-Time and Total Quality Management.
What can the construction industry learn from other industries

Whether in manufacturing or services industries, there have been increases in efficiency that a few decades ago no one thought were possible. This efficiency increase is partly due to the ease of movement of goods in international markets, highly motivated by the emergence of international standards, that do not exists in construction.

Despite the obvious differences between the construction industry and the rest, it will be interesting to see how other industries have improved and become more efficient.

In this paper were identified six points that has driven the production and service industries to implement these improvements and that are as applicable to the construction industry as to any other [6]. They are:

• Committed leadership;
• Focus on the final consumer;
• Integration of the project and the team around the product;
• Commitment to quality;
• Commitment to people.

Once the conditions outlined above are met, the construction industry can learn and implement the following:

• Iterative process;
• Integrated project;
• Focus on the final product.

This paper focuses in more detail the first two points, that is, the repetitive process and the Integrated project, through the themes of industrialized construction and integrated supply chain management.

The supply chain management

The supply chain management is a concept that appeared in the manufacturing industry. The first visible signs of supply chain management system are the delivery Just-in-time (JIT), as part of the Toyota production system [7].

The supply chain management sees the supply chain as a whole, instead of seeing only the next level or the part that follows, and attempts to increase transparency and coordination and alignment of supply chain configuration.

This has been used in many other industries to gain competitive advantage. From the retail industry to the automotive and agriculture, this philosophy has examples of successful applications [8].

Recently, especially in the last decade, the construction industry has recognized the importance of supply chain management to improve the performance of their projects. This is due in part to a greater competition and consumer demand for lower prices, higher quality, lower execution time and greater compliance with deadlines.

However, the industry has been slow to implement the concept, probably due to the context in which the supply chain management should be applied, that is, an organizational structure that consists of individual elements acting as a whole.
The problems in the implementation of a good supply chain collaboration in the industry are associated with an inappropriate culture and the unique characteristics of its organizational structure. The trust, a key element for a successful implementation, is the only one that is currently cultivated by the industry.

The greatest barrier to implementing a successful supply chain partnership is the lack of commitment of top management, followed by a poor understanding of the concept, an inappropriate organizational structure to deal with the concept and lack of commitment from partners. The least important factor was the lack of appropriate information technology, followed by lack of clarity of strategic benefits.

The industrialized construction

Abraham Warszawski [9] defines a project of industrialization as an investment in equipment, facilities and technology in order to increase output, reduce labor and improve quality. It considers that for a successful process of industrialization should be considered the following prerequisites:

• Centralized production;
• Mass production;
• Standardization;
• Specialization;
• Good organization;
• Integration.

Another important concept is automation. The computer controlled automation puts the manufacturing process in a new dimension. The standardization and specialization are no longer prerequisites for industrialization.

Abraham Warszawski also advocates that a radical increase in productivity and quality in construction will only be possible if the industry make intensive use of industrialization and automation.

The greater the number of components which are prefabricated in advance in a factory, the more effective is the industrialization process.

It’s easy to conclude that the greater the number of prefabricated elements, the less labor on site and lower the dependence on skilled labor, weather and other unforeseen events that can occur on site.

That said, the benefits of an industrialized construction can be summarized as the following [9]:

• Reduction of the workforce in the work site (40-50%);
• Faster construction process;
• Highest quality components.

Despite the benefits, the proportion of work that used industrialized construction is not increasing in most countries, largely due to [9]:

• Market volatility and decline in demand for major construction projects in most developed countries, which makes investment in facilities riskier;
• The bad image of industrialized construction, long seen as housing of a lower social level;
• The industrialized construction is considered to be very rigid with respect to changes in the buildings over their lifetime;
• Technology, organization and design of industrialized construction systems is not part of the general knowledge of engineers and architects and hasn’t great importance in their academic curriculum.

The case study
To better understand these concepts was elaborated a case study of a fictitious construction company to work in foreign locations: Luanda, Huambo, Brasilia and Rio de Janeiro. In this, will be determined whether or not to choose an industrialized construction method and what’s the optimal setting for the supply chain.
Briefly, the problem of the case study will aim to find out what’s the most effective solution, that is, what’s the economically most advantageous solution.
The problem will be solved using mathematical optimization.

The construction methods considered for the case study
As mentioned before, two construction methods will be analyzed: the traditional method and industrialized.
From the standpoint of the supply chain, aim of this study, the major difference between the two lies in the places in which the work occur. In the first, the whole construction is carried out in the construction site. In the second, part of the work is carried out in a different location from the site.
However, there is a huge diversity of industrialized methods. Therefore, is necessary to choose one.
The choice fell upon a method with considerable similarities to a developed and used by the swedish construction company NCC, the NCC Komplett [10].
This consists in the prefabrication of modules that are then assembled on site. That requires a factory to produce modules and assembling tents at the work site. The tents are equipped with cranes and assembly tools that facilitate the installation and all the manual work.
In comparison to traditional methods, NCC have projected a 50% reduction in the total duration of the work and a reduction in costs and increase in final quality.

Despite apparently promising, the whole process has been more expensive, more complex and time consuming than estimated at the beginning and NCC opted to close the factory in 2007. However, the process is still a reference and a way for the construction industry to learn and take conclusions.

Thus, the case considered in the case study (as industrial method), will have the following differences compared to the NCC’s, in order to make it more competitive:

- The various assembly lines do not need to be on the same assembly unit. That is, there may be different locations for each assembly line;
- The assembly units may be located in a different country than the one in which the work site is. So it's possible to benefit from a differential in costs between countries.

The supply chains of the case study

To reduce the complexity of the problem this study will only focus on the supply chain of the kitchens.

As common elements to the supply chains of both methods there are components, suppliers, transportation and construction site. In the industrial method, in addition to these there are the assembly units and modules. Each one is defined below.

1. Components

The components are essential to building a kitchen. A kitchen consists of a series of components: appliances, masonry, tiles, windows, doors and kitchen furniture.

2. Suppliers

The suppliers are companies that manufacture and sell the components.

3. Modules

The kitchen module consists of various components that are mounted on the assembly unit. The kitchen module can be decomposed into pieces for easy transport.

4. Transport

Are the means of transport that move products through the supply chain. There will be considered two modes of transport: by road and by sea.

5. Assembly Units

These are the places where the modules will be assembled. The components enter the assembly unit and are processed into a kitchen module. The assembly units will be located in Lisbon or Fortaleza.

6. Construction site

These are the places where the buildings will be built.

There are, therefore, two possible configurations for the supply chain, according to the chosen construction method.
The mathematical models developed for the case study

To solve the case study was necessary to develop two types of models: one for cost (Model 1), and another for the supply chain itself (Model 2).

Since the objective is to find the most economical solution, the costs are a key element. However, given that it is a fictitious case and given the enormous complexity involved in calculating the costs to assess the benefits of prefabricated construction in face of traditional construction, it was decided to develop a model that generates approximate costs, instead of determining the actual costs.

As a starting point, the model takes a cost structure of a traditional work. All other costs will be calculated using this structure. For the calculations the model takes into consideration, basically, relations between costs.

The costs generated by the cost model will be introduced later in the second group of models, the models of the supply chain.

The mathematical models developed for the supply chain consists in several problems of linear programming (optimization), in which the objective functions are the sum of the costs.

Thus, the problem described is decomposed into several simple problems. The simpler the models are, the easier and quicker are to solve. This also greatly reduces the likelihood of errors in the mathematical formulation. The mathematical models of the supply chain are:

1. **Model of the Lisbon Assembly Unit (Model 2.A)**

   The first model aims to minimize the costs of a assembly unit located in Lisbon. To this, it enters into account the costs of each component from the various suppliers and the cost of transporting these to the assembly unit. The objective function of this model is the following:

   \[
   \min(kil) = \sum x \sum j \left[ alisboa_{xj} \times (cfmvl_{xj} + cup_{xj}) \right]
   \]

   With \( kil \) being the integer variable representing the total cost of the components and transport related with the Lisbon Assembly Unit; \( alisboa \), the total of components \( x \) bought by the Lisbon Assembly Unit; \( cfmvl \), the cost of transporting a component \( x \) between the supplier \( j \) and the Lisbon Assembly Unit; and \( cup \) being the cost of the component \( x \) from the supplier \( j \).

2. **Model of the Fortaleza Assembly Unit (model 2.B)**

   Like the previous model, this aims to minimize the cost of a assembly unit, but this time located in Fortaleza. The objective function is:

   \[
   \min(kif) = \sum x \sum j \left[ afortaleza_{xj} \times (cfmvf_{xj} + cup_{xj}) \right]
   \]

   With \( kif \) being the integer variable representing the total cost of the components and transport related with the Fortaleza Assembly Unit; \( afortaleza \), the total of components \( x \) bought by the Fortaleza Assembly Unit; \( cfmvf \), the cost of transporting a component \( x \) between the supplier \( j \) and the Fortaleza Assembly Unit; and \( cup \) being the cost of the component \( x \) from the supplier \( j \).
3. **Model of the various work sites, using the traditional method (Model 2.C)**

This model aims to minimize the costs for each work site, when using the traditional method. To this end it enters into account the costs of each component from the various suppliers and the cost of transport. The objective function is:

\[
\text{min}(ket) = \sum \sum \sum \left[ \text{aestaleiro}_{sji} \times (\text{cfov}_{sji} + \text{cup}_{sji}) \right]
\]

With \( ket \) being the integer variable representing the total cost of the components and transport from all the work sites; \( \text{aestaleiro} \), the total of components \( x \) bought by the work site \( i \); \( \text{cfov} \), the cost of transporting a component \( x \) between the supplier \( j \) and the work site \( i \); and \( \text{cup} \) being the cost of the component \( x \) from the supplier \( j \).

4. **Model for the choice of the location of the Assembly Unit (Model 2.D)**

This model minimizes the costs of the industrialized solution, that is, it identifies which assembly unit correspond to the most economical solution. To this, the model enters into account the optimized costs of the models 2.A and 2.B, with transport costs between the units and the work sites and with the fixed and variable costs of each of the assembly units. The objective function is:

\[
\text{min}(sol) = \sum \left[ \text{eumont}_k \times \left( \sum (\text{nr}_i \times \text{cdo}_{ik}) + \text{ntotal} \times (\text{cum}_k + \text{ki}_k) + \text{CFum}_k \right) \right]
\]

With \( sol \) being the integer variable representing the total cost of the industrialized optimal solution; \( \text{eumont} \), the integer variable that represents which Assembly Unit must be chosen; \( \text{nr} \), the total number of kitchens at the work site \( i \); \( \text{cdo} \), the cost of transporting a module between the Assembly Unit \( k \) and the work site \( i \); \( \text{ntotal} \), the total number of kitchens; \( \text{cum} \), the cost of assembly a module in the assembly unit \( k \); \( \text{ki} \), the total cost of the components and transport related with the Assembly Unit \( k \); and \( \text{CFum} \) being the fixed costs of the Assembly Unit \( k \).

5. **Model for the choice of construction method (Model 2.E)**

This model aims to minimize the final cost of the kitchens construction at the work sites, that is, calculate what construction method is the most advantageous. To this, the model enters into account the optimized costs of the models 2.C and 2.D. The objective function is:

\[
\text{min}(T) = \sum (m_s \times \text{total}_s)
\]

With \( T \) being the integer variable representing the total cost of the optimal solution; and \( m \), being the integer variable that represents which construction method must be chosen.

**Solving the case study**

To solve the problem, the aforementioned models needs to be executed. The first model to be executed will be the cost model (Model 1), for such will be used the Microsoft Excel.

With those costs, it’s time to run the supply chain mathematical models (Model 2). These models are implemented and executed in the GAMS software, a tool used to solve linear programming optimization problems.
To be able to perform a analysis of the problem as completely as possible, and since this is a fictional case study, several different scenarios were used to understand how the models behave. Thus, was created fifty-six different scenarios.

Each scenario comprises a scenario group (A, B, C and D), a demand sub-scenario (i, ii, iii, iv, v, vi and vii) and a transportation cost sub-scenario (1 and 2). Thus, a scenario is represented by an uppercase letter, one number in roman format and a number in arabic format.

All scenarios represent variations of the scenario A1i (which will be called base scenario). This scenario is taken as a starting point, that is, one that has all the costs equal to those calculated in the cost model (Model 1).

The two models were executed for each of these scenarios, which generates fifty-six different results. Three of them are shown in table 1.

**Table 1. Results**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Construction method</th>
<th>Assembly unit</th>
<th>Supplier 1</th>
<th>Supplier 2</th>
<th>Supplier 3</th>
<th>Supplier 4</th>
<th>Supplier 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1i</td>
<td>Trad.</td>
<td>Rio Grande</td>
<td>Rio Grande</td>
<td>Sevilha</td>
<td>Xingang</td>
<td>Brno</td>
<td>Bangkok</td>
</tr>
<tr>
<td>A1ii</td>
<td>Ind.</td>
<td>Rio Grande</td>
<td>Rio Grande</td>
<td>Sevilha</td>
<td>Oporto</td>
<td>Brno</td>
<td>Bangkok</td>
</tr>
<tr>
<td>A2ii</td>
<td>Trad.</td>
<td>Rio Grande</td>
<td>Rio Grande</td>
<td>Sevilha</td>
<td>Xingang</td>
<td>Brno</td>
<td>Bangkok</td>
</tr>
</tbody>
</table>
Conclusions

The construction industry needs a change. There's a whole range of concepts that can be learned in other industries and can be applied to construction. Among these, this paper focused on the concepts of industrialization and integrated supply chain.

To analyze the application of those concepts was created a hypothetical case study of a company with international works. Given the wide range of industrialized building methods was necessary to choose one among the rest. The chosen one was a method recently developed by the Swedish construction company NCC. However, since it was inefficient, some changes were made.

The analysis of the results demonstrates that, for the values and parameters considered in the problem, the industrial method is certainly an alternative that should not be discarded. It follows, also, that a tool such as linear optimization is extremely important in this type of analysis. Without it, the analysis of all cases would be quite time consuming, given the large number of alternatives and variables. Finally, it is concluded that, in addition to reducing costs, it’s important to maximize the profits. This requires an economic analysis of these scenarios, because the most cheaper alternative isn’t necessarily the one that will be the most profitable.

Acronyms

COSEC - Companhia de Seguros de Crédito;
ERP - Enterprise Resource Planning;
GAMS - General Algebraic Modeling System;
GPS - Global Position System;
GDP - Gross domestic product;
NCC - Swedish construction company;
SME - Small and medium enterprise.

References


