DIFFUSION OF RESIDENTIAL CONSTRUCTION INNOVATIONS IN COLOMBIA

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ABSTRACT

The purpose of this thesis is to explore how the nature of innovations themselves and the interactions among the participants in the Value Chain, along with the distribution of benefits, can affect the innovation-diffusion process in residential construction companies in the Colombian construction environment. In developing countries, construction innovations can and do reach successful diffusion, despite the many unfavorable circumstances for technological innovation that often exist in such environments. Through the analysis—using innovation-diffusion models from existing literature—of the history of the diffusion of eight residential construction innovations that have been introduced to the country in the last two decades, the most relevant factors affecting construction innovation diffusion in Colombia are discussed. The primary implication of this research for current technological development and diffusion is that successful inter-firm diffusion in Colombia often depends more on influences in the form of government regulation and incentives, extensive dissemination of written technical information at all levels—including practitioners and academia—, and frequent contact with sources of information from abroad than on the intrinsic characteristics of the innovation itself.

Thesis supervisor: E. Sarah Slaughter
Title: Assistant Professor of Civil and Environmental Engineering
To my parents
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Chapter 1

INTRODUCTION

1.1 OBJECTIVE OF THE THESIS

The present work examines the introduction and implementation processes of several technological and managerial innovations in the construction sector in Colombia. The purpose of this thesis is to explore how the nature of the innovations themselves and the interactions among the participants in the Value Chain, along with the distribution of benefits, can affect the innovation-diffusion process in residential construction companies in the Colombian construction environment. The purpose is to analyze how several important developments in the Colombian residential construction sector have evolved, and what factors have contributed to their successful diffusion.

This research is based on theoretical models and empirical research on the US and international construction industry. In conjunction with this theoretical background, information on the development and diffusion of eight specific innovations introduced to the residential construction industry was gathered from personal interviews with builders, designers and other AEC-related firms in Colombian metropolitan regions, and from Colombian technical literature.

The present analysis is focused mostly on urban residential construction. All eight innovations studied are either directly related to residential construction, or are potentially applicable in this sector of the industry. While this approach could overlook very interesting technical developments in heavy construction projects in the public and industrial sector such as dams, highways, petrochemical facilities and massive transportation systems, this does not make the present work less relevant: residential construction represented 66.76% of Colombian construction industry in 1996 (CAMACOL, 1996), and created 31% of new jobs in the economy during 1990-1994 (Superintendencia de Sociedades, 1998). Its share of the Colombian GDP is 2.5% and the economic implications of major changes in the residential construction sector cannot be ignored.
1.2 THESIS ORGANIZATION

The rest of Chapter 1 is a general review of the Colombian Construction sector (Section 1.3) and the current predominant technologies in residential construction (Section 1.4). Section 1.5 states the need for Colombian residential builders to innovate given some new macroeconomic, environmental and financial trends.

In Chapter 2, some of the most relevant theories and models of innovation and diffusion are briefly explained, in order to provide the reader with a general context of the research. This literature is used as a basis to identify critical factors and patterns relevant to the Colombian residential construction industry.

Chapter 3 explains the methodology used to collect data from eight innovations actually in use in Colombia. This information was gathered from personal interviews, complemented with field visits and technical literature in some cases. The chapter discusses the selection of the innovations, the interview process, and ends with some considerations on the representativeness of the data gathered.

Chapter 4 presents each of the eight innovations, discussing their main technical characteristics and presenting the history of their diffusion in the Colombian residential construction sector. The eight innovations studied are:

- Outinord formwork system
- Project Administration Software - SAO package
- Prestressed slabs and beams
- Engineered Concrete Masonry
- Concrete Block Paving (CBP)
- Tilt-Up
- Hand-portable panels formwork system
- Structural Steel Buildings
Chapter 5 uses the theory presented in Chapter 2 to analyze how the nature of the innovations, the interactions among the participants in the Value Chain, the distribution of benefits and other contextual factors have affected the innovation-diffusion process. The purpose is to determine which factors have been more critical to the diffusion of the innovations.

Chapter 6 (Conclusions) summarizes the results of the theoretical vs. practical analysis of the innovations. After checking which specific factors of the Colombian environment are more likely to influence the diffusion of the innovations, Chapter 6 ends with some strategic implications derived from our study relevant to different firms in the residential construction value chain. Other ways to expand the present research are also discussed.

1.3 THE COLOMBIAN CONSTRUCTION SECTOR - GENERAL OVERVIEW

In order to give the reader a better understanding of the Colombian construction industry, some comparisons with the US construction sector and other general information is included in the following pages. Data comes mainly from the Colombian National Administrative Department of Statistics (DANE, 1993; 1996 and 1998) and the Statistical Abstract of the United States (1996).

1.3.1 General country statistics

- Area: 1,138,914 km$^2$ (439,737 square miles).
- Population: 39,500,000 (1997)
- Capital: Bogotá, population 6,300,000.
- Main cities:
  - Medellín (pop. 1,940,000), Cali (1,950,000), Barranquilla (1,150,000), Cartagena (700,000).
- GDP: $89,185 million dollars (1996)
- GDP per capita: $2,257 (see Figure 1.1)
- Exchange Rate: 1,360 Colombian Pesos per US Dollar (March 1998)
More than 70% of Colombia’s population lives in the large cities located in the Andean mountains in the western part of the country and in the Atlantic coastal region (see Figure 1.2).

(Source: National Geographic, 1998)
1.3.2 Economic Impact of the Construction Industry

The construction sector in Colombia is not very different from the US from the economic standpoint. Both share some characteristics, as explained below (DANE, 1996; DiPasquale and Wheaton, 1996).

1.3.2.1 High cyclicality

The volatility of the construction industry affects a large number of firms backward and forward in the construction value chain, which amplifies the macroeconomic impacts of construction in the GDP (Cárdenas and Bernal, 1997, see also Figures 1.3, 1.4 and 1.5). It can be seen from the figures that both in the US and Colombia, construction activity during the booms can more than double the levels during recessions.

There is some debate on whether this cyclical nature of the residential construction business has effects in the innovativeness of the sector, regardless of the country (Quigley, 1982). When there is a boom, many small investors enter the business. It can be argued that those firms are less likely to adopt innovations, which inherently imply some degree of risk (Nelson and Winter, 1977). The rationale for this hypothesis is that the entry and exit of these marginal firms as demand increases and declines (responsible for the high fragmentation of the industry), leads to the unwillingness to use production processes with high fixed costs and, in general, to very low investments in R&D. This implies an overall lower rate of innovation diffusion among this group. More experienced firms, on the other hand, know how to "ride the waves" and can be more willing to try new products and processes. In general, there is some acceptance on the hypothesis that the cyclical nature of residential construction slows down the diffusion of innovations.
Figure 1.3

Private construction activity in Colombia

(Source: CAMACOL, 1997)

Figure 1.4

Private construction activity in the US

(Source: Statistical Abstract of the US 1996)
1.3.2.2 Low concentration

Although no statistics are kept in Colombia regarding the number of construction companies, it is possible to infer that the construction sector has a very low industry concentration: the 5 largest construction companies in Colombia had revenues of COL$230,000m in 1995, which represented only 5.9% of construction GDP in that year (Superintendencia de Sociedades, 1998). In the US the industry is also highly fragmented (Quigley, 1982).

This low concentration also has consequences on the efficiency and degree of innovativeness of the sector (Nelson and Langlois, 1983). Smaller firms usually cannot achieve economies of scale. The diffusion of innovations can also be slower among smaller firms (Dibner and Lemer, 1992a and 1992b).

1.3.2.3 High macroeconomic impact

Construction in Colombia represents between 3.0% and 4.5% of Colombia’s GDP, not very different from the figures for the US (see Figure 1.6).
1.3.3 Residential Construction Value Chain

Figure 1.7 is a very simplified version of the value chain in residential construction projects in Colombia, in which the main firms (or individuals) involved in the execution of a project and the interactions between them are included. It should be noted that the interactions in the value chain are not completely rigid. It is possible, for example, that the owner of the project is at the same time the builder, or that a subcontractor supplies its own materials. The arrows in the diagram describe the interaction and flow of resources among the different firms. The boxes with darker borders indicate those firms more likely to influence the adoption of innovations.
It is also important to notice that the interactions in the value chain may change as different types of delivery systems are used. The value chain presented here corresponds to the traditional delivery system, which is the most commonly used in residential construction in Colombia.

The main participants in the value chain are:

- **Supplier.** Producer of the most basic products and materials used for a project. In the case of kitchen cabinets, for example, the supplier is the lumber mill.

- **Manufacturer.** Transformer of the basic products produced by the supplier. Normally, the manufacturer would deliver the transformed goods to the builder either directly or through distributors (not shown). For the example of kitchen cabinets, the manufacturer and assembler would be the wood shop, using the agglomerate material. The manufacturer and the supplier could sometimes be the same firm. For example, a cement factory produces a very basic material—cement—to be used directly by the builder, so it would be supplier and manufacturer simultaneously. In other instances, the cement factory would be the supplier only, while other firm—a block producer, for example—would be the manufacturer.

- **Subcontractor.** Party involved in the construction of a part of a project. A subcontractor is usually a specialized labor supplier, working for the builder under a certain type of contract. There are instances in which a subcontractor will supply its own materials. In the kitchen cabinets example, the subcontractor would be the firm or individual that actually puts in place the cabinets produced by the manufacturer. It is necessary to differentiate between specialty subcontractor and general subcontractor: the first one provides not only labor but also technical expertise, special tools and sometimes materials for a portion of the total project.

- **Builder.** Main coordinator of the construction process. Usually working for a third party (the developer or owner), the builder coordinates the work of subcontractors and suppliers—and sometimes designers—to deliver the finished project. A builder, for the context of this thesis, can be though as the General Contractor (GC) which directly controls some part of the construction and subcontracts other parts.
• **Designer.** Party in charge of the design, layout and technical planning of the project. Usually there are several designers—architect, structural designer, etc.—who work to a certain degree of coordination. The designers usually work for the developer, although their main deliverables—the blueprints and drawings—are used by the builder.

• **Developer.** Party in charge of the overall coordination of the project, including not only construction, but also financial, contractual and commercial issues. In Colombia the developer is usually the main investor in the project, although it could also be the coordinator of a group of investors. For the purposes of this thesis it will be understood that the developer is the main investor and does not remain as the owner of the project once it is finished, but sells it to other individuals at completion. In the case of a residential multifamily building, for example, a developer sells the individual apartments to families that will actually occupy the units, or to landlords who will rent them. In this case, the developer acts as a short-term owner, with expectations for immediate turnover and profit. (This is not the typical case for the US, where owners are usually long-term).

### 1.4 THE COLOMBIAN CONSTRUCTION SECTOR - PREDOMINANT TECHNOLOGIES

Most of new residential construction in Colombia nowadays can be classified into two major groups: single and multi-family houses, and apartment buildings.

#### 1.4.1 Single and Multi-Family Houses

Houses account for 81% of existing residential construction in the country (DANE, 1993). This percentage is much lower if only new construction—in which apartment buildings is a large percentage—is considered. New houses are usually built in developments of closed condominiums. In low-income projects, usually subsidized by the government, multiple-family houses (up to two levels and with separate entries) are very common, while for other developments single-family houses are the norm.
Typical characteristics of this type of construction are:

- Foundation in concrete beams or slabs
- Walls in concrete or clay bricks. Concrete bricks are more common in low-income projects due to savings in interior finishings such as cement plaster, finished coat, paint, etc.
- Floors in concrete (low-income projects), tiles, finished wood and carpet
- Roofing in concrete slabs and asbestos-cement tiles (especially in low-income projects), wooden frame covered with clay tiles (after the Spanish tradition, common in both low and high-income projects)
- One or two floors, with structure in concrete or bearing walls.

1.4.2 Apartment buildings

Apartments contribute to a majority of the area of new residential construction in urban zones. Height and number of floors vary widely according to local regulations and urban zoning, but typical apartments buildings are 5 to 15 stories high, with one or two basements for parking. Predominant technologies are:

- Foundation in spread footings and/or piles.
- Structure in reinforced concrete, mainly moment-resistant frames
- Voided flat slabs (the voids in the slab are usually made with raw wood boxes that are never removed from the structure).
- Interior walls in clay bricks finished with cement plaster, finished coat and paint.
- Exterior walls in clay bricks of superior quality and aesthetic characteristics
- Floors in ceramic or marble-stones tiles, carpets and finished wood
- Interior services (plumbing, electrical wiring ducts, phone lines, sewage, etc.) are usually set up after masonry is finished and before applying cement plaster.

1.4.3 Technological lag

Construction in Colombia is still very labor-intensive, and predominant construction techniques have evolved little in the last decades. The average labor intensity of residential construction for
the traditional systems, in use since several decades ago, can be as high as 20 man-hour/m², even for relatively large projects (see Table 1.1.)

Table 1.1 Labor intensity of traditional construction systems in Colombia

<table>
<thead>
<tr>
<th>Total area of project</th>
<th>Labor Intensity</th>
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<tbody>
<tr>
<td>Less than 200 m²</td>
<td>54 man-hour / m²</td>
</tr>
<tr>
<td>200 - 500 m²</td>
<td>43 man-hour / m²</td>
</tr>
<tr>
<td>500 - 1,000 m²</td>
<td>32 man-hour / m²</td>
</tr>
<tr>
<td>1,000 - 10,000 m²</td>
<td>23 man-hour / m²</td>
</tr>
<tr>
<td>More than 10,000 m²</td>
<td>Varies</td>
</tr>
</tbody>
</table>

(Source: Gallego, 1982)

The reasons why rather rudimentary techniques are still in use instead of widely adopting more modern methods are summarized below:

1.4.3.1 Labor costs

Wages in Colombia are still very low compared to the standard wages of developed countries. Even though local engineers are very capable and are technically prepared to use more modern methods, the wide availability of cheap labor has made many interesting technologies uneconomical.

Use of heavy machinery during foundation works, for example, is almost entirely limited to the excavation process. In small and medium-size residential projects, the formwork and casting of concrete foundations (footings and piles) is done almost entirely using labor and light tools and equipment. Only in some public heavy-construction projects is some specialized machinery used, such as pile drivers and hammers and soil nailing equipment. The use of such equipment in residential construction is still very limited, although it is becoming more accepted every day, particularly in larger projects.
In public and industrial construction there is a more intensive use of machinery. A reason for the more widespread use of sophisticated equipment in this subsector is that schedule constraints are more important. While a new road or power facility needs to be finished as soon as possible, in residential construction timing is closely associated with market conditions. Unless a project is completely pre-sold before beginning, building (and therefore, spending) too fast without selling at the same pace can negatively affect the financial performance of a project.

During the erection of structure, labor is also widely used for the placing of reinforcement bars, assembly of wooden formwork, and casting of concrete columns. The preparation of concrete on-site for even large castings was a common practice until the early 1980s, and is still the norm for castings of less than 3 or 4 m$^3$ of concrete (for larger casts, mixers and pumps are widely used nowadays). Masonry and cement scratch coat also require intensive use of cheap labor.

However, as Figures 1.8, 1.9, 1.10 and 1.11 show, labor is becoming more expensive every day compared to the other costs involved in the construction process. According to Hernando Gómez, codirector of the Banco de la República (Colombia’s Central Bank), labor costs during the 90’s have grown 25% more than the CPI. In his own words, “the notion that Colombia is a country of cheap and widely available labor must be abandoned...before, it was viable to use simple technologies, intensive in unskilled labor. This must be seriously questioned today. The construction industry in the next decade must face the challenge of technological modernization, in the same way that the industrial and agricultural sectors have managed it after the economic ‘apertura’ policies.” (Gómez, 1996)
Figure 1.8
Minimum Wage vs. Producers Price Index
(1992=100)

(Source: Poder y Dinero, 1997b)

Figure 1.9
Annual Change in Minimum wage vs. Inflation to producers

(Source: Poder y Dinero, 1997b)
Minimum monthly wage is likely to keep raising faster than other production costs (see Figures 1.8, 1.9, 1.10 and 1.11). Moreover, welfare and social regulations are making the benefits portion of wages to increase. In general, as countries develop and GDP per-capita increases (see Figure 1.1), the structure of the economy shifts from the low-wages, low-education job force toward a more sophisticated model in which cheap labor is no longer the norm.
1.4.3.2 Low Environmental impact controls

Almost without exception, the aforementioned techniques cause harmful impacts in the environment:

- Formwork: More than 50% of formwork is made out of wood, and from this portion, more than 50% is assembled on-site. There is little control over the supply of this wood, and the waste on the construction sites is significant, not to mention the low level of reuse of wooden-made formwork.

- Dust and waste: Given the little degree of modularity in the projects, too many on-site adjustments have to be made to masonry and tile units, which creates unnecessary waste on the construction site. Even if no adjustments were necessary, the very nature of masonry and plastering work generates mortar waste that even under the best supervision can be as high as 20% of the material put in place. Other common waste-generating practices are floor tiles finishing, non-modular carpentry and ceramic tiling of floors and walls.

Recent environmental laws by the 1991-created Ministry of Environment are currently weakly enforced, although environmental agencies are likely to become more strict in the near future.

1.4.3.3 High flexibility in the design-construction process

Almost all of the mentioned techniques currently predominant allow a high degree of flexibility during the design and construction processes. There is no need, for example, for floors to be of certain specific dimensions or for rooms and kitchens to accommodate to specific standards. Almost all the major items are either built on site or “tailored” to the specific dimensions of the buildings, which results in a slower and more waste-generating process. The high degree of flexibility can be a disadvantage as well as an advantage: flexibility allows the designer to be more creative and try more ideas for a project, and for the builder also means that the construction process is somewhat less “linear” and flexible. However, too much flexibility also means less need for planning, which causes the projects to be poorly studied and analyzed before construction begins, with the subsequent problems during the construction stage.
1.5 THE NEED TO INNOVATE

As stated in the previous chapter, most Colombian residential construction companies continue to use the same basic techniques they have been using for decades. Innovations have indeed been introduced, but traditional systems are still prevalent. A business environment of low-cost labor and little environmental consciousness is not sustainable.

As Figures 1.8, 1.9, 1.10 and 1.11 reveal, labor is becoming more expensive everyday. “Cheap” labor is not so cheap anymore relative to average income. Although labor in Colombia is still very cheap compared to the costs in the US, the gap has narrowed in the last decades.

The introduction of new materials, a direct consequence of the globalization of the economy (a policy known in Colombia as *apertura*, or “opening”) with the subsequent reduction in import taxes, has made economically more attractive several options that were not even considered before. For example, the introduction of steel structures, although still limited, has been eased by the reduction in import taxes for steel members coming from Venezuela, Ecuador and Mexico.

Another important factor is the new residential construction financing methods available, like Fiducia and Titularización (similar to fiduciary deposits and REITs in the US, respectively). Up until very recently (past decade), it was not necessary for some projects to finish construction soon, since many of them were financed by pre-payments from customers and IRR (the rate of return on the projects) depended more on early sales than on fast construction. Building too fast without selling at the same pace could negatively affect the financial performance of a project. “Rushing” makes more sense nowadays than before, so there is a need for faster construction methods.

As stated before, environmental regulations are likely to become more strict as the recently created Ministry of Environment reaches maximum enforcing capabilities. Also in the regulatory side, the new Colombian Seismic code (CCCSR), recently enacted (1998), contains more stringent regulations than the previous one. This implies that builders either will have to bear higher costs for traditionally built structures, or will have to search actively for new alternatives that are economically more viable.
Chapter 2
LITERATURE REVIEW

The present chapter describes some of the relevant theoretical concepts that will be used throughout this thesis. It is possible to gain a good insight applicable for the residential construction industry from many of the theories and models that follow. The reader should bear in mind, however, that most of the studies of innovation and diffusion have been developed with reference to the manufacturing industry. For this reason, a discussion of some of those general concepts in construction-related terms is provided in Section 2.3

2.1 Definition of basic terms

- **Invention**: An invention is a new combination of pre-existing knowledge which satisfies some want. (Schmookler, 1966).

- **Innovation**: An innovation is a nominal improvement in component, method or system that is actually used and is novel to the developer or user. The main difference between Innovation and Invention is that an innovation needs not to be totally new. If the combination of pre-existing knowledge is new for the firm, even if it is not new for other firms, it is considered an innovation. The term is not applicable to trivial or cosmetic changes.

- **Diffusion**: Is the process by which an innovation is transferred to and implemented in other firms or to more applications within the same firm.

- **Product innovation**: Innovation that is embodied in a physical component or remain as a physical manifestation at the end. This is the most easily recognizable type of innovation.

- **Process Innovation**: Innovation that is related to a change in the way tasks are performed or to the use of new equipment to produce essentially the same product.
2.2 Models of Innovation

Innovation theory is a developing field. No uniform theory exists yet that integrates the current theories and models of innovation. This section describes the most relevant innovation models for the diffusion of residential construction innovations.

2.2.1 Innovation and diffusion processes

Figure 2.1 shows the different stages of the innovation followed by the process of diffusion, according to Marquis (1988) and Voss (1988). Although different authors have different models, the simplified model presented here shares most of the characteristics of the others and is helpful in understanding how an innovation develops.

Figure 2.1 Stages of the Innovation and Diffusion processes

For the purpose of this research, the emphasis is put on the diffusion of innovations in Colombia that have already been developed in other countries. Although the model above describes the stages of the evolution of the innovation from its inception, it is also applicable—with some modification—to the process of diffusion. If the innovation can be adopted without modification,
the three steps “problem solving”, “solution” and “development” become only two: “evaluation” and “decision.” If the adoption of the innovation requires some modifications, the diffusion process resembles Figure 2.1 closer.

Although it was stated that innovation is essentially different from diffusion, some of the models developed for innovation can be useful in analyzing the diffusion of innovations in new environments, as is the case with the present thesis: the cases to be studied in Chapter 4 (with one exception) deal with the diffusion in Colombia of construction technologies coming from abroad. From the adopter’s perspective, the implementation process shares many characteristics with the process of innovation itself (Voss, 1988).

One of the most relevant areas—for the purpose of this research—in the study of innovations is the analysis of how and why firms succeed and fail in implementing innovations, and how the characteristics of the innovations and the firms themselves affect such implementation. Marquis (1988), limiting the scope of his study to incremental innovations, concludes that successful innovations share several of the following characteristics:

- Require little or no adaptation of information readily obtainable from some source
- Are modifications of existing products or processes rather than new items
- Require little or no change in processes
- Are stimulated by market demand rather than by technical potential
- Originate within the firm

Marquis’ study, however, makes no mention of more complex types of innovations. Other authors, focusing on radical and incremental innovations, have found different competitive consequences and a need for different organization capabilities: incremental innovations often reinforce existing capabilities, while radical innovations make existing capabilities obsolete and force companies to acquire new technical and commercial skills.
2.2.2 Types of innovations

A very important advance in the field was made by Henderson and Clark (1990). In contrast to the traditional categorization of innovations in the incremental to radical "continuum", Henderson and Clark point out that there are some apparently incremental innovations that in reality prove to be very difficult for companies to identify and accommodate to. This new kind of “disguised” incremental innovation is called an architectural innovation, and its main characteristic is its alteration of existing linkages with other components of the entire system, although the modification itself appears simple at first sight.

This poses significant challenges to the innovating firm, because an architectural innovation requires new organizational capabilities but at the same time demands the reaffirmation of existing ones: part of the firm’s knowledge is still useful and necessary, but some of it is not only not useful but obstructs the development of the innovation. The great challenge of architectural innovations for a company is to recognize what is still useful and what is not.

The following table summarizes the model by Henderson and Clark:

<table>
<thead>
<tr>
<th>Linkages</th>
<th>Reinforced</th>
<th>Overturned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unchanged</td>
<td>Incremental Innovation</td>
<td>Modular Innovation</td>
</tr>
<tr>
<td>Changed</td>
<td>Architectural Innovation</td>
<td>Radical Innovation</td>
</tr>
</tbody>
</table>

Definition of terms in the Henderson and Clark model:

- **Incremental Innovation**: Relatively minor changes to an existing product, exploiting the potential of established designs, or minor changes in the process. Incremental innovations do not change the core concepts and the linkages between components. Its consequences are not
minor, however. Incremental innovations reinforce the dominance of existing firms and may have significant economic consequences over time.

- **Radical Innovation**: Based on a new set of engineering and scientific principles, creating great difficulties for established firms. Radical innovations establish a new dominant design and a new set of concepts (embodied in components) that are linked together in a new architecture.

- **Modular Innovation**: Changes only to the core design concepts, leaving the linkages unaltered.

- **Architectural Innovation**: Changes to the links among components (physically distinct parts that embody a core design concept), leaving the core concepts unaltered. Linkages are configuration or spatial relationships among components.

Henderson and Clark, however, concentrate their analysis in the how the innovation is perceived by the innovator/adopter firm itself. Afuah and Bahram (1995) go one step further and notice how an innovation which is, say, architectural at the innovator level, can be perceived as radical by customers, incremental to suppliers and modular to complementary innovators. In other words, while Henderson and Clark introduced a second dimension to the incremental-radical line by recognizing the importance of linkages, Afuah and Bahram introduce a third dimension by considering the importance of firms other than the innovator in the Value Chain (Figure 2.2).

**Figure 2.2 Afuah and Bahram's Hypercube of Innovation**

(Source: Afuah and Bahram, 1995)
Afuah and Bahram notice that the impact of the innovation in the capabilities of customers and suppliers is critical, as is the impact on the innovator firm itself. In other words, innovations that fit perfectly in the capabilities of the innovator entity and that apparently should become successes, can turn out to be failures if such innovations require extensive changes or accommodation by other firms in the value chain.

The distribution of benefits among the innovator, its customers, suppliers, etc. is another important concept, because it can explain why innovations which appear to be intrinsically "easy" to most or all of the firms in the value chain can sometimes fail: if none of the firms has a strong incentive to pursue the innovation (such as due to poor profit potential), then the innovation will not succeed. On the other hand, innovations that are intrinsically difficult to several of the firms can have a chance if there is one or more firms that can benefit greatly from them.

2.2.3 Benefits from Innovation

Teece (1988), explains the distribution of benefits as dependent on the benefits appropriability regime, the dominant design paradigm and the complementary assets concept. Teece's model does not distinguish between the different categories of innovations (incremental, modular, architectural and radical), in the nature and appropriation of benefits.

The Appropriability regime is the set of factors that affect the innovator's ability to capture the benefits, and depends on the nature of the technology itself as well as on the property rights environment. If the technical knowledge is codified in the product (for example, a newly designed shovel), imitation is easier that if the knowledge is tacit (for example, the Coca-Cola formula). Also when the innovation is embedded in processes rather than in products imitation can be more difficult. As for the legal aspects, patents, copyrights and trade secrets are the main factors that affect the appropriability regime.

The emergence of a dominant design determines the degree of convergence of the competition on the primary attributes and performance characteristics of an innovation. In general, before a dominant design appears, competition is based on design and differentiation, while after the
appearance of a dominant design, competition depends more on scale economies and ability to imitate.

The technical know-how of the innovation must be accompanied by complementary assets such as marketing expertise, competitive manufacturing, brand, manufacturing facilities, etc. Teece classifies such assets as generic (need not to be tailored to the specific innovation), specialized (unilateral dependence between innovation and asset), and co-specialized (bilateral dependency). Complementary assets can be internally held or can be contracted out.

In summary, Henderson and Clark and Afuah and Bahram provide a very useful classification of innovations that helps to explain why some innovations are intrinsically more difficult than others to be implemented, while Teece explains what the nature of the benefits for the firms from such implementation and the mechanisms to appropriate them.

2.2.4 Contextual factors that affect innovation and diffusion

Besides the models that deal with the innovation and the innovating firm itself, other models have a broader perspective which take new factors into consideration. The organization itself can significantly influence the relative success of innovation implementation (Meyer and Goes, 1988). Specifically, the assimilation of innovations is determined by three classes of antecedents (Figure 2.3): innovation attributes (e.g. risk, complexity, observability of benefits), contextual attributes (e.g. environmental, organizational and leadership-related factors) and attributes arising from the interaction of contexts and innovations (e.g. compatibility of innovation with organizational skills, CEO advocacy, etc.)

Figure 2.3 Model of Innovation Assimilation

(Source: Meyer and Goes, 1988)
Previous experience in different contexts can also influence the implementation and diffusion of innovations. Late adopters can experience faster rates of diffusion than early adopters in different contexts. Late adopters are often in a position to utilize earlier experience by the earlier adopters, even if the innovation complexity and organizational capabilities are the same. In addition, expected rates of return for innovations can influence the initial consideration and use of an innovation by a company, and its later decision with respect to wider intra-firm diffusion (Mansfield, 1989). The relevance of this concepts for the present work lie on their emphasis on the diffusion of technologies already adopted in other environments, as is the case with most of the eight innovations that will be analyzed.

While large companies appear to adopt innovations more frequently than small companies, a critical determinant is actually the opportunities to adopt (Rose and Joskow, 1990). If this concept is extrapolated to construction, it would predict that, for example, a small contractor with several clients doing several small jobs per year would be more likely to adopt innovations that a large firm doing one large project every two or three years.

2.2.5 Summary of discussed models

In order to better understand how the discussed models will be used in this thesis, it is useful to think of them as part of a broader model. While Henderson and Clark (1990) and Afuah and Bahram (1995) deal more with the inherent characteristics of the innovation and its classification, Teece (1988) focuses in the distribution of benefits. All of the above is affected by the general environment in which the innovation and diffusion processes develop (Figure 2.4).

![Figure 2.4 Summary of Innovation Models used](image-url)
2.3 Models of innovation and the construction industry

The theoretical models of Afuah and Bahram and Teece address different aspects of the innovation-diffusion process, and each model by itself is insufficient to explain a broader picture that includes both the categorization of the innovation and the distribution of benefits among firms in the value chain. A significant opportunity exists to integrate these two approaches into a general examination of the effects of the nature of innovation on the means and effectiveness of appropriating benefits.

This calls for a study that integrates those two important concepts, taking into consideration in the particular attributes of the residential construction industry (immobility, uniqueness and durability of each individual product, project-specificity of the value chain, and complexity of the constructed facilities), accompanied by empirical evidence.

In order to do that, it is necessary first to translate the theoretical concepts into the context of the construction industry.

2.3.1 Types of innovations

The models of Henderson and Clark and Afuah and Bahram are very manufacturing-oriented. The original article by Henderson and Clark explored the validity of their framework within the semiconductor photolithographic alignment equipment industry. Afuah and Bahram examined RISC and CISC semiconductor chips and supercomputers. The construction industry, and more specifically, the residential construction industry bears significant differences with manufacturing. Its products are immobile, very durable and with little obsolescence, each of them is unique, the value chain is temporary and changes for each product, etc.

Slaughter (1998) adopts the Henderson and Clark model adding a fifth category, which is Systems innovation. Her definitions, fitted to the specific characteristics of the construction industry, are as follows:

- **Incremental Innovation.** Is a small change, based upon current knowledge and experience. Occurs constantly and its impacts are fairly predictable. Its interactions with other components
**Modular Innovation.** Entails a significant change in concepts within a component, leaving the links to other components and systems unchanged. For example, a new machine that automatically ties the wire for reinforcing bars in cast-in-place concrete. Mechanizing this activity is a significant change in concept, but implies no changes in other components, methods or materials.

**Architectural Innovation.** Involves small changes in a component, but major changes in the links to other components and systems. This type of innovation requires change and modification in the set of interacting components and systems. For example, self-compacting concrete uses standard available materials in the cement, admixtures and aggregate, but controls their size and homogeneity to the extent that vibration can be eliminated. The resulting elements are much stronger and more durable, which leads to major changes in the linkages among construction activities.

**Radical Innovation.** Breakthrough in science or technology which often changes the nature of an industry. For example, the introduction of structural steel in the past century changed dramatically the type of buildings that could be erected, and created a whole new industry of steel manufacturing, as well as new components and systems linked to the new structural forms and systems.

**System Innovation.** Is the integration of multiple independent innovations, which must work together to perform new functions or improve the performance of a facility as a whole. The linkages are explicitly among the innovations. System innovations appear relatively frequently in the construction industry, since construction facilities are by nature complex systems which must interact to perform the overall functions for which they are intended. For example, the zone module construction method for large coal fired power plants is a system innovation. It incorporates several specific independent innovations (e.g., split boilers, hydraulic lifting devices).

### 2.3.2 Types of benefits

Construction innovations has a set of benefits that differs from that of manufacturing innovations. In general, benefits from construction innovations can be classified in: (Slaughter, 1998).
• Macroeconomic benefits. Economic growth, increase in productivity, more efficient allocation of resources.
• Market growth.
• Social benefits. When facilities are less expensive, they become accessible to a wider segment of the population.
• Environmental benefits.
• Improved technical and/or economic feasibility of projects. Innovations allow the construction of projects that were unthinkable before.
• Improved competitive position
• Improved reputation for the innovating firm
• Ease of work
• Reduction in costs
• Reduction in time to completion

For this thesis, we are interested in how the nature of the innovation itself and the interactions among the participants in the Value Chain, along with the distribution of benefits, can affect the innovation-diffusion process in residential construction companies. Some previous work in this direction has already been done: Johnson and Tatum (1993) address the issue of benefits distribution in the particular context of marine construction firms. Slaughter has expanded the concepts of Afuah and Bahram and applied them to construction, specifying the requirements for implementation of an innovation according to its classification. Laborde and Sanvido (1994) have also developed an innovation implementation model for construction companies.
Chapter 3
METHODOLOGY

3.1 Data Collection

Data from eight innovations in the Colombian residential construction sector was gathered through semi-structured personal interviews, accompanied by some field visits and literature review. Table 3.1 summarizes the innovations.

Table 3.1 Principal Data sources for the Innovations studied

<table>
<thead>
<tr>
<th>INNOVATION</th>
<th>Type of Interview</th>
<th>Contact company - person</th>
<th>TYPE OF FIRM</th>
<th>INFLUENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outinord formwork system</td>
<td>Person, 1.5 hr</td>
<td>ConConcreto (heavy and residential construction company)</td>
<td>Builder/Developer</td>
<td>National</td>
</tr>
<tr>
<td>Project administration software</td>
<td>Person, 1 hr</td>
<td>SAS (Systems Services and Consulting)</td>
<td>Supplier</td>
<td>National</td>
</tr>
<tr>
<td>(“S.A.O.” package)</td>
<td>Person, 1 hr</td>
<td>Jorge Iván Hurtado</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prestressed slabs and beams</td>
<td>Person, 1.5 hr</td>
<td>AREA Consultant Engineers - Hector Urrego</td>
<td>Designer</td>
<td>Local/National</td>
</tr>
<tr>
<td></td>
<td>Person, 1.5 hr</td>
<td>(complementary info. Carlos Arturo Madrid, Bernardo Vieco)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineered Concrete Masonry</td>
<td>Person, 1 hr</td>
<td>Muros y Techos (residential construction) - Jorge Gómez</td>
<td>Builder</td>
<td>Local</td>
</tr>
<tr>
<td></td>
<td>Person, 1.5 hr</td>
<td>(complementary info. ICPC - Germán Madrid)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Block Paving (CBP)</td>
<td>Person, 1 hr</td>
<td>ICPC (Colombian Cement Producers Institute) - Germán Madrid</td>
<td>Supplier's association</td>
<td>National</td>
</tr>
<tr>
<td></td>
<td>Person, 1.5 hr</td>
<td>(complementary info. ICPC - Carlos Madrid, Cipriano Londoño)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tilt-Up</td>
<td>Person, 1.5 hr</td>
<td>ConConcreto</td>
<td>Builder/Developer</td>
<td>National</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Enrique Acevedo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand-portable panels formwork</td>
<td>Phone, 0.5 hr</td>
<td>PSI (Engineering Projects and Services - residential construction)</td>
<td>Builder/Developer</td>
<td>Local</td>
</tr>
<tr>
<td>system</td>
<td></td>
<td>Antonio Cano</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structural Steel Buildings</td>
<td>Person, 0.5 hr</td>
<td>Industrias del Hierro (steel construction)</td>
<td>Designer/Subcontractor</td>
<td>Local/National</td>
</tr>
<tr>
<td></td>
<td>+ 2 hr presentation</td>
<td>Luis Garza</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All of the interviewed people in Table 3.1 have been directly involved in one or more of the diffusion stages of the innovations, either as main promoters of the technology or as recognized early users. Consequently, all of them were well informed of the early diffusion of the innovations. All of the interviewees have relatively senior positions, ranging from owners or partners to technical directors, in widely recognized companies in their local or national markets. For some of the innovations, complementary information was gathered through interviews with additional sources (see Table 3.2).
Table 3.2 List of people interviewed or contacted

<table>
<thead>
<tr>
<th>Person</th>
<th>Company</th>
<th>Position</th>
<th>Profession</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enrique Acevedo</td>
<td>ConConcreto S.A.</td>
<td>Technical VP</td>
<td>Civil Engineer</td>
</tr>
<tr>
<td>Jorge Hurtado</td>
<td>S.A.S.</td>
<td>Owner and General Manager</td>
<td>Systems Engineer</td>
</tr>
<tr>
<td>Héctor Urrego</td>
<td>AREA Consultant Engineers</td>
<td>Owner</td>
<td>Civil Engineer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MS Braunsweigh University</td>
</tr>
<tr>
<td>Jorge Gómez</td>
<td>Muros y Techos</td>
<td>Partner - Technical VP</td>
<td>Civil Engineer</td>
</tr>
<tr>
<td>Germán Madrid</td>
<td>I.C.P.C.</td>
<td>Technical Director</td>
<td>Civil Engineer, MS in Civil Engineering</td>
</tr>
<tr>
<td>Antonio Cano</td>
<td>PSI S.A. (Engineering Projects and Services)</td>
<td>Partner - Technical VP</td>
<td>Civil Engineer</td>
</tr>
<tr>
<td>Luis Garza</td>
<td>Industrias del Hierro (Steel Industries)</td>
<td>Technical VP</td>
<td>Civil Engineer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MS UNAM, Mexico</td>
</tr>
</tbody>
</table>

Additional Information:

<table>
<thead>
<tr>
<th>Person</th>
<th>Company</th>
<th>Position</th>
<th>Profession</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jesús Humberto</td>
<td>Ingeniería del Concreto Ltda.</td>
<td>Owner and General Manager</td>
<td>Civil Engineer</td>
</tr>
<tr>
<td>Arango</td>
<td>(construction consulting company)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cipriano Londôñ</td>
<td>I.C.P.C.</td>
<td>Technical Engineer</td>
<td>Civil Engineer</td>
</tr>
<tr>
<td></td>
<td>Colombian Cement Producers Institute</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carlos Madrid</td>
<td>Independent Consultant</td>
<td>Owner</td>
<td>Civil Engineer</td>
</tr>
<tr>
<td>Bernardo Vieco</td>
<td>Vieco Soil Engineers</td>
<td></td>
<td>Civil Engineer</td>
</tr>
<tr>
<td>Mario Eraso</td>
<td>Napco precast company, USA</td>
<td>Owner</td>
<td>Civil Engineer</td>
</tr>
<tr>
<td>Juan R. Ibáñez</td>
<td>CHI Asociados Ltda. (Primavera software distributors)</td>
<td>Owner</td>
<td></td>
</tr>
</tbody>
</table>

The type of companies, the kind of innovation and the stage of diffusion were varied in order to have as wide a spectrum as possible within the reduced number of case studies, to identify major issues and to demonstrate the application of the concepts to this context.

Some of the innovations analyzed were introduced two decades ago or slightly more. It was considered important to present a contrast between past innovations and more recent ones, in order
to discuss the future diffusion of the most recent innovations based on the analysis of the older ones.

### 3.2 Interview Process

Each individual was initially contacted by telephone, providing him with a brief explanation of the purpose of the interview. It was made clear from the beginning that no specific or confidential information of technical nature was required, but rather than a general overview of the characteristics of the innovation and the implementation process was the purpose of the interview.

With only one exception, all principal interviews in Table 3.1 were conducted in person and lasted at least one hour. In most cases the interviews were followed by e-mail questionnaires in order to standardize the information and ask for more specific details. Personal interviews were semi-structured, with the respondents being allowed to elaborate or expand in each question.

The purpose of the interviews was to gather as much information as possible on the history of the introduction of the innovations, such as the first users, the type of projects in which the innovations were first implemented and technical characteristics of the innovation.

### 3.3 Representativeness of the data

As stated in the introduction of this thesis, the purpose of this work is not to report comprehensively on AEC (architecture-engineering-construction) innovations in the Colombian residential construction sector, but rather to apply the concepts of the character of the innovation, the nature of the value chain, and the appropriation of benefits to innovations in this sector.

The innovation set was selected to be as varied as possible: There are technical as well as managerial innovations, companies range from large contractors to well-recognized designers to producers associations, and the innovations selected were in different stages in the diffusion
process. In such a way, it was attempted to cover a wide spectrum of the Colombian residential construction sector.

Although no claims are made regarding the statistical representativeness of the sample of innovations, the innovations portrayed in this work provide a very good idea of the recent trends in the Colombian construction sector and on the particular factors that affect the diffusion of innovations in this environment. Three clear disclaimers must still be made:

- All eight innovations studied are product innovations rather than process innovations, although most of them have certain process components. The reason is that product innovations are much more clearly identifiable and can be more easily traced to their origins, which was crucial for the purposes of this thesis. Process innovations are difficult to study, but are certainly an interesting field to expand the present research.
- Six out of the eight innovations are related to structures.
- The initial use in Colombia for most of the innovations studied has taken place in the city of Medellín or has been accomplished by firms headquartered in this city. Most of the firms studied have been in the market for decades and are highly regarded by competitors, professionals and customers. The author considers that given the fragmented nature of the construction industry in Colombia, and the relatively even technical expertise of construction companies of similar size across the country, this should not be a limitation to the validity of this study for the whole country.
Chapter 4
IMPLEMENTATION AND DIFFUSION OF INNOVATIONS

Despite the somewhat difficult circumstances for new technologies to be introduced in the Colombian residential construction industry—as shown in Chapter 1—many innovations have been successfully implemented over the last two decades.

This chapter presents eight of those innovations. A summary of these innovations is presented in Table 4.1 according to the classification by Henderson and Clark (1990) and Slaughter (1998).

Table 4.1 Classification of innovations (from the builder’s perspective)

<table>
<thead>
<tr>
<th>Linkages</th>
<th>Core concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reinforced</td>
</tr>
<tr>
<td>Unchanged</td>
<td>Incremental Innovations</td>
</tr>
<tr>
<td></td>
<td>Post-tensioned slabs</td>
</tr>
<tr>
<td></td>
<td>Structural Concrete Masonry</td>
</tr>
<tr>
<td>Changed</td>
<td>Architectural Innovations</td>
</tr>
<tr>
<td></td>
<td>Structural Steel Buildings</td>
</tr>
<tr>
<td></td>
<td>Outinord</td>
</tr>
<tr>
<td></td>
<td>Hand-portable panels</td>
</tr>
</tbody>
</table>

This set of innovations represents a small sample of design and technological developments in the Colombian residential construction which were identified as important additions to the industry by the experts interviewed (Tables 3.1 and 3.2). Many other new technologies or improvements over existing technologies have been also introduced.
4.1 OUTINORD FORMWORK SYSTEM

4.1.1 Generalities

Outinord is a trademark of a French company that specializes in the design and manufacture of steel formwork for in situ and precast concrete construction. This chapter deals specifically with its Modular Tunnel Formwork (Figure 4.1), which allows simultaneous casting of walls and slabs.

Figure 4.1 Modular Outinord Tunnel Formwork

(Source: Outinord Group, 1998)

Figure 4.2 Outinord use in Medellín, Fuerte San Diego apartments project (A)

(Photograph by the author)
Figure 4.3 Outinord use in Medellín, Fuerte San Diego apartments project (B)

(Photograph by the author)

Figure 4.4 Outinord use in Medellín, Fuerte San Diego apartments project (C)

(Photograph by the author)
Outinord is not the sole producer of tunnel formwork; there are other similar patented systems by companies such as Feran, Hunnebeck, S.E.C.T.R.A., Pascal, Rush, F.I.C.S. and Tracoba (Ariza, 1981; Gallego, 1982; Restrepo, 1981). These systems generally allow a faster and more predictable construction sequence. The resulting structure is much more monolithic and rigid than a moment-resistant cast-in-place concrete frame.

4.1.1.1 Main components of the formwork system

- L-shaped metallic formwork units, with spans varying from 1.25m to 6.25m (increases of 0.625m), and perpendicular dimension of 2.50 m. Steel walls are 3mm to 5mm thick. The formwork units have wheels for easy repositioning.
- Metallic frames for window and door openings.
- Lateral panels.
- Anchors (to connect contiguous formwork)
- Platforms to remove the formwork units from an already cast floor and position them to be lifted to the next position.
- Crane capable of lifting the L-shaped molds (at least 750kg, and up to 2,000 kg)

(see Figures 4.5 and 4.6)

Figure 4.5 Tunnel Formwork diagram

(Source: Ariza, 1981)
4.1.1.2 Construction process

- Foundations. Are built using traditional systems. The most recommended are foundation slabs or foundation beams.
- Formwork assembly. Vertical reinforcing and utility ducts are put in place within the wall cavity before starting formwork assembly. Formworks are then placed in alternate rows to permit the positioning of window and door frames between consecutive pairs. Finally, lateral panels are put in place.
• Slab assembly. Slab lateral closings, reinforcing and utilities ducts are placed on top of the horizontal part of the formwork.

• Concrete casting. Walls and slab are cast in the same operation. Concrete should be fluid enough to prevent voids in the structure, and should also have accelerant additives to allow next-day formwork release.

• Formwork release (Figure 4.7).

• Wheeling to platform. Formwork units are wheeled to a platform, where they will be lifted by the crane and placed on the next floor (Figure 4.8).

• The process starts all over again

• Roofing. Any type of roofing can be used, according to architectural design, although the most economic solution is a flat slab, similar to the rest of the floors.

(see also Figures 4.9, 4.10, 4.11 and 4.12)
All plumbing and electric utilities are embedded in walls and slabs. However, since slabs are very thin (12 cm to 15 cm), sewage ducts will remain visible in the lower floor, which requires the use of false ceilings.

Adequately planned, the Outinord system allows the construction of one floor every day, provided that enough formwork units, labor and cranes are available.

4.1.2 Diffusion of Outinord and similar systems in Colombia

Tunnel formwork systems were first introduced in Colombia in the late 1970s, when the ICT (Colombian Territorial Credit Institute—a now disappeared governmental institution in charge of promoting low-cost residential construction) implemented the “Open bidding” contractual system. With this system, the ICT specified only the area and quantity of housing units for a certain project, and the bidders were left free to propose the most efficient construction system. The largest and
most experienced building companies at this time searched for the best alternatives, and tunnel formwork was one of them.

The system reached some diffusion among several firms, especially in the city of Bucaramanga, where one large builder (Constructora Martinez Villalba) adopted the system for most of its projects. With the disappearance of ICT (due to poor management), however, the system almost disappeared as well, and only this firm continued to use it for apartment buildings up to five floors.

In recent years, due to an increase in material costs and a reduction in sales, many companies have searched again ways to reduce their costs. They have came back again to this methods as a mean to achieve this goal.

One firm that has used the Outinord system for residential applications during the present decade is ConConcreto. The initiative to adopt the system came directly from the company’s CEO, J. Mario Aristizábal, and the system has been used for several projects such as Milán (300 apartments in low-rise buildings, late 1980s), La Vega condominium, and Fuerte San Diego (in construction in 1997).

In all cases, the projects were conceived from the beginning to use Outinord, because adapting the system to an already designed building is almost impossible. It is imperative that architects and structural designers know the characteristics of the system. Currently, at least three architectural and structural design firms in Medellín have experience with Outinord construction.

ConConcreto has updated the system as the French vendor makes improvements, and has counted on continuous assistance through consulting from the French vendor. One significant improvement over the original system introduced in the 1970s has been the adaptation of Outinord formwork to two-directional walls. With the previous Outinord system, it was only possible to cast walls in one direction (Figures 4.12), which resulted in structures vulnerable to lateral loads perpendicular to the walls that sometimes needed to be reinforced in the other direction. The new system, used in Fuerte San Diego (Figures 4.2, 4.3 and 4.4), produces structures with walls in both directions, much more resistant to earthquakes.
Based on the architectural drawings, the available crane capacity and the required completion time, Outinord’s Methods and Engineering department prepares proposals for each project, providing technical recommendations of required equipment, daily formwork cycles planning, and an entire jobsite organization study that includes:

- Positioning of crane and hoisting equipment (number and type of crane, lifting capacity, length of boom)
- Daily production schedule, covering required manpower and use of crane time.
- Detailing of formwork assemblies in order to optimize the use of the crane.
- Definition of the concrete production and supply, as well as of precast elements.

Outinord has also sent its training staff to Colombia to help with the implementation during the first three months of use of the system. This orientation program includes training of foremen, superintendents and project managers, to achieve thorough familiarization with the formwork system, related labor requirements, and the overall jobsite scheduling process. ConConcreto has implemented the system using its own labor (no subcontractors), and currently employs 4 groups of approximately 20 workers each that have been trained in the use of the system.

4.1.3 Advantages and Disadvantages

4.1.3.1 Advantages (Outinord Group, 1998; Acevedo, 1977)

4.1.3.1.1 Economic benefits

- Possibility to industrialize the building process: re-usable forms, same materials, same workload, one workstation, one schedule, one control system.
- Savings in material costs: concrete is the most economical material and the easiest to use.
- In seismic zones, the savings in reinforcement steel can be as high as 20% compared to the traditional moment-resistant concrete frame.
- Savings in direct labor: qualified construction crews are expensive and hard to come by.
- Optimum design of walls results in improved distribution and usage of livable space.
• The Developer completes his product earlier and secures a higher rate of return on his investment.

4.1.3.1.2 Technical benefits

• Load bearing wall structures avoid concentrated loads.
• Consistent wall sizes and reinforcement steel design result in perfectly homogenous buildings, impervious to windloads and highly resistant to seismic forces.
• All walls behave uniformly over time; differential cracks caused by the use of different materials are eliminated.
• Natural density of concrete walls results in a better sound transmission coefficient.
• Foundation design is highly simplified due to the consistent load distribution.
• Perfectly smooth concrete walls and ceilings, ready to be painted or to receive wallpaper.
• A variety of exterior finishes and facade designs is available.

4.1.3.2 Disadvantages

• The system is very rigid from the architectural design standpoint.
• Slabs are very thin, and intersection of two or more service ducts can be impossible. This demands a very careful planning and coordination of designs.
• Initial costs of the formwork units are high, and the payoff requires use of the system in at least 2 or 3 projects (50 to 60 uses).
• Technical assistance is excellent, but is also costly.

The ConConcreto engineers report savings in total construction time up to 30%. If the structure alone is considered, the time savings are even greater, because Outinord allows the construction of one floor per day, as opposed to a minimum of 5 or 6 days per floor using the traditional systems. In residential construction, however, construction speed is not as critical a factor as the speed of sales is. If the project is selling slowly, rapid construction may result in excess inventory.
4.2 PROJECT ADMINISTRATION SOFTWARE - SAO PACKAGE

4.2.1 Generalities. Construction software in USA and Colombia

Currently, the most commonly used construction management software packages in the USA are produced by Primavera and Timberline. Primavera’s main product is its Project Planner (P3), which is essentially a very complete schedule control program, capable of managing several projects in multi-user environments, leveling resources across tasks and controlling calendars of activities. It is based on PERT and Critical Path Method. P3 has been integrated recently with other programs from the same vendor. These additional modules include end-user simplified interfaces, control of communications among project members, Monte Carlo simulation and database exchange capabilities (Primavera, 1998). Primavera, however, is not very strong when it comes to cost control and budgeting, because it does not allow precise control of budget items and subitems.

Precision Estimating (PE) from Timberline Software Corporation, on the other hand, is a package conceived to estimate and control project costs. It can be used from the conceptual stages of the project, calculating economic feasibility, to the most detailed unit price analysis. It can be linked to accounting, CAD, scheduling and bidding software (Timberline, 1998). Its integration with scheduling, however, is not its strongest feature.

Primavera and Timberline products have effectively become standards in the US construction industry. In Colombia, however, use of these products has been very limited so far. Only 400 copies of Primavera have been licensed in Colombia since 1990 (Ibáñez, 1998). In Colombia, medium-sized and large construction companies that do use software for schedule and cost control, use packages developed locally by Colombian professionals, which are highly customized for the particular needs of the Colombian construction industry such as usual contractual relationships among firms in the value chain, Colombian accounting standards, methods of payment for subcontractors, etc.

SAO (initials in Spanish for “Project Administration System”) is probably the best known of those software packages. It integrates budgeting, cost control and schedule planning and control (among
other features) in a single package. Besides SAO, other indigenous software for construction include Construyendo, Licitat, Edifica, Supercontrol, SAI-4, Cobra, Obra 60 and Factiplan (source: personal interviews).

4.2.2 Development and diffusion of SAO software

In contrast to the rest of the innovations discussed in this thesis, SAO is a case of an innovation that originated in Colombia, not the diffusion of an innovation developed somewhere else.

In the mid 1980s there were only two locally developed construction management software programs, Micro-Diez and Construyendo. However, Micro-Diez disappeared and Construyendo stopped releasing new versions of the software. Those programs, exclusively for budgeting, were written in BASIC for the recently introduced IBM PC computers with 64KB RAM. Imported programs, such as Harvard Project Manager (HPM), were exclusively for scheduling and their use was very limited. No cost control or budgeting imported programs were known at that time.

SAO was initially developed in 1984 and 1985 by Jorge Hurtado, a Systems Engineer from Medellín’s EAFIT University. This package is focused primarily in budgeting, cost control, and economic feasibility.

The first version of the program was made upon the request of a construction firm, Hernán Vieira Posada y Cia. Mr. Hurtado worked closely with the firm’s staff and got acquainted with the budgeting, controlling, scheduling and construction process, and created a completely customized program, whose first version was released in May 1985. The project did not stop there, and in the same year he received a request by SENA (Colombia’s National Training Service, a governmental institution in charge of training of industrial workers and semi-professional personnel) to make a presentation on the program and evaluate the possibility of creating a course on the use of locally developed software, as a part of an initiative called Laboratorio Empresarial (“Corporate laboratory”).
The SENA course spurred interest among other construction companies. Two of them, AIC and V&Y (Velásquez y Yepes) agreed to buy the software, conditional on Mr. Hurtado implementing some additional features. The same process followed with other companies, and the end result was a program generic enough to be usable by a wide range of construction companies, but at the same time very customized to the needs of the medium size Colombian residential construction companies.

SAO was initially criticized for being very rigid and difficult to use. It relied heavily on codes and numeric IDs for the budget items, and it was not user-friendly. The program required very detailed inputs from the user because it controlled costs “to the last nut and bolt.” These problems led to the diffusion of competing programs such as Licita and Factiplan which, although less powerful and with more limited capabilities, beat SAO in terms of user friendliness. It was only in 1989 that the developer of SAO solved those problems.

Nowadays, SAO is in its 11th version, is Win-95 compatible, and has licensed more than 4,000 copies all across the country to more than 1,500 companies. SAO is the flagship product of S.A.S (Service and Consulting in Systems), a software company that has grown with the program. Typical SAO buyers are medium-size residential construction companies, although the program has been diffused to other construction-related industries, such as electric and road contractors. From the earliest versions of the program, SAO has been accompanied by extensive price databases for residential, electric, and highway construction.

Some larger builders still rely on their own internally developed software, although there is increasingly a tendency by this group to use more standardized solutions. For example, ConConcreto—one of the largest and most renowned construction companies—, did not adopted SAO until 1996. Some public companies, like Empresas Públicas de Medellín, require SAO-database compatibility for bidding proposals, and job postings in the newspapers requesting engineers with knowledge of SAO are common.

SAO has evolved to be much more than just a budget and cost control program. Its latest versions consist of five integrated modules. The features of each module are presented below:
PROJECT BUDGET
- Unit price analysis
- Budgeting
- Bidding proposals elaboration
- Export to spreadsheet programs such as Excel and Lotus
- Continuous price database updates (three different databases for residential construction, civil works and electric contracts)
- Database compatibility with other commercial price databases such as CAMACOL database
- AutoCAD and ArchiCAD interface for quantities survey
- Specifications management

INTEGRATED PROJECT CONTROL
- Cost Control
  - Invoice or Inventory-based
  - Actual costs vs. budgeted costs (Variances in unit costs - variances in efficiency - inflation)
  - Project advance reports
  - Total cost forecasts
- Inventory
- Control of Permits, Licenses and other regulations by Municipal and Provincial authorities.
- Contracts management
  - Billing control
  - Advance payments
  - Payroll control
  - Salaries, extra time and other benefits
  - Colombian social security costs and withholding taxes
- Equipment
  - Inventory control of rented and owned equipment
  - Time and cost control for rented equipment

ECONOMIC FEASIBILITY
- Net Present Value and Internal Rate of Return analysis (for both project and investor)
- Cash flow analysis, period by period
- Forecast Income Statement
- Bank loan management, customized for Colombian inflation-indexed loans (UPAC system)
- Different scenarios for fast and slow sales
- Different scenarios for increase in sale prices
- Detailed opportunity cost analysis

SCHEDULING
This module includes some of the same features found in Primavera, although it is much less powerful than Primavera. Its main advantage is its integration with the rest of the modules.
- Linked to Project Budget module
- Critical Path Method
- Four types of links (finish-to-finish, start-to-finish, etc.)
- Gantt and PERT diagrams
- Includes Colombian holidays
- Resource allocation

REIMBURSABLE CONTRACTS
- Invoices, payment orders and indirect costs recording
- Link with accounting systems
- Billing control
- Consolidated reports by client and by project

SAO is currently included in undergraduate Project Control courses in several Colombian universities such as Universidad Nacional, Universidad Santo Tomás, Universidad del Quindío, and Universidad Industrial del Santander, and in graduate Construction Management courses in Universidad EAFIT and Universidad de Medellín. Courses on basic SAO management are also included in the SENA curriculum.

As can be seen, SAO is a very different program compared to Primavera or Timberline. It could resemble Timberline as far as budget and cost control are concerned, but its integration with the other modules and its high degree of customization for the Colombian environment makes it very different.
4.2.3 Difficulties in the diffusion of SAO

SAO is far from being a standard in Colombia, despite its wide acceptance. Several obstacles have restrained its further diffusion:

- Many companies still associate the SAO name with inflexibility and difficult-to-memorize numeric codes, a problem that its author claims has been resolved since 1989.
- Not playing local in the cities where the program is promoted. S.A.S. (the parent company) has offices in Medellín (headquarters), Pereira, Bucaramanga and Sincelejo, but in other cities, potential customers are concerned with lack of support.
- In Bogotá, the largest potential market for the program, introduction has been difficult because companies' cost control practices are very accounting-oriented, not management-oriented.
- Ironically, language has been a barrier in a 100% Spanish-speaking country. Construction terminology varies a lot from city to city (cement plaster, for example, is known by five different terms in different cities).
- Although the scheduling module is integrated with the other four, the module itself is not very powerful. Other solutions like Primavera or TimeLine have much better scheduling capabilities, but cannot work with SAO.
- Costs: SAO costs about $3,200 US dollars, a comparable figure with Primavera (distributed at $4,000 US dollars per license). Although SAO presumably offers a better overall value for the Colombian user this is still a considerable price for smaller companies.

4.2.4 Advantages and Disadvantages

4.2.4.1 Advantages

- Interface in Spanish
- Developed from its inception for the medium-sized Colombian construction company. Highly tailored product
- Integrates Schedule and Cost control under the same package
- Wide diffusion in the Colombian environment, which creates some positive network externalities (although it is not yet a de-facto standard)
4.2.4.2 Disadvantages

- Not as good as Primavera in schedule control. It does not include some advanced features that the Primavera package includes, such as Montecarlo simulations.
- Price is not attractive for the smaller users
- User interface is less attractive than the average US-developed software
4.3 PRESTRESSED SLABS AND BEAMS

4.3.1 Generalities

4.3.1.1 Pre-tensioning vs. Post-tensioning

Prestressed concrete is a type of reinforced concrete in which the steel reinforcement is tensioned against the concrete, resulting in a self-equilibrating system of internal stresses that improves the response of structural elements to external loads. There are two main procedures for prestressing concrete: Pre-tensioning and Post-tensioning (Figures 4.13a and 4.13b). In pre-tensioning, high-strength strands are stretched between two abutments and jacked, then the concrete is cast around the tensioned steel, and after the concrete has hardened, the steel is released, which results in a compression of the concrete. Pre-tensioning is mostly used for pre-cast concrete elements.

In post-tensioning, cables are embedded in ducts and are tensioned only after the concrete has hardened. Post-tensioned is used mostly on-site.

Figure 4.13 Prestressing techniques

(Source: Collins and Mitchell, 1991)
4.3.1.2 Recommended practices

The following is a summary of the recommended practices for on-site post-tensioning and its differences with respect to normal reinforcing (Noticreto, 1991).

4.3.1.2.1 Storage and Installation

- Cables and anchors should be carefully stored. Contact with soil should be avoided and protection against weather should be provided to avoid corrosion. This is not much different from the normal practices for storing reinforcing steel bars.
- Ducts also require careful storage to avoid perforations or crushing that could lead to problems during the tensioning and injection processes.
- Cables must be carefully positioned on the beams, fixing them rigidly to avoid movement during the pouring of concrete. This is no different from what must also be done with rebars.
- Ducts must be carefully inspected for perforations and crushing before installing the cables.

4.3.1.2.2 Tensioning and Injection

These two steps are completely different from what is done with reinforced concrete:
- Before starting the tensioning process, concrete resistance must be checked (using concrete cylinders)
- Pressure gauges must be checked
- Cables should move freely into the ducts
- Anchors should be properly positioned
- Tensioning of the cables (using jacks) must be carefully documented, controlling the entire process by filling special forms.
- After the tensioning operation is complete, cables are blocked.
- Before the injection operation, cables should be washed with water, which must be expelled later using compressed air.
- Mortar grout is injected in order to protect cables against corrosion and adhere cables to concrete.
• To guarantee a good injection, ducts should have no obstacles and injecting equipment should be powerful enough to push the mortar all the way through the duct.

It can be seen how post-tensioning, in general, requires more supervision and control than normal reinforcing. More skilled labor is required, but what is really critical is adequate supervision by engineers, and good equipment. Unskilled labor in this case is an obstacle that can be overcome with good training.

4.3.1.3 Cost comparison to reinforced concrete (Urrego, 1994)

Based on the costs of labor and materials prevalent in Colombia, a cost comparison study was made by AREA, a structural design firm in Medellín (Urrego, 1994). The theoretical structure analyzed was a typical one-directional slab with three beams separated 6 m, subject to service loads of 200 kg/m² and 500 kg/m² (to encompass the spectrum of residential, parking, retail and storage typical loads).

The analysis concluded that for typical structures with spans above 7.0 m, the 100% prestressed solution was more economical than the 100% reinforced solution (Figures 4.14 and 4.15). According to the author of the study, it is possible to reach even larger reductions in costs if partial prestressing is used.

Figure 4.14

Costs of Slab (COL$/m²)

(Source: Urrego, 1994)
4.3.2 Origins of prestressing worldwide

Worldwide diffusion of prestressed concrete started about 50 years after reinforced concrete use had been adopted in a majority of countries. The concept of prestressing had its origins in the past century, with the patents of Jackson for floors (1886) and Dohring (Germany, 1888). Steiner in the USA (1908) proposed the use of curved cables so the compression stresses matched the magnitude of moments. Great advances in the technique were accomplished by Freyssinet, who in 1928 patented a prestressed concrete system using high-strength steel cables. By 1945, prestressed concrete was widely used in Europe. In North America, the diffusion was slower due to resistance by designers and builders and lack of formal training in universities (see Table 4.2)

Table 4.2 Diffusion of prestressed concrete worldwide

<table>
<thead>
<tr>
<th>Diffusion in North America</th>
<th>Diffusion in Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 1951 more than 10 structures had been built</td>
<td>• France led initial diffusion, followed by Belgium, England, Germany, Switzerland and The Netherlands</td>
</tr>
<tr>
<td>• 1952 about 100 structures built</td>
<td>• Up to 1951, 175 bridges and 50 buildings had been erected using prestressed concrete</td>
</tr>
<tr>
<td>• 1953 In Pennsylvania alone more than 76 prestressed bridges were built</td>
<td>• In Germany, between 1949 and 1953, 350 out of 500 bridges used prestressed concrete</td>
</tr>
<tr>
<td>• Design practices evolve to become very standardized and rigid</td>
<td>• Design evolves without leading to standardization</td>
</tr>
<tr>
<td>• Diffusion is slower than in Europe</td>
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</tbody>
</table>
Currently the main technology used is partial prestressing, combining reinforced steel and prestressing in the same structural elements, to take advantage of the best characteristics of both systems, and to increase the ductility of the elements.

4.3.3 Diffusion of prestressing in Colombia

As it was mentioned before, the predominant structural system for buildings in Colombia is the moment-resistant concrete reinforced frame. For relatively long span bridges (40-50 m or more), steel was the predominant material until the 1960s.

4.3.3.1 Initial diffusion

The primary factor responsible for the initial diffusion of prestressing techniques in Colombia in the late 1960s was the Italian civil and mechanical engineer Doménico Parma, who spent great part of his professional life in Colombia. Parma, considered “the father of prestressed concrete in Colombia” (Noticreto, 1991), not only made the drawings for the buildings, but also designed machines and procedures to make possible the execution of the projects.

This initial diffusion of prestressing in Colombia was approximately 20 years later than the diffusion in the US.

Some representative commercial projects by Parma are (Figure 4.16):

- Avianca Headquarters (1968). Built for the largest airline in the country, it was the tallest building in Colombia when it was finished. It has only eight large columns, four central and four in the corners, which required very long and rigid beams. Post-tensioning was used for 5 high-rigidity slabs that subdivide its height in 5 “tall floors”, each of them containing about 10 floors with post-tensioned beams and pre-tensioned precast nerves.
- Colseguros Tower (1971). Similar to the Avianca building, its reduced number of columns required very long and rigid beams. The building has post-tensioned main beams 1.30 m high,
and post-tensioned cantilevers 10.0 m long at each side of the nucleus. For this project 11,500 m of 40 ton cable were used.

- Banco Central Hipotecario (Central Mortgage Bank) and Museo del Oro (Gold Museum). This single project consists of a central nucleus composed by two rigid elements joined by post-tensioned beams 1.20 high.

**Figure 4.16 Representative prestressed concrete projects by Parma**

Edificio Avianca (1968)

Torre Colseguros (1971)

Banco Central Hipotecario and Museo del Oro

(Source: Noticreo, 1991)
Although many designers today recognize the high technical achievements by Parma and admire the structural elegance of his projects, many question the economic rationale for his projects. Some of those buildings, according to them, could have been erected using more traditional methods at much lower costs. In Medellín, in general, design engineers were much more skeptical than in Bogotá, where the system was widely used. Prestressed structures in Medellín were rarely used, and among the few projects that used them are the Banco de la República (designed by Enrique Kerpel) consisting on a square of 25m × 25m, supported by four columns in its corners, and the Suramericana auditorium (Urrego, 1997).

Pre-tensioning has been used on a relatively regular basis for pre-cast elements, especially pre-cast beams for urban bridges.

4.3.3.2 Decline of post-tensioning

After the “golden age” started by Parma in the 1960s and 1970s, the use of the system declined significantly. The proceedings of the 2nd National Symposium of Prestressed Concrete in Colombia in 1991 registered that the supply of prestressed elements had reduced with respect to the 1960s levels, while the rate of construction had increased significantly during the same period (Noticreto, 1991).

Most of the obstacles that led to this decline are still present:

- Limited Supply of materials, services and equipment. There was only one national cable supplier (Emcocables) and one national post-tensioning subcontractor (Coltensa, owned by Parma.)
- Most structural designers know the theoretical principles of the system. However, a majority of them do not know the practical aspects of its design and construction, and lack the confidence necessary to design a post-tensioned structure.
- Structural designs for post-tensioning are more costly and complex than for traditional moment-resistant frames.
• Construction of the structure has to be delegated to a specialty subcontractor. Many builders prefer to build the structure themselves and contract out other parts of a project: they feel that the structure is too important to be left to a third party.

• Post-tensioned structures courses at undergraduate level are very elementary, and most of time are elective rather than mandatory courses.

• Many architects do not design buildings with long spans, because they have been used to the normal spans of 7 or 8 m maximum that moment-resistant structures allow. Many of them do not know that there is a structural solution that would allow them more spacious designs.

• There are still many misconceptions among a majority of designers and construction companies about post-tensioned and pre-tensioned concrete structures. Most professionals still associate these techniques with very long spans and heavy loads.

4.3.3.3 Recent uses

In the last few years, there has been a resurgence of the system, as more and more architects realize that they can design much more open spaces with longer spans, which are made possible by this alternative. Some engineering design firms are specializing in this system, as is the case of AREA in Medellín, founded by Héctor Urrego, a graduate from Braunshweig University in Germany. This firm has designed 11 large projects (including hospitals, offices and residential buildings) from 1991 to 1996 using the system, for a total of approximately 130,000 m². According to Mr. Urrego, four construction companies in Medellín have already used the system (ConConcreto, Pórticos, Bernal Llano and Urco), and AREA has designed projects for other firms in other Colombian cities, such as Bogotá, Pereira and Barranquilla.

The main characteristic of the designs by AREA is its combination of the post-tensioning technique with the traditional construction system of casetones (empty boxes used to reduce the weight of the slabs), resulting in a slab similar to the waffle slab in Figure 4.17. This approach has facilitated enormously its adoption by more traditional builders, and is also more economical because it reduces concrete consumption. According to Mr. Urrego, the construction process is almost the same, and the decision to use post-tensioning versus reinforced concrete does not interfere with the other components of the building, such as HVAC installations, masonry, etc. The construction of the structure itself is not very different either; for example, the formwork is the same and columns
are built in the same way (although their design is different). The only difference is in the post-tensioning, which with adequate supervision and control can be executed without problems by an expert subcontractor.

Figure 4.17 Typical prestressed slabs

(a) One way slab on beams  (b) Flat plate
(c) Slab with wide shallow beams  (d) Slab with column capitals and drop panels
(e) Waffle slab  (f) Two way slab on beams

(Source: Collins and Mitchell, 1991)

Figure 4.18 Post-tensioned slab

(Source: Collins and Mitchell, 1991)
Other structural design firms, such as Jaime Muñoz Duque are also using the system. This firm designed the new headquarters of EPM (Empresas Públicas de Medellín - Medellín Public Utilities Company), a large project of more than 100,000 m² with beams 36m long separated 18m among them (Pérez, 1994; Pérez and Restrepo, 1994). These beams were designed using post-tensioning and diagonal tensors in concrete (Figures 4.19 and 4.20), that subdivided the 36 m beam in three sections of 9m, 18m and 9m.

**Figure 4.19 Facade of EPM headquarters**

![Facade of EPM headquarters](Source: Pérez. 1994)

**Figure 4.20 Structural solution for EPM headquarters**

![Structural solution for EPM headquarters](Source: Pérez. 1994)
Some of the reasons that explain this renewed use of post-tensioning techniques are:

- Some urban regulations restrict the total height of buildings (either offices or residential) in certain zones, requiring thinner slabs which are only possible using prestressed elements. This was the case of the Edificio Quirama in Bogotá, built in 1991 by ConConcreto (6,400 m²). Beams in this project were 12.4 m long and their height could not be more than 0.35 m, otherwise, it would have been necessary to eliminate one of the floors, with adverse economic consequences. After analyzing several alternatives, the designer opted for prestressed nerves in the long direction and partially post-tensioned beams in the short direction.

- Modern computer-based design methods have helped achieve more rational designs, avoiding the excessively conservative—and thus, costly—designs that were typical during the initial diffusion of the system in the 1960s and 1970s.

- Economic apertura policies that started during President Gaviria administration (1990-1994). Thanks to a lowering in import taxes and tariffs, construction companies now import cables, anchoring and other supplies from USA and Panamá (Florida Wire and Cable, for example), while only two national suppliers were available before (Emcocables for the cables and Coltensa for the anchorings).

In general, it can be said that there is a greater awareness of the possibilities offered by post-tensioning in the design and construction community. Thanks to the technical diffusion of knowledge through seminars, conferences and local construction magazines, the economic advantages of the system (Figure 4.14 and 4.15) are being recognized by the more sophisticated construction companies.

4.3.3.4 Other uses

Prestressed concrete is also used in Colombia—to a limited extent—for applications different than buildings (Noticreto, 1991):

- Bridges: Some representative examples are the Chinchiná bridge near Pereira, Juanambú bridge and the bridge over Río Pontevedra in the Atlantic Highway. Prestressing has been competing against steel for this type of applications since the 1960s.
• Medellin’s Massive Transportation System (Metro). Post-tensioning was extensively used in this elevated transportation system (Figure 4.21), the largest urban construction project in Colombia in the last decades. German and Spanish contractors used post-tensioning for the piers, columns, prefabricated beams and even the 100,000 sleepers for Lines A and B (Naranjo, 1993).

Figure 4.21 Tren Metropolitano, Medellin

(Source: Reynolds, 1998)

• Urban bridges: Usually with spans less than 40m. Pre-tensioning has been widely used for this type of structures.

• Bent roofs: Have been used for long spans, where the number of columns is limited by architectural design. Most applications have been in industrial buildings.

• Curved bridges.

• Foundation slabs.

• Soil nailing. This technology was introduced in Colombia in the early 1980s, and is used for retaining walls in excavations, mainly.

There has been recently some interest in prestressed storage tanks for the petroleum industry (Cardeñoso and Aschner, 1994).
4.4 ENGINEERED CONCRETE MASONRY

4.4.1 Generalities on Masonry use in Colombia

Masonry, along with reinforced concrete, is one of the predominant construction materials in Colombia. Productivity of masons is high compared with other construction trades, although it is not as high as in North America. The combination of a low-cost labor and relatively good productivity makes masonry a still-popular solution for architectural divisions (García and Yamín, 1994). Structural use of masonry, however, is not as widespread as it could be, due to the disproportionate predominance in Colombia of the moment-resistant reinforced concrete frame system (García, 1993).

Masonry is used for almost all single family dwellings and for partitions and facades in low-rise and high-rise apartments and office buildings. Masonry units in Colombia are manufactured in clay, concrete and sand-lime.

Clay brick units are made using coal-fired furnaces of several levels of sophistication, some of them incorporating the most updated technology. Industrial production of clay bricks is very developed and is found in all major cities (García and Yamín, 1994). Typical dimensions are 10x20x40 cm and 15x20x40 cm, although other sizes are also available. Clay is widely available almost all over the country, with the exception of the Atlantic coastal area.

Concrete block is also produced in all major cities, and manufacturing follows the North American practice. Sizes tend to be compatible with clay brick sizes.

Sand-lime brick, only used in Bogotá, is produced using European technology.
The following parts of Section 5.3 will deal mostly with concrete masonry, with special emphasis in its structural uses that comply with the seismic code (engineered masonry). Both engineered and non-engineered masonry are used in Colombia, the latter mainly in single dwelling low-cost construction.

Masonry can be found in many types (Figures 4.22 and 4.23).
Structural uses of masonry can be classified as reinforced masonry, confined masonry, stiffening walls and unreinforced load-bearing masonry.

4.4.1.1 Reinforced Masonry

Reinforced masonry is a type of engineered masonry built using masonry units with vertical cells, with vertical rebars and horizontal joint reinforcement. Concrete blocks are the preferred material for this type of system, although clay hollow bricks (Figure 4.22) are also used. Usually only the vertical cells containing reinforcement are grouted.

Reinforced masonry is used from one story homes (very common) to high-rise buildings (uncommon). Use for higher income apartment buildings is very rare because seismic restrictions require equivalent amounts of walls in both directions, which makes it impossible to use the first story for parking.

The labor used for this type of masonry is more skilled and costly than for more conventional masonry. Construction follows the North American practice and requires mandatory inspection according to the CCCSR (Colombian Code of Seismic-Resistant Construction).

4.4.1.2 Confined Masonry

Clay units, rather than concrete blocks, are preferred for this type of system (Figure 4.24). Confined masonry consists of masonry walls surrounded by a light reinforced concrete frame, and is usually engineered, although the CCCSR includes a chapter on empirical design of this type of masonry.

All vertical loads are carried by the masonry wall, and usually the walls are built before the reinforced concrete columns are cast.

Confined masonry dates from the 1930s, and is used from single story dwellings to apartment buildings up to five floors. Moderately skilled masons are used for this type of masonry.
4.4.1.3 Stiffening Walls

Stiffening walls (also known as diaphragm walls) are used to stiffen a reinforced concrete frame structure for lateral loads (Figure 4.25). Masonry units in this system are usually made of concrete. Walls are built after the concrete frame is built, and walls must be completely surrounded by the reinforced concrete frame at all stories. The stiffening walls must have no window or door openings.

All vertical loads are carried by the concrete frame, while horizontal shear loads are carried by both the frame and the walls.

This system requires mandatory inspection only for large projects, and moderately skilled labor is used.

4.4.1.4 Unreinforced load-bearing masonry

All housing and building construction in Colombia, since the colonial times up to the introduction of reinforced concrete in the 1920s was load-bearing unreinforced masonry. It was used in houses, churches and public buildings. This type of construction uses clay tiles mostly.
Its use in new construction is restricted by the CCCSR to one and two-story dwellings only in low-seismicity regions. There are, however, many houses with this system in high seismicity areas, built before the enactment of the CCCSR in 1984. Labor requirements are low (unskilled masons).

4.4.2 Advantages and Disadvantages

In this section, the main advantages and disadvantages of using *engineered* concrete masonry (as described in Section 4.4.1.1) as opposed to the traditional moment-resistant concrete frames for buildings are discussed. Some of the disadvantages can turn into advantages: for example, the need for better planning and more detailed design can result in less on-site surprises, etc.

4.4.2.1 Advantages

- Better organization on-site
- Construction site is much cleaner, thanks to absence of mortar plastering
- Can save up to 2 months in a typical project
- More rigid structure than a frame building, so non-structural elements suffer less during earthquakes.
- Structural design is simpler than for framed structures
- Savings in interior finishings

4.4.2.2 Disadvantages

- Demands better study of architectural designs
- Requires very high-quality blocks and workmanship
- Architectural designs are very rigid
- Users cannot make changes to the final design
4.4.3 Introduction and diffusion of engineered concrete masonry in Colombia

The development of engineered concrete masonry in Colombia has taken place in less than 20 years. Two factors have been critical in this process (García and Yamin, 1994):

- Interest by builders and designers, after the earthquakes of 1979 and 1983, in using more sensible structural solutions for low and medium income housing
- Inclusion of structural masonry requirements in the CCCSR.

It can be argued that the CCCSR, instead of being a restraining force in the introduction of construction methods, has actually served as an effective channel for the diffusion of technical knowledge across the country. Teaching and research on masonry has increased over the last years, and several Colombian universities have regular courses on masonry, and the CCCSR has certainly spurred the process.

4.4.3.1 Initial uses of concrete masonry

Concrete masonry units were introduced to Colombia during the late 1950s, and were initially used in the first layers of masonry walls over the foundations, replacing clay units to avoid their decay due to soil humidity and salt absorption. Those first blocks had no special quality characteristics, since their use required little structural properties (Madrid, 1994; Madrid and Peláez, 1994a and 1994b).

4.4.3.2 The ICT impulse

Governmental low-cost housing programs started in Colombia during the 1950s, as a result of the massive migrations from the countryside to the larger cities caused by several social and political phenomena. During this time, the ICT played a central role in developing housing solutions. After recognizing the potential for the use of concrete blocks in low-income projects, the ICT awarded contracts to produce several million concrete blocks to be stored in open courts for future use. This spurred the industrialization of concrete block production and spread the use of this technology throughout the country as an alternative to clay units, especially in larger cities where plants were
set up using foreign equipment (much like the story of CBP, see Section 4.5). In the Atlantic coast area, where clay material is scarce, concrete blocks immediately became a very good alternative compared to the more expensive (due to transport costs) clay bricks.

4.4.3.3 First generation: Low-income dwellings

One characteristic of concrete blocks is that they can be produced in very small quantities, as opposed to clay tiles, which require large capital investments in furnaces, and other equipment (Madrid, 1994; Madrid and Peláez, 1994a and 1994b). This facilitated an increased use of concrete blocks in one and two-floor houses during the 1960s and 1970s, in which blocks simply replaced clay units. While economies of scale are lost when concrete blocks are produced in low scale on site, this is often compensated with almost zero transportation costs, and quality does not suffer.

Concrete masonry did not alter the traditional design of low cost houses, from the user’s perspective (i.e., in terms of space distribution and sizes), although a clear advantage of concrete blocks was its flatter surface, which allowed the builder to save on the cost of cement plaster. In facades, naked blocks were rarely seen: concrete blocks were a symbol of cheap housing and, even in low-income projects, architects tried to avoid this connotation by at least painting or covering the façade blocks with synthetic finishings.

**Figure 4.26 El Límonar low-cost housing project**

(Source: Madrid and Peláez, 1994a)
Additionally, in steep topographical conditions (very common in the Andean cities of Colombia, where walking paths can be as steep as 20% to 50%), concrete masonry provided the alternative of having the same material for earth retaining structures and for walls built over them, which reduced construction costs (Figure 4.26).

4.4.3.4 Second generation: First structural uses

Engineered concrete masonry was first introduced during the mid 1970s with the appearance of low-rise (up to five story) apartment buildings. Those structures were the first bearing-wall buildings in large multi-building housing complexes. From the architectural point of view, concrete blocks slowly changed the tradition of cement plastering every wall, which represented enormous savings in those projects. Those first structural uses were also in low and medium income projects.

Figure 4.27 Nueva Andalucía apartments project

(Source: Madrid and Pelaez. 1994b)

The step from the first generation to the second was a big one: the structural behavior of a one or two-story house is very different to that of a low-rise building. In the 1970s, the alternative of reinforced masonry was considered ‘exotic’ by most builders and designers. The step, then, did not occur by itself but was eased by the technical knowledge of several professionals trained overseas.
who recognized the advantages of the system and were not reluctant to use it. Another major step was the introduction of the CCCR in 1984, which contained design specifications structural systems different to the traditional ones (Table 4.3).

Table 4.3 Structural systems in the CCCR-84

<table>
<thead>
<tr>
<th>Structural system</th>
<th>Seismic resistance system</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOMENT-RESISTANT FRAMES</td>
<td>• Reinforced concrete</td>
</tr>
<tr>
<td></td>
<td>• Structural steel</td>
</tr>
<tr>
<td>STRUCTURAL WALLS</td>
<td>• Reinforced concrete</td>
</tr>
<tr>
<td></td>
<td>• Non-reinforced masonry</td>
</tr>
<tr>
<td></td>
<td>• Partially reinforced masonry</td>
</tr>
<tr>
<td></td>
<td>• Reinforced masonry</td>
</tr>
<tr>
<td></td>
<td>• Confined walls</td>
</tr>
<tr>
<td></td>
<td>• Laterally supported Frames*</td>
</tr>
<tr>
<td>DUAL SYSTEM</td>
<td>• Reinforced concrete walls</td>
</tr>
<tr>
<td></td>
<td>• Partially reinforced masonry</td>
</tr>
<tr>
<td></td>
<td>• Reinforced masonry</td>
</tr>
<tr>
<td></td>
<td>• Laterally supported Frames*</td>
</tr>
</tbody>
</table>

(*) Translation from Spanish expression “Pòrticos Arriostrados.”
(Source: García, 1993)

It has been necessary to emphasize to architects and developers the need to design with the concrete block system in mind from the beginning, because this product is much more demanding than clay tiles in terms of the modularity of the spaces, and other requirements, although apparently it should not be that different. This continues to be a major obstacle to the introduction of the system in many firms.

Another obstacle for the case of medium-high class buildings is the need for at least one or two parking spaces in the basement or first floor of the building, something that is not possible with a "pure" reinforced masonry system. One solution, which many structural designers consider inappropriate or at least uneconomical, has been to set up an hybrid structural system with the first
floors built in concrete frames (allowing parking spaces), and a reinforced masonry building on top of it. Despite all criticism, however, these hybrid buildings have behaved well during the most recent earthquakes.

High-rise reinforced masonry buildings are very rare in Colombia, with the record now in Cali: a pair of 14 floor apartment towers. Despite the structural advantages of this system, more evident in the case of taller buildings, most builders keep using the traditional concrete frame structure.

4.4.3.5 Third generation: Architectural concrete blocks

This is not necessarily a structural use of concrete masonry, but it is worth mentioning that architectural concrete blocks have changed the image of concrete blocks as a poorly appealing material used in cheap houses, to its current image as a first-class facade alternative. A variety of textures and colors has eased its acceptance in some applications, not only residential, but also retail applications such as in the SuperLey superstores, car dealers and government buildings. This could be a crucial factor in promoting further use of concrete blocks in more upscale markets.

4.4.4 Adoption and development of engineered concrete blocks in Medellín

The structural design firm Indycon was the initial promoter of the use of concrete masonry as an structural solution back in the 1970s. The firm was founded by the dean of the renowned Escuela de Minas of Medellín—the oldest engineering school in the city—and another engineer with graduate studies in the US. As explained before, concrete block production already existed in the country, serving the market for low-income houses. What is interesting in this case is that one of the partners of Indycon was also partner of Imprebloc, a concrete block producer. There was a clear interest by Indycon to promote the system and thus favor Imprebloc.

Indycon and its partners started at this time an aggressive promotion campaign. This campaign included courses for masons in the SENA as well as conferences in the local Engineers Associations and Universities by American experts from the ACI Committee 531. Some of these
conferences were sponsored also by Columbia Machine (an American company), the world's leading manufacturer of concrete products equipment.

All these efforts resulted in the decision by ICT and the Cooperativa de Habitaciones (Dwellings Cooperative, another semi-private institution) to build the first low-rise buildings using concrete blocks as structural elements in the mid 1970s. Some of these first projects include:

- Trianón (c. 1975): five buildings of seven floors each (about 100 apartments)
- Simón Bolívar (c. 1975): two blocks of five floors buildings (about 120 apartments)
- Tricentenario (1975 and 1976): Directed by the ICT, this project consisted of 1,800 dwelling units, and was built in three consecutive stages. The first one (about 700 units) used the traditional methods, but the next two stages shifted to the new concrete block system, which made direct comparison between the two methods more evident, not only for the builders and designers directly involved, but also for the building community (this was a highly-visible project, backed by the President’s office at this time). The director of the ICT used to organize visits to the project for the members of CAMACOL (Colombian Construction Chamber) and other engineers and architects, to show them the advantages of this and other innovations that were implemented in this development.
- Nueva Andalucia: 700 units in 5 and 6 floors buildings (1978) (Figure 4.27)
- Cataluña: Approx. 700 units.

At this point it is worth mentioning the case of a particular firm from Medellín: Muros y Techos, founded in the 1970s. One of the partners of the firm, Jorge Gómez, started his professional career as junior designer at Indycon before starting Muros y Techos. The firm, whose main activities are concentrated in Medellín and some neighboring cities, has used the system for a great number of its projects. One of them was Mallorca (108 apartments), in the nearby city of Pereira, built before the earthquake of November 1979. This project of seven identical six-story apartment buildings of reinforced hollow concrete blocks was designed following the recommendations of the ACI Committee 531, and the blocks were manufactured following the North American practice. This project was built with great care, because it was one of the first projects using this system in the country (García and Yamin, 1994). The project suffered no damage from the earthquake, while
several neighboring concrete frame buildings suffered severe damage due to the intensity of the shaking. This was an important milestone in the introduction of the system for its visibility effects.

Mr. Gómez admits that the system was not easy to adopt at the beginning: they experienced problems with the quality of the labor, and the finished surfaces of the walls were such low quality that in these very first projects, they had to use mortar plaster to cover the imperfections (one of the main economic advantages of the system, when correctly implemented, is the elimination of mortar plaster). Despite these problems, the company persisted, and the improvement in the practice of this system is a clear advantage for Muros y Techos today: many builders that use the system report fissure problems and abandon its use, while only a handful of firms (Muros y Techos among them) obtain satisfactory results.

During this period, many large construction companies (most of them contractors for the ICT and similar institutions) adopted the system, and were followed by smaller ones. Many of the small firms, however, abandoned the system in the late 1980s and early 1990s. Several reasons account for this phenomenon in smaller firms:

- Fissure problems, due to lack of adequate control in the quality of the mortars.
- Modernization of the clay bricks industry. This has resulted in more economical clay units, with better dimensional tolerances, which also reduces the consumption of cement plastering.
- The system itself is not easy to implement. As mentioned before, it requires a high quality of the concrete blocks and the labor, and also requires careful planning and design.

Despite this slowdown in the diffusion of engineered concrete masonry, the system is still used in many projects, although the traditional moment-resistant frame is prevalent. Even in moment-resistant frame structures, concrete masonry is used to a limited extent: The elevators hoistways or shafts, for example, are usually built with concrete blocks, which creates a rigid vertical axis that confers some advantageous structural properties to the building.
4.5 CONCRETE BLOCK PAVING (CBP)

4.5.1 Generalities

Concrete Block Paving (CBP) is a paving system widely used in residential construction for parking lots, access roads, garage entries and walkways, although its main application is in low speed roads. CBP is substantially different from other paving systems in many aspects (Table 4.4, Figures 4.28 and 4.31). The most important differences between CBP and asphalt paving can be classified in three categories: structural properties, construction process and applications.

4.5.1.1 Structural properties

- The surface, once adequately compacted, behaves as an homogeneous layer, similar to asphalt (flexible) paving. This homogeneous behavior is reached because each piece does not work independently but transfers charges to its surrounding pieces through the sand seal between them.
- If the joints between blocks are adequately filled with sand and the surface is well compacted, the surface becomes impermeable. This has been one of the main arguments against the use of CBP by the initial potential users. Although an adequate construction method guarantees impermeability, the joints between blocks have to be refilled with sand every year.
- The units that constitute the road surface are precast, thus, its quality is controlled in the factory rather than on-site.

4.5.1.2 Construction process

- The road surface is consists of small pieces placed over a layer of sand, instead of a uniform surface, which gives CBP an immediately identifiable aspect. No construction joints are necessary, as opposed to concrete roads).
- CBP allows easy installation and repair of underground service networks, such as energy, sewage and water supply. It is just a matter of removing the pavers, excavating the dig, and put the pavers in place again after the work is finished. No “patches” are visible, and the road surface is left in identical conditions as before.
- Due to the simplicity of the construction process, the whole structure of the pavement can be constructed and start being used in the same day, so the interruptions to vehicular traffic are minimal.
- Construction with CBP uses less machinery and more labor than concrete or asphalt paving. For the base layer, the equipment used is the same than for asphalt pavement, and for the road surface only labor and small vibrocompaction machines are required (Figure 4.30).

4.5.1.3 Applications

- CBP is capable of supporting pedestrian and vehicular traffic (Figure 4.29). However, for speeds over 60 km/h, CBP is not recommended for vehicular traffic due to the vibrations induced by the surface.
- Worldwide, CBP is used in airports (e.g. Dallas-Forth Worth), ports, warehouses, etc. (Madrid, 1991)

Initial costs (not considering maintenance) of CBP are similar to those of asphalt paving. Considering maintenance costs, however, CBP is much more economical than asphalt (Table 4.4)

Figure 4.28 Basic Structure of a CBP paving

(Source. Madrid and Londoño, 1986)
Figure 4.29 Urban residential and road applications of CBP

Los Rincones apartments in Medellin
(Town road in Ciudad Bolívar
(Antioquia province)
(Source: Madrid, 1985)

Figure 4.30 CBP Construction Process

(Source: Madrid and Londoño, 1986)
Table 4.4 Comparison between different types of floor and pavement materials

<table>
<thead>
<tr>
<th>Type of Pavement</th>
<th>Type of Structure</th>
<th>Reparability</th>
<th>Costs</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Initial</td>
<td>Maintenance</td>
</tr>
<tr>
<td>Concrete Block Pavers</td>
<td>Flexible</td>
<td>High</td>
<td>Medium to High</td>
<td>Low</td>
</tr>
<tr>
<td>Clay pavers</td>
<td>Flexible</td>
<td>High</td>
<td>Medium to High</td>
<td>Low</td>
</tr>
<tr>
<td>Concrete Flags</td>
<td>Flexible</td>
<td>High</td>
<td>Medium to High</td>
<td>Low</td>
</tr>
<tr>
<td>Concrete Slabs</td>
<td>Rigid</td>
<td>Low</td>
<td>Medium to High</td>
<td>Low</td>
</tr>
<tr>
<td>Stamped or colored concrete</td>
<td>Rigid</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Clay veneers on mortar</td>
<td>Rigid</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Plain mortar</td>
<td>Rigid</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Asphalt concrete</td>
<td>Flexible</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

(Source: Madrid, 1996)
4.5.2 Diffusion of CBP worldwide

Concrete Block Pavers (known is Spanish as adoquines) is in fact a reinvention of a very old idea, but with a new material. Paving with natural and cut stones has been an extended practice for thousand of years in many cultures around the world, reaching its maximum development in the Roman empire (Lilley, 1991). In regions where natural stone was not available, paving with bricks made of burnt clay and wood became common some 900 years ago. Paving with stones accompanied European development until the late 19th century, until it was no longer practical or economical to cut the increased amount of stones required for the needs of accelerated urbanization and the appearance of the automobile. Thus, with the advent of bituminous and cementitious binders at the turn of the century, the use of stone paving declined significantly, in favor of asphalt and concrete roads (Lilley, 1991)

Although the first experiences with CBP date from the late 19th century, it was only after World War II that Belgium and the Netherlands, traditional users of clay paving bricks, begun using concrete instead of clay. This was the situation until the 1950s, until the invention in Germany of machines capable of economically making concrete blocks of high quality and precise dimensions, which started the “CBP revolution” worldwide. From Germany and the Netherlands, this technology arrived to UK in the early 1970s (where formal research on CBP was started), and then to South Africa, Australia, New Zealand and Japan. CBP later reached the US and other European countries. Diffusion in Latin America started in Mexico, Central America, and Argentina by German machine manufacturers (Madrid, 1992 and 1994)

Most of research in CBP is done in Germany, Australia, Canada, US, Netherlands, UK, Japan, and New Zealand. Some research is done in Belgium, Colombia, and Italy. In the 1970s and early 1980s, most of the research effort worldwide was done in design methods and development of technical standards for all countries. Since the late 1980s, more emphasis has been placed on the refinement of the design methods and the development of new applications worldwide (e.g. ports, service roads of airports, bulk storage and military facilities). Most recent research on CBP is done in the field of the mechanization of pavers placing.

Currently, more than 500 million m² are produced annually worldwide (Lilley, 1991)
4.5.3 Diffusion of CBP in Colombia

During the implementation of CBP in Colombia, the Colombian Cement Producers Institute (ICPC by its acronym in Spanish) has played a central role as the promoter of the system among designers, builders, official entities and future professionals (Ossa and Madrid, 1991). It seems now that without the drive of ICPC—obviously interested in promoting cement use for as many applications as possible—the diffusion of CBP would never have reached the present levels. This is particularly remarkable, given that CBP survived in Colombia without any other supporting institution: in Colombia there is no “Concrete Masonry Association” or “Concrete Precasters Association.” The only liaison is ICPC, and is mostly an academic-like relationship, without much direct lobbying power.

Five stages can be identified in the diffusion process: Knowledge of the system, Initial Diffusion, Development, Intense Promotion, and Growth.

4.5.3.1 Knowledge of the system (late 1960s - 1974)

Since the end of the 1960s it was heard in Colombia about the appearance in Europe of a new paving system with concrete blocks. The ICPC was well aware of this development, and in 1974 coordinated the travel of a group of consultant engineers, the owner of a concrete block plant (Indural, from Medellín) and the manager of a project in which CBP could be used to Managua (Nicaragua) to observe the use of the system in the reconstruction of this city after the earthquake in December 1973.

As a result of this trip, both the producer and the user committed to produce and use CBP, and under close guidance by ICPC, production of pavers was started for a specific project: the outyard of the new Medellín Convention and Exhibition Center, to be inaugurated in 1974. The second known use of CBP was in a high-end residential project in Medellín (Edificio Los Rincones) also in 1975 (Madrid, 1997).

After these successful first and second experiences, the ICPC published the first Manual de Adoquines (“Concrete Block Pavers Handbook”) in 1975, which served as the guide for CBP construction until 1982.
It is important to note that in Colombia, as opposed to other countries' initial diffusion, CBP was regarded as "safe" for both pedestrian and vehicular traffic. From the beginning, CBP has been used in Colombia for vehicular traffic, especially in parking areas and low-traffic roads. In other Latin-American countries (Venezuela, particularly), it has been difficult to convince users of the structural capability of CBP.

4.5.3.2 Initial Diffusion (1975 - 1981)

During this period, the ICPC played a role of depository and diffuser of the knowledge without much direct involvement in the implementation of the system. Most of this initial diffusion was directed towards professionals, designers, and some major producers of concrete blocks, and consequently, the initial uses were mostly among private builders. A CBP paper was presented during the First Colombian Symposium of Pavement Engineering in 1976, and the system was introduced to some mayors of small towns and some Non-Governmental organizations. A very simple machine to produce pavers by small entities was designed, and three of these machines were produced (Madrid, 1988 and 1997). However, this stage was characterized by some early failures. The machines were not heavy-duty and broke down frequently, and, in many municipalities, CBP projects were abandoned. At the commercial level, a major setback was the Oviedo mall in Medellin in 1978-79. In this highly-visible project the contractor used arenilla (lime-sand) instead of sand for the road base layer, and all the paving was a total failure (Madrid, 1997). This setback slowed the ongoing diffusion process among private users in this city.

During this period most of the CBP use was in residential and commercial projects in major urban areas. The diffusion of CBP for streets and squares paving in small towns would begin later.

4.5.3.3 Development (1981 - Mid 1990s)

As a consequence of the excess cement supply, in 1981, ICPC decided that the widespread diffusion of CBP was a priority in order to increase the consumption of cement nationwide. ICPC then became much more directly involved in the diffusion and implementation of CBP. From being simply a depository and diffuser of knowledge, ICPC started to play a much more direct role.
Two clearly defined groups were identified: commercial paving in cities, and communal paving programs in small towns and low-income urban areas. The diffusion among official entities was intensified, and the ICPC was directly involved in giving financial aid to some entities for the purchase of machines. Most of the ICPC work during this period was directed toward the second group, because it offered greater potential for growth in cement use, and because the use by private builders had already gained some momentum.

The technical documentation was expanded. Until 1982 only the first "Concrete Block Pavers Handbook"—which did not included detailed design and construction information—was available, and some pavement designers were still reluctant to use the system. The initial failures of the system also called for better diffusion of technical norms.

The first ICONTEC (Colombian Institute of Technical Norms) standard referring to CBP dates to 1983 (Madrid, 1997).

4.5.3.4 Intense Promotion

Simultaneously with Development, CBP was more intensely promoted in Universities, official entities, professional associations and even the President's Counselorship in charge of social programs.

4.5.3.5 Growth

In recent years the promotion of basic CBP uses in Colombia seems to have reached its peak. With the existing documents and audiovisual support, ICPC can prepare any conference or course upon request very rapidly. However, more work is to be done in the diffusion of new applications.

Technical documentation has been expanded, updating in most recent uses of CBP worldwide, and "pushing" of the technology toward new applications in Colombia.

By request from several universities and institutions across Latin America, the ICPC is currently preparing a book on CBP to be used by professionals, and as textbook in Universities in the region.
4.5.4 Main strategies used to increase CBP diffusion

The diffusion of CBP in Colombia has followed different paths for the two subgroups identified by the ICPC: commercial and residential users, and municipalities-communities. The diffusion process among these two groups, however, share some common characteristics:

- Permanent contact of the ICPC with sources of technical information abroad. ICPC representatives have participated actively in all the five International Conferences and two Workshops held on this field: University of Newcastle (UK, 1980), Delft University (Netherlands, 1984), Pavitalia Rome (1988), Oslo (Norway), Melbourne (Australia), Auckland (New Zealand, 1992) and Pave Israel Tel Aviv (1996). The next Workshop, being organized by the ICPC itself, is to be held in Cartagena, Colombia, in 1998 (Pave Colombia'98). This activity has increased the credibility of the ICPC technical support, and has helped ICPC to be constantly updated.

- During the 1970s and 1980s, ICPC was the only institution in Colombia acting as the depository of sufficient information about CBP. In Universities and other institutions, CBP material was rare, and consisted mostly of ICPC publications.

- Until the mid 1970s there was not a single article on CBP in the PCA (Portland Cement Association). The first “CBP Handbook” by ICPC in 1975 was mostly the result of observations and recompilation of scarce information by ICPC employees.

- In the early 1980s, after the success of the “Concrete Block Pavers Handbook” and due to the accelerated diffusion of CBP in cities and small towns, ICPC published additional six “Technical Notes” from 1983 to 1986, amply illustrated and aimed at different groups of users with different degrees of complexity. Other publications on the same topic have been issued by the ICPC (the most recent in 1996).

- Technical specifications by ICONTEC (Colombian Institute of Technical Norms) have been developed with the assistance of ICPC and under agreements among the CBP manufacturers, and with the help of several theses at the undergraduate level (since graduate programs in Civil Engineering and Architecture are not common in Colombia.) The Colombian standards are adjusted to the climate conditions of a tropical country (with heavy rain areas but no freezing temperatures) and the technical and economical capabilities of the testing facilities (bending test). Technical standards in Latin-American countries have appeared between 8 and 15 years
after the introduction of the technology. Most of the Latin American norms refer or are originated from European or American standards: DIN (Germany) are cited by Argentinean, Chilean, Guatemalan and Mexican norms. NEN (Netherlands) is cited by Colombian norms, which are the base for the Venezuelan norms. ASTM (USA) is cited by Chilean, Ecuadorian, Mexican and Peruvian standards.

- Other publications by ICPC have dealt with economical and production topics, targeting specifically concrete block producers (to convince them to produce CBP as well) and a more “managerial” public. The first precaster to produce CBP exclusively began activities in 1982.
- The design method has also been adapted by ICPC to the knowledge of Colombian designers. Since most of them were already familiar with asphalt design, the “thickness design method” for CBP was selected, based on the similar structural behavior of CBP and asphalt.
- The number of “large producers” of CBP in larger cities using imported high-performance machinery (Columbia, Prensoland, Rosacometta, Fleming, etc.) is currently more than 90 companies nationwide. There are more than 200 small plants in towns and small cities. Registered production in 1992 was over 1,000,000 m² of pavers per year, which could easily be doubled if small plants are counted. The per-capita production of CBP is less than 0.05 m²/year/hab, small compared to 1.65 m²/year/hab in the Netherlands, 1.60 in Germany or 0.45 in Canada. However, this is a good figure since no individual project had exceeded 12,000 m² until 1988 (versus multiple individual projects in the Netherlands of 800,000 m² and more), which means that the technology has spread among a large number of small users. It must also be considered that Colombia has a very poor road system: only 0.004 km/inhabitant, of which only 30% is paved, compared to 0.025 km/inhabitant in the US (6 times more), 60% of which is paved.
- The average factory price of CBP is about US$8/m² and US$9/m² (for 60 mm and 80 mm thick pavers, respectively), which is a competitive price compared to asphalt.

At this point it is important to analyze how different was the approach of ICPC with the two main targeted groups of users during the development stage.
4.5.4.1 Commercial paving in larger cities

When ICPC decided that CBP was a priority, the technology had already gained some momentum among private users in cities. However, an additional impulse was given to this segment. Close technical guidance was provided by ICPC to large paver producers, the main suppliers of CBP to this segment. The initial targeted group of users consisted of residential and retail builders. The main applications for which CBP was promoted were outyards of new residential and retail (malls) developments.

Technical proposals were presented to engineers and architects at the highest technical levels, and specifically designed conferences for official entities in charge of supervision of public works. This was critical in order to gain entry to the market of closed detached house developments, where access roads are built by the developer but have to be maintained by the municipality. By convincing public officials of the benefits of the CBP system, they would allow its use in this important segment.

ICPC also started a program of lectures in the Universities, proposed to include the topic in the curriculum of Civil Engineering, Architecture and Two-years college programs.

The use of CBP for commercial applications started in Medellin (ICPC headquarters location), then it was extended to Cali and Bucaramanga (third and fifth largest cities), later on in Bogotá, and then in almost all the cities. Nowadays, the most common uses are internal roads of condominiums and closed residential developments, parking lots, gas stations, and pedestrian ways.

4.5.4.2 Community programs in small towns and low-income urban areas

The group of users initially identified consisted of financial institutions of social and community character (similar to charity or subsidies), non-governmental organizations and official entities. For this group of users, the CBP alternative was considered attractive for several reasons:

- It fits within their programs of improvement of living standards of communities
- Represents additional sources of employment for depressed communities

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• Fit within the limited budgets of this kind of organizations, since it can be accomplished “step-by-step.”
• It is ideal for those villages with incomplete underground service networks (sewage, water supply, telephone and energy), since CBP allows easy installation of them without permanently damaging the surface of the road.

For this group of users, it has been key to diffuse the knowledge of the system among the municipal offices in charge of maintenance of public roads, in order to gain their acceptance and the inclusion of CBP standards in their bid specifications. An important milestone for the diffusion of CBP among this group of users has been the publication in 1997 by the Ministry of Transport of the specifications for CBP use in roads (up to 1997 no major road built by the national government has used CBP, only at municipal level or in private projects.)

The social effects of diffusion in this group have been immediate (Madrid, 1988). Jobs are created, life conditions are improved and the sense of community is increased. Frequently the paver machine represents the principal financial burden for the program, and is therefore donated by some NGO or by the cement producers. The machinery used has been mostly low-performance and locally manufactured (which implies lower purchase costs and no import taxes). A typical machine costs about US$3,000.

Very often, only words and conferences have not been enough. It has become necessary to arrange visits with the interested people to locations where CBP has already proven successful.

In 1988, there were 8 machine producers, four of them manufacturing the same model of which approximately 800 machines were installed in the 1980-1988 period. A very attractive characteristic of this machine is that it can produce standard concrete masonry blocks as well, by only changing the mold. This machine can produce about 19,000 m² of pavers per year, enough to pave 3,100 m of 6 m-wide road, or the roads surrounding about 18 blocks of residences, 3,600 people in total. Calculations by ICPC show that if each of the municipalities of the Antioquia province (4.5 m inhabitants, 1.0 m of them living in the urban areas of 116 small towns) undertook a paving program simultaneously, using only one “Bucaramanga” machine each, a coverage of 41% would be achieved within one year, and 91% in 5 years (assuming that all urban roads were to
be paved with CBP). This demonstrates the great potential of this rather rudimentary system in massive and continued social programs.

In 1991, 200 of the 1015 municipalities of Colombia had already completed CBP programs. It has been used from the Colombian Caribbean Islands to the Western Plains and even remote locations. CBP has been adapted, technically and culturally, to the conditions of this group. For programs of high social content, ICPC has provided economic aid for the purchase of the machinery and has arranged special discounts on the cement with the associated cement producers.

Three main models of work have been used with this group, made up of combinations of institutions providing financing, resources, and local authority.

4.5.4.2.1 Development Bank - Community - Municipality

The development banks and social financial institutions have also played a significant role in the diffusion of CBP. Besides providing the financial aid, this institutions also provide technical assistance (in a similar way to the ICPC) on the set up of small CBP manufacturing plants and the construction of the pavement itself.

In many of the small municipalities, it is the mayor’s office which sets up plants and manufactures the pavers with their own workers (not contractors). This has allowed important savings, and also a continuity of the programs, since otherwise the fixed investments would remain idle. The social financial institutions usually finance the whole program, including the plant set-up. Other means of financing for the municipalities are “Valorización” Tax (charged to the properties which benefit from the increase in value due to the paving). In some cases, the communities themselves (the parish, for example) set up the plant, and the municipality buys the pavers from them.

4.5.4.2.2 Non-governmental organization - Community - Municipality

This model is more common in low-income urban areas in large cities than in small towns. The municipality builds the base of the pavement and provides the town or neighborhood with services. The community provides itself with part of the financing, with the profits from small communal
enterprises. The NGO and the social financial institution fund the plant and machinery set-up and operation, employing workers from within the community. Cement distributors provide the cement with 25% discount

4.5.4.2.3 Municipality - Community

Under this arrangement, which is similar to the previous model, the municipality provides the machinery and plant set-up. Labor is provided by the community on a voluntary basis (i.e. no wages are paid).
4.6 TILT-UP

4.6.1 Generalities

Tilt-up wall panels are flat concrete elements cast horizontally in the construction site (on the building slab itself or on adjacent casting beds) and then lifted by a crane, where they are temporarily supported by braces. The walls can be cast in single units or in layers or stacks, the latter method requiring liquid bond breakers or plastic sheeting to prevent bonding of the panels.

During the casting process, lifting inserts are placed at specific positions to allow for later lifting by the crane. Such inserts may also be used later to connect panels to each other. When the cured concrete achieves enough strength, the panel is tilted into position. Temporary bracing is installed with adjustable braces previously anchored to the slab or floor. Pre-erected steel or concrete columns support the panel after placing. The panel is then bolted or welded in its permanent position between the supporting columns.

Tilt-up can be used for warehouse facilities and industrial buildings, office complexes, shopping centers, low-rise commercial buildings, residential applications, and, in general, low to mid-rise structures.

4.6.2 Advantages and Disadvantages

4.6.2.1 Advantages

- Economy. Direct construction costs can be reduced 15% to 20%
- Labor savings. Up to 50% reduction in labor.
- Safety. Two thirds of work is done at ground level.
- Speed of construction. Up to 20% reduction in construction time.
- No shipping size restrictions as with other precast systems. No transport costs or delays.
- Architectural design versatility.
- The same panels can be used again if the building is to be expanded.
- Fire resistance. Tilt-up systems can be designed to resist fires up to 4 hours.
• Aesthetics. During the casting process is very easy to obtain textured surfaces.
• Availability of materials. Tilt-up construction is accomplished with local materials and labor.
• Energy savings. For industrial buildings, even in tropical climates, heating and/or air conditioning expenses can be significant. The concrete mass of the tilt-up panels (10 cm to 20 cm thick) is an effective thermal isolator.
• Tilt-up panels can be supported by several types of foundations, including spread and continuous footings, slabs and beams.

(ConConcreto, 1997)

4.6.2.2 Disadvantages

• Construction can be completely paralyzed if crane service is suspended.
• System still relatively unknown to architects and structural engineers in Colombia.
• Application in residential construction is less straightforward than industrial applications.

(ConConcreto, 1997)

4.6.3 Diffusion of Tilt-up construction

Tilt-up construction has been used in the US since the 1900s, and currently, over 15% of all industrial buildings in the US are tilt-up (Tilt-Up Concrete Association, 1998). In Colombia, similar precast systems have been used in the past two decades, but since they have used elements precast in factory instead of on-site, they have not used the main tilt-up advantage of avoiding shipping size restrictions and transport costs. The precast company “Industrial de Construcciones”, for example, have used precast panels (not tilt-up) during the last two decades in Bogotá and Cali.

In Medellín, the only reported case of residential use of Tilt-Up was in the mid 1980s, by the largest residential builder at this time for two apartment complexes of about 200 units each (Arango, 1998).

In Colombia, the firm ConConcreto has recently used the system for industrial building applications (ConConcreto, 1997). One application has been at the factory of Enka, a Dutch-owned polyester and synthetic fibers manufacturer (Figure 4.32). The 4,000 m² expansion project
required only two crane days, the rest of the time was spent in the casting of the panels. To accomplish this efficiency, careful planning is required, both from the builder and the client, to avoid disruptions in the production process. The fact that the system allows upgrades has a clear competitive advantage for the construction firm: whenever the client needs an expansion and wants to re-use the panels, it is very likely that he will have to hire the same contractor for the job. The panels will then be detached, lifted, and repositioned to another location in the expanded facility.

Figure 4.32 Tilt-Up construction process in a project by ConConcreto
(Source: ConConcreto, 1997)

a. Foundation beam

b. Concrete floor pouring

c. Tilt-Up panels formwork setup

d. Pouring
Figure 4.32 (continued)

e. Release

f. Lifting

g. Bracing

h. Final positioning

i. Channel beam lifting

j. Structure ready for roofing
4.7 HAND-PORTABLE PANELS FORMWORK SYSTEM

4.7.1 Generalities

This system uses rectangular 100% aluminum panels for formwork of reinforced walls and slabs. The same type of panel is used for the formwork of both walls and slabs. Similar formwork systems (Figure 4.33) include the “Western” and “Con-tec” (also 100% metallic), and an Italian system consisting on panels with wooden surface and metallic structure. With most of these systems walls and slabs are not cast in a single operation, as is the case with the Outinord system (Section 4.1).

These hand-portable panels systems are somehow an intermediate step between the masonry walls system (Section 4.4) and Outinord (Section 4.1): structurally, the walls resist both vertical and horizontal loads, and are made of reinforced concrete, just as with the Outinord system; the construction process, however, is less rapid, since usually walls and slabs are not cast in a single operation and there are more steps for the formwork assembly and release. Additionally, the formwork used is different, and, as its name indicates, does not require the use of cranes. One advantage the hand-portable systems used to have over the Outinord system was that they allowed the casting of walls in both directions while the old Outinord system did not. This advantage has already disappeared as Outinord has made improvements to its system.

Formwork systems similar to the hand-portable panels have been already used in Colombia since the early 1980s. Hand-portable panels cover half of the total height of each floor, similarly to the "Western" formwork system used in the US. Other similar systems, like the Italian formwork mentioned above, cover the entire height of each floor.
4.7.2 Advantages and disadvantages

4.7.2.1 Advantages

- Construction is faster than with columns and beams (moment-resistant frame).
- Less variable labor efficiency
- High quality of resulting wall surfaces. No cement plastering is necessary.
- Structural rigidity (new CCCSR-compliant)
- Hand-portable, requires no crane or other heavy equipment
- Some similarity to existing techniques that use raw wood panels
4.7.2.2 Disadvantages

- High cost of initial investment in panels
- Requires many projects to payoff
- Architectural design becomes less unconstrained
- Demands better planning and more complete drawings
- Speed of construction can result in excess inventory, which can worsen financial results depending on financing mechanism.

Under optimal conditions, the hand-portable panels system can represent savings of 10% to 15% of direct construction costs. Time savings can be over 30% (Cano, 1997).

4.7.3 Diffusion of the system in Medellín

The system has been used in Colombia for at least 10 years by Fervel, a Bogotá-based construction firm, and other firms from the same city such as “Pedro Gómez Barrero.” Similar systems have been used in Bogotá by “Ospinas y Cía.” and other firms. In Medellín, the firm PSI (Engineering Projects and Services, one of the largest residential development and construction firms in the city) has pioneered the use of this system.

In 1995, it was already evident that an updated version of the CCCSR was soon to be released, with more stringent seismic restrictions, particularly more rigidity demands. PSI then started looking for a construction system that met the new demands of the upcoming CCCSR and that was efficient and fast at the same time. They started searching for information at the ICPC library and found several systems that could suit their needs. The Outinord and other tunnel formwork systems were dismissed because PSI considered that they lacked versatility and required extensive use of cranes. The panel system offered more flexibility from the architectural design standpoint, and was considered to be more easily adopted by labor, since it resembled the use of wooden panels (“teleras”) for slab formworking.
After making a decision for the panel system, PSI sent one engineer, one foremen and some of its best laborers to Bogotá to observe the use of the system by Fervel. Fervel provided PSI with most of the practical information not contained in the ICPC manuals.

PSI used the hand-portable panel system for the first time in 1995 in "Cristales", a 3,600 m² apartment building of eleven floors (two of them as underground parking) and four apartments per level, for a total of 36 units. This project was originally designed as moment-resistant frames and voided slabs (the traditional system), and was redesigned so that the interior spaces were compatible with the modularity of the new system. PSI has used the system in other seven projects (two finished, and five in construction).

Other firms in Medellín such as CASA, Umbral and Coninsa have rapidly adopted the system due to its many advantages and similarity with traditional systems.
4.8 STRUCTURAL STEEL BUILDINGS

4.8.1 Generalities

Steel structures are composed of elements that are either rolled to a cross section in a mill or welded together from smaller elements or steel plates. Elements are worked to the desired size and form in a fabricating shop or on the job site. The assembly of elements in the final structure can be done by welding or bolting.

For the reader unacquainted with the steel structure construction process in Colombia the main steps are presented below.

- Foundation is made of concrete, with anchoring for columns embedded in the foundation.
- Columns, pre-assembled in the factory, are mounted with a crane in sections more than one floor tall. Columns already include welded joints for the beams.
- Beams are attached on site either by welding or bolting.
- Afterwards, a steel-deck (already cut to fit the dimensions) is put in place. The steel-deck works as formwork and reinforcement to the slab at the same time. Steel-decks are already being produced in Colombia by two manufacturers.
- A welded wire fabric is put above the steel deck (to control concrete shrinkage) and the slab is cast. Typical slab is thickness 10 cm, versus 40 cm with reinforced concrete.

4.8.2 Advantages and Disadvantages

4.8.2.1 Advantages

- Weight of the structure can be reduced by 30%-50% compared to the traditional reinforced concrete structures. This is very important in Colombia, where the largest cities are located in high-seismicity areas, because lighter structures are subject to lower seismic lateral forces.
- Beams span safely and economically over 10 meters, which is almost impossible with reinforced concrete.
- More ductile structures.
• Higher precision in dimensions, so the final measurements of window spans, and other elements can be guaranteed, which allows early ordering of such items and faster construction. With other systems, it is necessary to wait until everything is in place to take the actual measurements before ordering. For example, differences with designs under traditional system can be as much as 3 or 4 cms for each window opening.

• Cleaner worksite.

• Faster construction.

• Internal divisions can be made in clay masonry units, just as with the traditional moment-resistant concrete frame system. This approach does not take full advantage of the possibilities of steel structures, but it allows for the internal finishing surfaces to be exactly the same as with the traditional system, which can be critical for very conservative customers. Dry-Wall (gypsum boards on light interior framing), which take full advantage of the new construction system, is only starting to be introduced in Colombia.

• Slabs casting is independent of the structure assembly, and it is possible to cast two or more slabs at the same time (as opposed to the traditional reinforced concrete slabs, which need to cast each slab, wait for setting, then build the columns, then assemble the formwork, and then cast the next floor).

• It is not necessary to wait for concrete settings. Work on the slab can begin just a few hours after pouring.

4.8.2.2 Disadvantages

• More detailed design is required. A steel structure may require 10 or more times more drawings than a concrete structure (Garza, 1997b).

• Demand for better planning of the construction process (which can turn out to be an advantage).

• Very well trained (and better paid) personnel are required for welding. Currently, there are not many qualified welders in Colombia’s urban areas. Good welders have to be contracted from the petrochemical industry from other regions in the country, and it is possible to find some working for industrial maintenance (mechanical assemblies and the like). Training on welding practices by public institutions like SENA is of very low quality. The wages of a well-qualified welder can be as high as that of a recently graduated professional (US $1,200 a month).
• Direct costs can be 15% to 20% higher than for concrete structures. However, steel is economically feasible for spans over 10 m.
• Civil engineers and architects know very little about welding. Mechanical Engineers have to be hired to supervise the construction process, especially at the shop.
• Steel structures are more vulnerable to fire than concrete structures. For instance, the new seismic construction code includes a chapter in fire protection.

4.8.3 Diffusion of steel structures in Colombia

4.8.3.1 Earliest uses

A few steel structures were built in Colombia during the first half of the century (for example, Teatro Colón, Banco López, Banco de Colombia, Caja de Crédito Agrario, Banco de Bogotá, Esso de Colombia and a few others). These buildings used imported elements (Uribe, 1997).

In 1954, after the opening of Acerías Paz del Río (the largest steel producer in Colombia), the country raised protectionist tariffs that immediately stopped the development of steel structures for buildings in Colombia, limiting its use to frames and trusses in bridges, since the production and variety of profiles was very limited in general. Acerías Paz del Río produced mostly steel reinforcing bars, plates and sheets, but no rolled elements. The 1950s and 1960s also witnessed the expansion of cement production in the country, which made the concrete alternative much more competitive. As a consequence, courses about steel structures in most of the Universities were almost eliminated, and structural steel was only used for bridges with relatively large spans (competing with prestressed concrete since the 1960s, when these new systems were introduced, see Section 4.3), warehouses, roofing, and some industrial buildings. Almost no commercial or residential building using structural steel was built until the beginning of the 1990s.

4.8.3.2 Recent diffusion

After the economic globalization policies that began during President Gaviria administration (1990-1994), import taxes for steel were reduced, which made steel structures, again, a feasible alternative. Simultaneously, international steel prices also decreased and cement prices increased.
Aggregates for concrete in Colombia have become more expensive as well, due to the new environmental regulations that strictly control the production of aggregates in quarries, and to the fact that aggregates sources close to the big cities are being exhausted so transportation costs from sources further away increase.

Simultaneously, there was a renewed interest in the academic community in the use of steel structures. In the Medellin campus of the Universidad Nacional, a research group was formed in 1991 with the objective of promoting and developing new steel-based technologies, and elaborating a Design Handbook aimed at Colombian professionals (Garza, 1997a). This academic activity coincided with the First and Second Latin American Convention on Metallic Structures in Bogotá (1994) and Medellín (1997), and the creation of graduate courses in Steel Buildings in the Universidad Nacional and the organization of the First National Meeting on Metallic Structures in Medellín (1996).

All of this activity resulted in the resurgence of steel structures. The first building from this new era was "Edificio Lugano" (1993) in Bogotá, a small apartment building (4,300 m², 9 floors + 2 basements) fabricated by "General Steel Structures" from Ecuador. Even with the costs of importing and transporting the steel from Ecuador for this job, this company won the competitive bid over Colombian contractors whose experience in steel construction was limited to industrial applications and bridges.

Typical residential and commercial buildings using steel structures in Colombia nowadays are in the 2,000 - 5,000 m² range (not very large).

4.8.3.2.1 Diffusion in Bogotá

Structural Steel buildings began to be used again in Bogotá 5 years ago by small to medium size companies like Aceral (9 residential and hotel buildings), Vargas Rubiano e Hijos, Tecmo Estructuras Metálicas and Ecuadorian and Venezuelan contractors. As mentioned above, the first use was residential, but most of the projects that followed were shopping malls (e.g. Iserra 100) and office buildings. Other developments include hotels (e.g. Holiday Inn Bogotá, 9 floors) and warehouses. No precise statistics exist on the diffusion of structural steel buildings in Bogotá, but
it is estimated that about 30 projects for a total area of 150,000 to 200,000 m² have already used the system in this city (Garza, 1997b). Use in residential construction is still limited, because some buyers are still reluctant to make large investments in properties built with a new method (Poder y Dinero, 1997a). Some residential projects in Bogotá include Lugano, San Sebastián, Terranova, Santa Catalina, and El Bosque.

The design and construction technology used in Bogotá is adopted primarily from Ecuador and Venezuela. However, the first 100% Colombian steel building (“El Bosque”, 8 floors) was built in Bogotá in 1995 with a system implemented by a Medellín-based firm leaded by a Mexican engineer. For this project the materials, design, assembly and labor were 100% Colombian.

4.8.3.2.2 Diffusion in Medellín

The first recent use of steel structures in Medellín was in a 5-stories apartment building in 1994 (edificio “Mirador del Lago”). The project, already designed as a reinforced concrete structure, was to be built in soil with very poor load bearing characteristics. At the same time, the architectural design required long spans to allow a generous parking area. Given these restrictions, steel structure was a viable alternative, which was approved by the owner. External and internal architectural style and finishings were similar to the traditional system. All of the apartments have already been pre-sold, so the increased speed in construction improved the financial results of the project.

The structural profiles were welded in shop, using Colombian-produced steel plates (not imported, as with the Ecuadorian technology used in Bogotá). Currently there is no production of profiles in Colombia, so they have to be welded using plates.

So far, about 10 structural steel buildings have been made in Medellín, mostly in commercial-retail applications (Parqueaderos Exito, Serviyá gas station, Prestolandia, AutoAires and in the expansion of the Oviedo shopping mall). Steel structures were also used in some parts of the new EPM (utilities company of Medellín) building, a highly visible project, and in parts of the Dann Hotel. The material was imported, but the design and construction were Colombian. The diffusion of the system in Medellín is, in general, more limited than in Bogotá, in both the number and the size of
the projects (Figure 4.34). The total area of new structural steel buildings in Medellín is estimated to be about 20,000 m² (Garza, 1997b). There is only one steel structures design firm in Medellín: Soluciones y Diseños Estructurales Ltda., founded in 1994 by a research group from the Universidad Nacional dedicated to the development of new steel technologies applicable in Colombia. This firm is managed by a Mexican engineer (Luis Garza) and has permanent contact with other Mexican design and engineering consulting firms in the area of structures.

![Figure 4.34 Structural Steel Buildings in Medellín](Source: Garza, 1997a)

4.8.3.3 Construction firms specializing in steel structures

Currently, there are about ten firms specializing in construction of steel structures in Colombia. In Bogotá some of these firms are foreign (General Steel Structures from Ecuador and Van Dam and Pellizari from Venezuela). Indigenous firms in Bogotá include Tecmo, Vargas Rubiano and SAC. In Medellín, Industrias del Hierro and Procił specialize in structural steel buildings erection. In Cali, Intermecánica and Estrumetal have started to build a few projects. Most of the indigenous firms are former designers and builders of steel trusses for warehouse roofing and manufacturers of steel beams for bridges.

4.8.3.4 Technical characteristics of currently used systems

Three clearly distinct systems are being used in Colombia nowadays. One is being introduced mainly in Bogotá (the capital), by Ecuadorian contractors. A second one is also being introduced
in Bogotá by Venezuelan firms. The third one, used in Bogotá and Medellín, is being introduced by “Soluciones y Diseños Estructurales”, which has close ties to “Industrias del Hierro”, a steel structures contractor. This second system is strongly influenced by steel practices in Mexico.

4.8.3.4.1 Ecuadorian system

In the Ecuadorian system, common in Bogotá, many of the beams are actually welded trusses, which are much lighter but require more welding labor on the shop. This design is economically rational because in Ecuador labor is even cheaper than in Colombia. As a consequence, although savings in steel are achieved, fire protection becomes more expensive. It is also argued that these structures are less safe, because if only one component fails, the whole beam or column fails (isostaticity). This system has been introduced by “General Steel Structures” (an Ecuadorian firm) and uses welded joints as opposed to bolted joints.

4.8.3.4.2 Mexican system

Uses almost the same technology of the US, but with some improvements in the column-beam moment-resistant joints introduced after the experiences of Mexico City’s earthquakes of 1957 and 1985, and Northridge earthquake of 1994. The main characteristics of this system is that principal and secondary beams are put in place screwed (not welded) to the joints in the columns. All the welding is done previously in shop under controlled conditions. This allows faster assembly on-site, as opposed to the Ecuadorian system to be discussed below. Also, the quality of the welding is controlled on the factory.

4.8.3.4.3 Venezuelan system

Venezuelan contractors use a somewhat more advanced system with rolled elements produced at very competitive prices by a large Venezuelan steel manufacturing company (Sidor). One advantage for the Venezuelan contractors is the long tradition in petrochemical industries in this country, which has created a broader base of qualified welders. One application of the Venezuelan system is the “Velódromo Luis Carlos Galán” (cycling stadium).
Chapter 5
ANALYSIS OF INNOVATIONS

The present chapter analyzes the data collected in Chapter 4 (Implementation and Diffusion of Innovations) using the concepts and models presented in Chapter 2 (Literature Review). The tables of this chapter present the characteristics of the eight innovations that are relevant to the theoretical models.

Table 5.1 classifies the innovations according to the model of Afuah and Bahram. In Table 5.1, in the cases indicated by an asterisk (*), the innovation requires an entirely new firm in the Value Chain to replace the established one. It could be argued that, in this case, the innovation should be classified as radical for the firm in the Value Chain being replaced. For example, Structural Steel Buildings could be classified as “radical” for subcontractors, because for subcontractors of reinforced concrete (the technology being replaced by steel structures), this innovation is radical. So radical, in fact, that entirely new subcontractors have to replace the existing ones. Notice that for the steel structures erector, this technology is its everyday job, and is not even an innovation. The model by Afuah and Bahram overlooks this important issue, which is analyzed in detail by other authors (Christensen and Rosenbloom, 1995).

Generally speaking, the level of difficulty for innovation advances from incremental innovations (the easiest ones to adopt) to modular, architectural, systems, and ends with radical innovations (the most difficult). Based on this argument, Table 5.1 indicates that some of the innovations (e.g. Outinord, Prestressed slabs and beams, Tilt-Up and Structural Steel Buildings) present, in general, more difficulties for more firms in the value chain that others (e.g. Project Control software, Engineered concrete masonry, Concrete Block Paving, and Hand-portable panels.)

This analysis of “implicit difficulty” of the innovation itself has to be complemented later with Teece’s analysis of benefits distribution, appropriability of benefits and complementary assets (Tables 5.3, 5.4, 5.5, 5.6 and 5.7). When discussing these issues, it must be clarified what type of firm in the value chain is being analyzed. It is not the same to discuss the appropriation of benefits by the builder and by other firms, although, in general, the benefits for the builder are expected to be of greater importance in the diffusion of innovations, because in many cases it is the builder...
who ultimately chooses whether or not to adopt the innovation. Even in cases when the decision to adopt a certain innovation is made by the owner or developer of the project, the builder can still exert significant influence in the decision (e.g., charging higher prices for its services).

In this chapter, the concept of “promoter” will be used. A “promoter” is an entity or firm within or outside the value chain that leads the first use of the innovation and is responsible for diffusing it further among new users. The “promoter” is different from the first user, as the latter is usually led by the promoter to adopt the innovation. Also, the promoter entity needs not be the originator of the innovation. For example, cement producers—“suppliers”, in the value chain and in the Afuah and Bahram’s analysis—can intensely promote the adoption of Concrete Block Pavers, which is a technology that originated in Europe. It is clear that the promoter in this case is neither the first user nor the originator of the innovation. Table 5.2 indicates which firm is the promoter for each of the eight innovations.

### Table 5.1 Classification of the Innovations. Afuah and Bahram’s model

<table>
<thead>
<tr>
<th>Innovation</th>
<th>Innovation as seen by</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Builder</td>
</tr>
<tr>
<td>Outinord System</td>
<td>System</td>
</tr>
<tr>
<td>Project Control Software (SAO)</td>
<td>Modular</td>
</tr>
<tr>
<td>Prestressed slabs and beams</td>
<td>Modular</td>
</tr>
<tr>
<td>Engineered Concrete Masonry</td>
<td>Architectural</td>
</tr>
<tr>
<td>Concrete Block Paving (CBP)</td>
<td>Modular</td>
</tr>
<tr>
<td>Tilt-Up</td>
<td>Radical</td>
</tr>
<tr>
<td>Hand-portable panels</td>
<td>System</td>
</tr>
<tr>
<td>Structural Steel Buildings</td>
<td>Radical</td>
</tr>
</tbody>
</table>

### Table 5.2 Promoters of each innovation

<table>
<thead>
<tr>
<th>Innovation</th>
<th>Promoter</th>
<th>Role in the Value Chain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outinord formwork system</td>
<td>Outinord Group (France)</td>
<td>Manufacturer</td>
</tr>
<tr>
<td>Project Control Software (SAO)</td>
<td>Servicios y Asesoria en Sistemas</td>
<td>Manufacturer (of software)</td>
</tr>
<tr>
<td>Prestressed slabs and beams</td>
<td>AREA Ingenieros Consultores</td>
<td>Designer</td>
</tr>
<tr>
<td>Engineered Concrete Masonry</td>
<td>ICPC - Cement producers</td>
<td>Supplier</td>
</tr>
<tr>
<td>Concrete Block Paving (CBP)</td>
<td>ICPC - Cement producers</td>
<td>Supplier</td>
</tr>
<tr>
<td>Tilt-Up</td>
<td>ConConcreto</td>
<td>Builder</td>
</tr>
<tr>
<td>Hand-portable panels</td>
<td>PSI</td>
<td>Builder</td>
</tr>
<tr>
<td>Structural Steel Buildings</td>
<td>Soluciones y Diseños Estructurales</td>
<td>Designer*</td>
</tr>
</tbody>
</table>

(*) Working in close alliance with “Industrias del Hierro”, a steel contractor
Teece’s concepts are used to elaborate Tables 5.3, 5.4, 5.5, 5.6 and 5.7. From Table 5.3, it can be concluded that Prestressed slabs and beams, Tilt-Up and Structural Steel Buildings offer more types of benefits (with less initial costs) for the promoters than the rest. This does not mean that other innovations are necessarily less attractive for the promoters: some individual benefits listed in Table 5.3 can be more significant than others. In the case of CBP, for example, most of the benefits are in the strategic area, but are important enough for the association of cement producers to find new uses for their product and expand their market.

Table 5.4 presents the benefits from innovations for the builders themselves. Some important observations from Tables 5.3 and 5.4 are listed below.

- In all eight innovations, there were both short and long term revenues for the promoters. This is typical of innovations that are meant to be repetitive (by diffusion among several firms) rather than one-time solutions for a particular problem.

- Although the benefits for the promoters are not necessarily aligned with the benefits for the builders, the three innovations with more benefits for the builders (prestressed slabs and beams, tilt-up and structural steel buildings) are also the same three with more benefits for the promoters. This can be more than a mere coincidence, and hint at a high potential for future diffusion of these three relatively new technologies for the Colombian construction industry.

- Structural Steel Buildings is the innovation that offers the most benefits for both promoters and builders.

In general, promoters benefit from inter-firm diffusion, while builders benefit from intra-firm diffusion. Limited inter-firm diffusion can, in fact, be desirable for the builder in order to keep competitive advantages with respect to other builders that have no access to the innovation.
### Table 5.3 Benefits and Costs from the Innovations for the Promoters

<table>
<thead>
<tr>
<th>Innovation</th>
<th>Promoter</th>
<th>Role in the Value Chain</th>
<th>Initial production investment</th>
<th>Short term revenues?</th>
<th>Long term revenues?</th>
<th>Benefits from diffusion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Relevance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Strategic</td>
</tr>
<tr>
<td>Outinord</td>
<td>Outinord Group (France)</td>
<td>Manufacturer</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Project Control Software (SAO)</td>
<td>Servicios y Asesoria en Sistemas</td>
<td>Manufacturer</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Prestressed slabs and beams</td>
<td>AREA Ingenieros Consultores</td>
<td>Designer</td>
<td>Moderate</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Engineered Concrete Masonry</td>
<td>ICPC - Cement producers</td>
<td>Supplier</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Concrete Block Paving (CBP)</td>
<td>ICPC - Cement producers</td>
<td>Supplier</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Tilt-Up</td>
<td>ConConcreteo</td>
<td>Builder</td>
<td>Low</td>
<td>Yes**</td>
<td>Yes**</td>
<td>Yes</td>
</tr>
<tr>
<td>Hand-portable panels</td>
<td>PSI</td>
<td>Builder</td>
<td>High</td>
<td>Yes**</td>
<td>Yes**</td>
<td>No</td>
</tr>
<tr>
<td>Structural Steel Buildings</td>
<td>Soluciones y Diseños Estructurales</td>
<td>Designer*</td>
<td>Moderate</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* Working in close alliance with “Industrias del Hierro”, a steel contractor  
** In the form of cost savings

### Table 5.4 Benefits and Costs from the Innovations for the Builders

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Outinord</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes**</td>
</tr>
<tr>
<td>Project Control Software (SAO)</td>
<td>Moderate</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Prestressed slabs and beams</td>
<td>Low</td>
<td>Yes*</td>
<td>Yes*</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Engineered Concrete Masonry</td>
<td>Low</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Concrete Block Paving (CBP)</td>
<td>Moderate</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes**</td>
</tr>
<tr>
<td>Tilt-Up</td>
<td>Low</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes**</td>
</tr>
<tr>
<td>Hand-portable panels</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes**</td>
</tr>
<tr>
<td>Structural Steel Buildings</td>
<td>Low</td>
<td>Yes*</td>
<td>Yes*</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* Depends on the span of beams  
** To the extent that wooden formwork are significantly reduced or eliminated
It is interesting to note that the more “difficult” innovations (from Table 5.1) are also those that offer more overall benefits for both promoters and builders, which seems to contradict some arguments by Afuah and Bahram. This apparent paradox can be explained by the fact that difficult-to-adopt innovations can also be difficult to imitate or offer greater rewards (positive risk-reward relationship). A closer look at the issue of appropriability and distribution of benefits should explain this issue more clearly. Table 5.5, built using some of the concepts of Teece on profiting from innovations, reveals that this is exactly the case: Prestressed slabs and beams, Tilt-Up and Structural Steel Buildings have, in general, more positive appropriability factors than the other innovations studied. Other innovations with good appropriability of benefits are Outinord and SAO.

Legal protection, as Table 5.5 indicates, is in general very weak in Colombia. Intellectual property rights are not as clear as in the US, and law enforcement is weak. Innovators and adopters in Colombia must then resort to other forms of appropriating benefits, such as picking difficult-to-imitate innovations or bet on technologies in which they can achieve some differentiation from competition, as is the case with those innovations in pre-paradigmatic stage of development.

<table>
<thead>
<tr>
<th>Innovation</th>
<th>Promoter</th>
<th>Knowledge</th>
<th>Legal Protection</th>
<th>Difficulty to imitate</th>
<th>Paradigmatic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Codified</td>
<td>Tact</td>
<td>Moderate</td>
<td>Weak</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outinord</td>
<td>Outinord Group (France)</td>
<td>✓</td>
<td>Moderate</td>
<td>Difficult</td>
<td>Yes</td>
</tr>
<tr>
<td>Project Control Software (SAO)</td>
<td>Servicios y Asesoría en Sistemas</td>
<td>✓</td>
<td>Moderate</td>
<td>Difficult</td>
<td>Yes</td>
</tr>
<tr>
<td>Prestressed slabs and beams</td>
<td>AREA Ingenieros Consultores</td>
<td>✓</td>
<td>Weak</td>
<td>Moderate</td>
<td>No*</td>
</tr>
<tr>
<td>Engineered Concrete Masonry</td>
<td>ICPC - Cement producers</td>
<td>✓</td>
<td>Weak</td>
<td>Moderate</td>
<td>Yes</td>
</tr>
<tr>
<td>Concrete Block Paving (CBP)</td>
<td>ICPC - Cement producers</td>
<td>✓</td>
<td>Weak</td>
<td>Easy</td>
<td>Yes</td>
</tr>
<tr>
<td>Tilt-Up</td>
<td>ConConcreto</td>
<td>✓</td>
<td>Weak</td>
<td>Difficult</td>
<td>Yes</td>
</tr>
<tr>
<td>Hand-portable panels</td>
<td>PSI</td>
<td>✓</td>
<td>Weak</td>
<td>Moderate</td>
<td>Yes</td>
</tr>
<tr>
<td>Structural Steel Buildings</td>
<td>Soluc. y Diseños Estructurales</td>
<td>✓</td>
<td>Weak</td>
<td>Difficult</td>
<td>No**</td>
</tr>
</tbody>
</table>

(*) Some builders in Colombia use voided slabs, other flat slabs
(**) The advantages and disadvantages of the system imported from Ecuador (full welding) vs. the Venezuelan and Mexican system are still not clear

Not everybody benefits equally from innovations. The distribution of benefits differs among the firms in the Value Chain, and incumbent firms can lose ground to newcomers or be debilitated from the introduction of innovations. Table 5.6 lists the winners and losers from the eight innovations.
Notice how the builder is always one of the winners with the introduction of the innovation. This contrasts with findings by Ventre (1979) and Quigley (1982), who sustain that builders are reluctant innovators because they receive no apparent benefits. This finding emphasizes the previous point that the benefits for the builder are, in general, of greater importance in the diffusion of innovations. Also, in the column of firms that lose with the innovation, we find mostly firms that are excluded from the new Value Chain. Again, these are firms for which the innovation was so radical that they simply cannot play in the new value chain.

Table 5.6 Distribution of benefits. Winners and Losers in the Value Chain

<table>
<thead>
<tr>
<th>Innovation</th>
<th>Winners</th>
<th>Losers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outinord</td>
<td>Formwork manufacturer</td>
<td>Raw wood panel manufacturers</td>
</tr>
<tr>
<td></td>
<td>Builder</td>
<td>Clay brick producers</td>
</tr>
<tr>
<td></td>
<td>Developer</td>
<td></td>
</tr>
<tr>
<td>Project Control Software (SAO)</td>
<td>Software producer</td>
<td>Other software producers</td>
</tr>
<tr>
<td></td>
<td>Builder</td>
<td>Public contractors not SAO-compliant</td>
</tr>
<tr>
<td></td>
<td>Developer</td>
<td></td>
</tr>
<tr>
<td>Prestressed slabs and beams</td>
<td>Cable and anchorings producers</td>
<td>Reinforced concrete structural designer</td>
</tr>
<tr>
<td></td>
<td>Prestressed concrete Structural designer</td>
<td>Reinforcing bar producers</td>
</tr>
<tr>
<td></td>
<td>Builder</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Developer</td>
<td></td>
</tr>
<tr>
<td>Engineered Concrete Masonry</td>
<td>Concrete Block Producers</td>
<td>Architects</td>
</tr>
<tr>
<td></td>
<td>Cement producers</td>
<td>Clay brick manufacturers</td>
</tr>
<tr>
<td></td>
<td>Builders</td>
<td>Cement plastering labor</td>
</tr>
<tr>
<td></td>
<td>Developers</td>
<td></td>
</tr>
<tr>
<td>Concrete Block Paving (CBP)</td>
<td>Cement producers</td>
<td>Asphalt producers</td>
</tr>
<tr>
<td></td>
<td>Developers (private and communities)</td>
<td>Asphalt subcontractors</td>
</tr>
<tr>
<td></td>
<td>Builder</td>
<td></td>
</tr>
<tr>
<td></td>
<td>New CBP manufacturers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Precasters now producing CBP</td>
<td></td>
</tr>
<tr>
<td>Tilt-Up</td>
<td>Builder</td>
<td>Clay brick producers</td>
</tr>
<tr>
<td></td>
<td>Lifting equipment owner</td>
<td>Concrete Block producers</td>
</tr>
<tr>
<td></td>
<td>Cement producers</td>
<td>Labor</td>
</tr>
<tr>
<td>Hand-portable panels</td>
<td>Builder</td>
<td>Wooden formwork manufacturers</td>
</tr>
<tr>
<td></td>
<td>Panels manufacturer</td>
<td>Clay brick producers</td>
</tr>
<tr>
<td></td>
<td>Developer</td>
<td></td>
</tr>
<tr>
<td>Structural Steel Buildings</td>
<td>Builder</td>
<td>Cement producers</td>
</tr>
<tr>
<td></td>
<td>New labor (welders)</td>
<td>Old labor (masons)</td>
</tr>
<tr>
<td></td>
<td>Structural Steel Designer</td>
<td>Reinforced concrete designers</td>
</tr>
<tr>
<td></td>
<td>Foreign Steel producers</td>
<td>Reinforcing bar producers</td>
</tr>
<tr>
<td></td>
<td>Specialty subcontractors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Suppliers of complementary products</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Dry Walls, Steel decks, etc)</td>
<td></td>
</tr>
</tbody>
</table>

From Table 5.7 it appears that firms promoting Outinord, SAO software, CBP, Tilt-Up and Structural Steel Buildings have more complementary assets to profit from the innovations than the rest. This reinforces the case for the successful diffusion of Tilt-Up and Structural Steel Buildings, and weakens slightly the case for Prestressed slabs and beams, for which the promoter (the
designer) has nothing but his knowledge as complementary asset. Table 5.7 also reveals that the Outinord formwork manufacturer can compensate for the lack of appropriability of benefits with its complementary assets.

<table>
<thead>
<tr>
<th>Table 5.7 Complementary Assets under promoter’s ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovation</td>
</tr>
<tr>
<td>Outinord</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Project Control Software (SAO)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Prestressed slabs and beams</td>
</tr>
<tr>
<td>Engineered Concrete Masonry</td>
</tr>
<tr>
<td>Concrete Block Paving (CBP)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Tilt-Up</td>
</tr>
<tr>
<td>Hand-portable panels</td>
</tr>
<tr>
<td>Structural Steel Buildings</td>
</tr>
</tbody>
</table>

So far, the analysis reveals that there are three “strong” innovations in the group: Prestressed slabs and beams, Tilt-Up and Structural Steel buildings. These are all innovations with significant and appropriable benefits for their promoters and the builders adopting them, and for which there exist complementary assets that can reinforce the strategic position for companies to profit from them.

One of these “strong” innovations (Structural Steel buildings) is still in its earlier stages of diffusion, and it is not possible to verify whether or not our predictions of its strong potential for successful diffusion will hold. The other two “strong” innovations (Prestressed slabs and beams and Tilt-Up) were introduced several years ago, and their use declined after reaching some level of diffusion, instead of having grown continuously. There are also some “weaker” innovations that have been introduced into the country and that have achieved successful diffusion. These two facts indicate that there are other important factors we have been ignoring.
Tables 5.8, 5.9 and 5.10 present some of the factors discussed by Meyer and Goes (1988) in their study of innovations in the health care industry, but this time translated to the context of the residential construction industry. It appears that these “contextual” factors are the piece of analysis that is missing. For the case of CBP, for example, Tables 5.8 and 5.9 indicate very favorable factors such as dominant promoter position in the market, strong governmental influence and high academic involvement in the diffusion of information. Also, for some innovations that have already reached successful diffusion, it appears that permanent contact with sources of information abroad has a positive effect (Table 5.9). If it is accepted that this new set of factors does have an influence, it should be no surprise, then, that CBP has been such a success in Colombia. Similarly, SAO software has been positively influenced by moderate to extensive involvement of government and academic institutions. In the same line of thought, Structural Steel Buildings see reinforced again its feasibility as a successful innovation given its positive contextual factors from Tables 5.8 and 5.9, while for Prestressed Slabs and Beams there could be again diffusion problems if more support does not come from the side of academic institutions or professional associations. In the particular case of Tilt-Up diffusion in residential applications, the dissemination of knowledge is critical, since residential builders tend to be less sophisticated than the large firm currently using Tilt-Up for industrial applications. In Table 5.10, “Risk of use” depends on the degree of damage associated with the failure of the innovations. For the case of CBP and SAO, this risk is very low, while for Prestressed slabs and beams, Tilt-Up and Structural Steel buildings the consequences of failures can be catastrophic. The high degree of hyperstaticity of bearing walls systems (Outinord, Engineered Concrete Masonry and Hand-portable panels) reduces the overall structural risks if any particular component fails.

<table>
<thead>
<tr>
<th>Innovation</th>
<th>Builder's size relative to competitors</th>
<th>Promoter's size Relative to competitors</th>
<th>Regulatory influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outinord</td>
<td>Large</td>
<td>Large</td>
<td>Strong</td>
</tr>
<tr>
<td>Project Control Software (SAO)</td>
<td>Medium</td>
<td>Medium</td>
<td>Moderate</td>
</tr>
<tr>
<td>Prestressed slabs and beams</td>
<td>Medium</td>
<td>Medium</td>
<td>Moderate</td>
</tr>
<tr>
<td>Engineered Concrete Masonry</td>
<td>Medium to large</td>
<td>Large</td>
<td>Strong</td>
</tr>
<tr>
<td>Concrete Block Paving (CBP)</td>
<td>Small</td>
<td>Large (regional monopolies)</td>
<td>Moderate</td>
</tr>
<tr>
<td>Tilt-Up</td>
<td>Large</td>
<td>Very Large</td>
<td>Little</td>
</tr>
<tr>
<td>Hand-portable panels</td>
<td>Medium to large</td>
<td>Large</td>
<td>Strong</td>
</tr>
<tr>
<td>Structural Steel Buildings</td>
<td>Medium</td>
<td>Medium</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
### Table 5.9 Contextual attributes for promoter firm

<table>
<thead>
<tr>
<th>Innovation</th>
<th>Size of promoter company</th>
<th>Information dissemination</th>
<th>Contact with Information from abroad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outinord</td>
<td>Large</td>
<td>Limited</td>
<td>Limited</td>
</tr>
<tr>
<td>Project Control Software (SAO)</td>
<td>Medium</td>
<td>Extensive</td>
<td>Extensive</td>
</tr>
<tr>
<td>Prestressed slabs and beams</td>
<td>Medium</td>
<td>Limited</td>
<td>Limited</td>
</tr>
<tr>
<td>Engineered Concrete Masonry</td>
<td>Large</td>
<td>Extensive</td>
<td>Moderate</td>
</tr>
<tr>
<td>Concrete Block Paving (CBP)</td>
<td>Large</td>
<td>Very Extensive</td>
<td>Very Extensive</td>
</tr>
<tr>
<td>Tilt-Up</td>
<td>Very Large</td>
<td>Limited</td>
<td>Limited</td>
</tr>
<tr>
<td>Hand-portable panels</td>
<td>Large</td>
<td>Limited</td>
<td>Limited</td>
</tr>
<tr>
<td>Structural Steel Buildings</td>
<td>Medium</td>
<td>Extensive</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

### Table 5.10 Innovation attributes

<table>
<thead>
<tr>
<th>Innovation</th>
<th>Risk of use</th>
<th>Skill requirements for builder</th>
<th>Compatibility with builder's previous</th>
<th>Observability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outinord</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Project Control Software (SAO)</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Prestressed slabs and beams</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Engineered Concrete Masonry</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Concrete Block Paving (CBP)</td>
<td>Low</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Tilt-Up</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Hand-portable panels</td>
<td>Moderate</td>
<td>Low</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Structural Steel Buildings</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Very High</td>
</tr>
</tbody>
</table>
Chapter 6

CONCLUSIONS

6.1 Diffusion of Innovations in Developing countries

From the analysis in Chapter 5, it can be argued that government construction regulations in Colombia have played a positive role in fostering innovations. For example, the seismic code of 1984 and its update of 1998 have promoted the use of structural masonry as a viable alternative to moment-resistant frames, and have fostered the use of some formwork systems that were slowly introduced before. One possible reason that regulations in Colombia have had this positive effect is the high dispersion (and in general, lower level) of technical knowledge in Colombia. For example, prior to the introduction of the CCCSR in 1984, many structural designers applied “bits and pieces” of the European and American seismic construction codes to the same project, without much guidance beyond their own criteria and judgement. The new CCCSR unified concepts and criteria, and incorporated the best of technical knowledge existing worldwide at this time. In this case, a new regulation, rather than an obstacle, served as an unifier of scattered knowledge and fostered the implementation of new technologies that, under other circumstances, engineers would have been reluctant to adopt due to a lack of knowledge. The government, however, is not the only one that can act as an unifier of knowledge. It has been presented in this thesis that large professional or producer associations can play a similar role with excellent results, as it has been the case with the ICPC and the diffusion of CBP.

It is sometimes argued that the effect of regulations is negative in the US, where the existence of large, non-governmental professional associations, which act as repositories of broad ranges of construction knowledge (e.g., ASTM, ACI, PCA, etc.) reduces the need for governmental, centralized knowledge. In fact, the construction sector in the US is characterized for its diversity of building regulations, so it could be said that what happens is that the “centralized knowledge” in private hands is scattered by the government, exactly the opposite of the conditions in Colombia.
In other developing countries under similar circumstances as Colombia, the effect of governmental regulations can be similar to that in Colombia.

Regarding other means by which government can influence residential construction innovations, the Colombian government can play “catch up” in construction technology without having to spend directly in R&D through national universities or government institutions, but rather providing R&D support for technologies where the government has strong procurement interests (Nelson and Langlois, 1983). This has already been the case with EPM and other Medellín municipal institutions that have adopted database standards based on the SAO software, and have provided diffusion support to it. In the case of CBP, there has also been a clear government interest in adopting the technology to the Colombian environment, which has been reflected in training and diffusion directly or indirectly supported by governmental entities. It should be noticed that basic R&D is rare in Colombia and in most developing countries, and that what is understood in this paragraph by “R&D support” is mostly expenditures in education and promotion of technologies. Another interesting experiment, not considered by Nelson and Langlois (1983), was the “open bidding system” used by the ICT in the 1970s, by which the ICT specified only the area and quantity of housing units for a certain project and the bidders were left free to propose the optimum construction system. The recent road and infrastructure privatization programs started after the “apertura” policies in 1990s somehow resemble this old idea of letting the private sector find novel and efficient technologies and providing it with adequate legal protection in order to let it reap the benefits. These policies have already led to the introduction of interesting innovations in large public infrastructure projects, and the question now is how to re-implement the idea in residential construction.

6.2 Structural Steel Buildings in Colombia. A look at the future

From the set of eight innovations studied, Structural Steel Buildings is the one that started its diffusion process most recently, and it is interesting to apply the lessons learned from the analysis of the diffusion of the other seven to this recent case.

The analysis in Chapter 5 revealed that Structural Steel buildings is an innovation with many favorable factors despite its difficult adoption at all levels of the value chain. It provides both
promoters and builders with significant benefits, those benefits are appropriable, the promoter has complementary assets to accompany the diffusion of the innovation, and the contextual attributes are also favorable. All these factors have already been proven to exert significant influence in the other seven residential construction innovations analyzed. It appears, then, that Structural Steel Buildings is an innovation with very good chances of reaching widespread diffusion in the Colombian residential construction industry.

Some adverse circumstances, however, can still affect the successful diffusion of this promising innovation. The recent entry of giant foreign cement producers such as Cemex and Lafarge in Colombia can result in a price war with the local producers, and this sole factor can override most of the positive factors previously discussed if the cement price reductions are dramatic. It can be argued, however, that if a price war leads to a dominant single cement producer, then cement prices would raise again, and the economic equation would be favorable again for Structural Steel Buildings.

Some "weak" factors for Structural Steel Buildings, already analyzed in Chapter 5, can still be improved. Dissemination of information among users can be intensified, and there is always room for more intense involvement from academic institutions. Also, as larger builders start to adopt this innovation, the confidence on the system will increase among both builders, developers, and occupiers.

6.3 Theoretical findings

The process of applying the innovation models to the actual innovations was not straightforward in most of the cases. Each individual innovation has its own peculiarities, and it was apparent during this research that it was not possible to cover all the important elements under one single model. This is the reason why the approach of the present research includes several models, to take advantage of the varied and rich nature of the empirical data available for each innovation. It has been apparent from the analysis that this approach from several fronts reveals a richer picture of analysis than if it had been limited to a single model.
Some theoretical findings were encountered during the analysis. The concept of "promoter", for example, proved to be of crucial importance in the issues of benefits appropriability and inter-firm diffusion. Afuah and Bahram (1995), for instance, do not include explicitly this player in their hypercube of innovation.

Another important finding was that, since residential construction value chains are actually "webs" of numerous firms playing as suppliers, manufacturers, etc., it was not straightforward to classify the innovations for each level of the value chain: for two different suppliers, for example, the same innovation can be radical for one and incremental for the other, in which case a shift from one supplier to the other is very likely to occur. In this instance, the level of implicit difficulty of the innovation for the entire value chain depends on which specific firms are considered.

Perhaps the more interesting finding was that contextual factors appear to be of greater importance than the difficulty of the innovation itself. It was analyzed how the level of "implicit difficulty", according to the hypercube of innovation, could in some cases be a positive factor in the successful diffusion of innovations, instead of being an obstacle as Afuah and Bahram predict. One hypothesis is that the negative risk-reward relationship could lead to greater benefits appropriation from firms that decide to adopt the innovation despite its difficulty.

6.4 Areas of future research

Some ideas for future research have already been hinted throughout this thesis. Those considered more viable are listed below.

6.4.1 Role of promoter in inter-firm diffusion

The present research highlighted that the promoter, as a firm related to or in the value chain, played an important role in early inter-firm diffusion. Some research already exists in the role of individuals within firms (e.g., roles of gatekeeper and champion, Tatum (1987)), and parallels can be drawn between the two concepts.
6.4.2 Location of the promoter in the value chain

Using Teece's concepts of benefits appropriation, it could be possible to determine a priori which firm in the value chain has both the interest and the capacity to introduce construction innovations, given some characteristics of the innovation itself and of the value chain firms. For such a purpose, much more extensive data would be needed than that available for the present research.

6.4.3 Relationship between the speed of diffusion versus profitability

It was interesting to note that most of the people interviewed, who played a central role in the decision-making process and were actually using the innovations, could estimate only roughly the cost savings being achieved. It would be interesting to explore whether the actual profitability from innovations is important in the process of early inter-firm diffusion, when the savings are still not clear for the adopters, and contrast this against other factors being considered in the decision-making process. Mansfield (1989) has already explored the issue in industries different to residential construction.

6.4.4 Include process innovations in the analysis

As stated in Chapter 3, all eight innovations studied were product innovations. A similar study can be done for process innovations, which are much more common but also less visible in residential construction.
REFERENCES


Arango, Jesús Humberto (1998). Telephone interview and correspondence. Medellín (Colombia)


CAMACOL (1996). “Informe Económico.” CAMACOL (Cámara Colombiana de la Construcción), 20 (3), Bogotá (Colombia)

CAMACOL (1997). “Informe Estadístico.” CAMACOL (Cámara Colombiana de la Construcción), 21 (1), Bogotá (Colombia)


Cárdenas, Mauricio and Bernal, Raquel (1997). “La Construcción en Colombia, Auge y Crisis, Causas y Consecuencias.” CAMACOL (Cámara Colombiana de la Construcción), 21 (1), Bogotá (Colombia)


Gómez, Hernando José (1996). “El Financiamiento a la Construcción.” CAMACOL (Cámara Colombiana de la Construcción), 20 (3), Bogotá (Colombia)


Madrid, Germán Guillermo (1994). “Factors Affecting the Development of Concrete Block Paving in Developing Countries, Based on the Latin-American Experience.” *Proceedings of the International Masonry and Paving Convention*, Sandton (South Africa)


Naranjo, Ricardo (1993). “Construcción de 100,000 Travesas de Concreto, Prefabricadas con Concreto de Alta Resistencia, Pretensadas y Curadas al Vapor.” *Simposio Panamericano sobre Construcciones en Mampostería Estructural en Zonas Sísmicas*, Sociedad Colombiana de Ingenieros, Asociación Colombiana de Ingeniería Sísmica, Bogotá (Colombia)


Restrepo, Héctor (1981). “Evolución de los Sistemas Constructivos en Colombia en la Última Década.” *Curso sobre Construcción en Muros Estructurales*, Instituto Colombiano de Productores de Cemento, Bogotá (Colombia)


Tilt-up Concrete Association (1998). Internet webpage (http://www.tilt-up.org)


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