AN EXPLORATION OF INTEGRALITY IN PROJECT PRODUCTION AND ITS FINAL OUTCOME: THE MOBILE PRODUCTION CELLS

by

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“It is imprudent to claim a complete understanding of a human phenomenon, since we are most likely just scratching the surface, using only one or few of the possible different perspectives. Having recognized this, I hereby present to you my view of project production.”

Antonio Nunes de Miranda Filho

I dedicate this thesis to the Vassalo family from Lisbon (Portugal): José Augusto, Arlete, Mafalda, Amelie, and especially Vânia Patricia. Words cannot express my feelings of love and gratitude for everything you have done for me during all these years. I deeply thank you all.

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ABSTRACT

A flexible production competence is a key internal dimension of competition for any production system dealing with variations caused by both internal and external sources. In construction projects, the development of autonomous, multi-skilled teams functioning like mobile production cells has received strong endorsement as a system flexibility type that enhances the achievement of project goals by reducing tradeoffs between competitive criteria. However, there is some confusion among academics and practitioners about what is truly meant by the term "mobile production cell". In fact, very often it is described as being just a work arrangement in which a group of workers is assigned to perform an entire set of closely affiliated tasks. This narrow perspective has been influenced by the adoption of a theoretical framework more appropriate for manufacturing operations and by the lack of understanding that, in any context, the emergence of a flexible competence is the result of not one but many internal adjustments in the content of production strategy. The mobile production cell is no different, since its implementation requires changes in system design and operation that defy basic assumptions within the ruling construction management theory. Thus, besides an extensive literature review, this dissertation builds on empirical research in the construction industry to study the following research questions: *"What are the changes that allow the emergence of real mobile cells?"*, *"How does this true best practice relate to other successful renewal initiatives in project production?"* and *"How does this system flexibility type contribute to the performance of the project production system as whole?"*. It is argued that the initiatives fostering effective cell functioning at the level of operations share a common rationale with those improving interactions in the higher levels of project organizations: integrality and simplicity. This is a particularly promising insight that leads to seeing the mobile cell concept as part of a larger paradigm shift. Because of this, the dissertation begins with a broad literature review to understand why integrality and simplicity, in contrast to complexity, are intuitively guiding the renewal initiatives in project production. This is followed by the proposition of an extended view on the content of production strategy so as to create awareness of the tangible and intangible attributes that impact the workings of an integral project production model and the emergence of its competences. Case studies involving a geotechnical engineering firm and firms that specialize in high rise buildings were also used and intentionally structured to examine different aspects of cell operation. The case studies revealed the impacts that this system flexibility type has on different control and buffer types. They also provided insight into different cell building enablers – policies, production practices, strategic choices, assumptions and other factors – adopted in each context. But more than that, they confirmed the existence of consistent patterns between the different initiatives, permitting the discipline of integrality and simplicity to be summarized in a small set of principles. This allowed to articulate a theoretical foundation of integrality and simplicity in project production and to thereby characterize the discipline of mobile cells through a proper underlying theory.

Keywords: mobile production cell, best practice, flexibility, organizational integrality.

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RESUMO

Em qualquer sistema de produção, a implementação de uma estratégia de flexibilidade significa desenvolver uma competência para lidar com as variações causadas por fontes internas e externas. Na construção civil, o desenvolvimento de equipas autónomas e polivalentes a funcionarem como células de produção móveis têm ganho crescente reconhecimento por ser um mecanismo de flexibilidade capaz de melhorar o cumprimento das metas nas obras. Entretanto, investigadores e profissionais da área discordam sobre o real significado do termo "célula de produção móvel". Frequentemente, esta é descrita como sendo apenas um grupo de trabalhadores incumbido de executar um conjunto de tarefas com características técnicas similares. Esta perspectiva pouco abrangente tem sido influenciada pela adopção de fundamentos teóricos mais apropriados para operações de manufactura e pela falha em compreender que, em qualquer contexto, o surgimento de um mecanismo de flexibilidade decorre de vários ajustes internos na estratégia de produção. O mesmo é válido para a célula de produção móvel, cuja implementação requer mudanças na estruturação e gestão do sistema de produção. Algumas destas mudanças inclusive obrigam a uma reavaliação dos paradigmas por detrás do tradicional modo de gestão de obras. Assim, através de uma ampla revisão da literatura e de uma investigação empírica na indústria da construção, esta dissertação busca responder as seguintes questões: *"Quais mudanças permitem o surgimento de verdadeiras células de produção móveis?"*, *"Qual é a relação entre as células móveis e outras "melhores práticas" desenvolvidas para a realização dos empreendimentos?"* e *"Como este mecanismo de flexibilidade contribui para o desempenho geral do sistema de produção?"*. Nesta dissertação, argumenta-se que a busca pela integralidade e simplicidade é o racional comum por detrás das várias iniciativas voltadas para a melhoria das interacções na realização das obras. Isto implica visualizar o conceito de célula de produção móvel como parte de uma mudança ainda maior a ocorrer no sistema produtivo. Diante disto, a dissertação inicia com uma extensa revisão da literatura para entender a razão pela qual a busca pela integralidade e simplicidade está a guiar intuitivamente as iniciativas para a melhoria da execução das obras. Em seguida, propõe-se uma visão mais ampla do conteúdo de uma estratégia de produção como forma de entender os aspectos tangíveis e intangíveis que afectam tanto o funcionamento de um modelo produtivo como também o surgimento de competências no mesmo. Com isto, estudos de caso envolvendo empresas de construção e uma empresa de geotecnia foram intencionalmente estruturados e realizados para a análise dos diferentes aspectos no funcionamento das células. Os estudos de caso revelaram os impactos que a implementação deste mecanismo de flexibilidade acarreta em diferentes estratégias de controlo nas obras. Os estudos também permitiram a percepção dos diferentes facilitadores – suposições, políticas organizacionais, práticas de produção, escolhas estratégicas e outros factores – do desenvolvimento de células em cada contexto. Mais do que isso, os estudos confirmaram a existência de um padrão comum entre as várias iniciativas, o que possibilitou a definição de um conjunto de princípios para a integralidade e simplicidade. Isto permitiu articular uma base teórica para a realização dos empreendimentos e, ao mesmo tempo, caracterizar o funcionamento das células móveis através de uma teoria mais apropriada.

Palavras-chave: célula de produção móvel, melhores práticas, flexibilidade, integralidade organizacional.

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RESUME

Dans tout système de production, la mise en oeuvre d'une stratégie de flexibilité signifie développer une compétence affin de travailler avec les variations causées par des sources internes et externes. Dans la construction civile, le développement d'équipes indépendantes et polyvalentes qui fonctionnent comme des cellules de production mobiles obtiennent une reconnaissance croissante dû au fait qu'elles sont un mécanisme de flexibilité capable d'améliorer l'accomplissement des objectifs dans les travaux. Néanmoins, les investigateurs et les professionnels du secteur sont en désaccord sur la réelle signification du terme "cellule de production mobile". Fréquemment, elle est décrite comme étant uniquement un groupe de travailleurs chargés d'exécuter un ensemble de tâches avec des caractéristiques techniques semblables. Cette perspective peu englobante a été influencée par l'adoption de fondements théoriques plus appropriés pour des opérations de manufacture et par la difficulté de comprendre que, dans n'importe quel contexte, l'apparition d'un mécanisme de flexibilité découle de plusieurs ajustements internes dans la stratégie de production. Le même est valable pour la cellule de production mobile, dont l'implémentation exige des changements dans la structuration et dans la gestion du système de production. Certains de ces changements inclusivement obligent à une réévaluation des paradigmes qui sont derrière la traditionnelle manière de gestion des travaux. Ainsi, par moyen d'une ample révision de la littérature et d'une recherche empirique dans l'industrie de la construction, cette dissertation cherche à répondre aux questions suivantes: *"Quels changements permettent l'apparition de vraies cellules de production mobiles?"*, *"Quel est le rapport entre les cellules mobiles et d'autres "meilleures pratiques" développées pour la réalisation des entreprises?"* et *"Comment ce mécanisme de flexibilité contribue-t-il à la performance générale du système de production ?"*. Dans cette dissertation, nous argumentons que la recherche par l'intégralité et par la simplicité est le rationnel commun derrière les plusieurs initiatives tournées vers l'amélioration des interactions dans la réalisation des travaux. Cela implique de visualiser le concept de cellule de production mobile comme faisant partie d'un changement encore plus croissant qui devra se produire dans le système productif. Vu cela, la dissertation débute par une révision étendue de la littérature pour comprendre la raison pour laquelle la recherche par l'intégralité et la simplicité est en train de guider intuitivement les initiatives, affin d'améliorer l'exécution des travaux. Ensuite, nous proposons une vision plus ample du contenu d'une stratégie de production comme façon de comprendre les aspects tangibles et intangibles qui affectent aussi bien le fonctionnement d'un modèle productif que la parution des compétences en lui-même. Ainsi, des études de cas qui impliquent des entreprises de construction et une entreprise géotechnique ont été intentionnellement structurées et réalisées pour l'analyse des différents aspects dans le fonctionnement des cellules. Les études de cas ont révélé les impacts que la mise en oeuvre de ce mécanisme de flexibilité cause dans de différentes stratégies de contrôle dans les travaux. Les études aussi ont permis la perception de différente facilitateurs – suppositions, politiques organisationnelles, pratiques de production, choix stratégiques et d'autres facteurs - du développement des cellules dans chaque contexte. Plus que cela, les études ont confirmé l'existence d'une norme commune entre les plusieurs initiatives, ce qui a rendu possible la définition d'un ensemble de principes pour l'intégralité et la simplicité. Ceci a permis d'articuler une base théorique pour la réalisation des entreprises et, en même temps, de caractériser le fonctionnement des cellules mobiles par moyen d'une théorie plus appropriée.

Mots-clé: cellule de production mobile, meilleures pratiques, flexibilité, intégralité organisationnelle.

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CHAPTER 1 – INTRODUCTION

Research that combines strategic choices in production strategy with theoretical frameworks to understand the achievement of particular flexibility types is an emerging area in project production. Among other system flexibility types, the mobile production cell concept is a relatively novel one and its development requirements and impacts on performance still lack a comprehensive understanding. Therefore, an exploratory research approach is appropriate due to the newness of the subject. The exploratory nature of the literature review and case studies is justified by the need to understand the workings of this system flexibility type within project production systems.

1.1 - RESEARCH FRAMEWORK AND PROBLEM STATEMENT

The construction industry is a project-oriented industry in which the focus of managerial actions and performance measurement is on the project more than the organizational level. Even new management thinking, like that of lean construction, tends to overemphasize the project-level perspective and conventional project performance measures like cost, time, and quality. This limited view has many implications, including the belief, shared by many firm owners, managers and supervisors, that improving productivity is mostly a project management issue (e.g., Rojas and Aramvareekul 2003). For this reason, efforts to utilize lean thinking in construction have been mostly about the introduction of project management techniques or technologies aimed at improving the reliability of flows.

However, there has been an increasing awareness that the project management approach is insufficient to ensure workflow stability in large-scale product developments. Experimentation with lean control initiatives shows that improving the timely availability of materials, information, and resources is not enough to generate a significant better project performance. Consequently, some practitioners and academics have been breaking away from the limited project management approach and paying attention to strategic choices in production strategy that require a more organizational level perspective.

A remarkable feature of the new project production paradigm is the development of autonomous, multi-skilled teams functioning like mobile production cells. Since more reliable flows can only improve to a certain extent labor and project performance (e.g., Thomas et al. 2003), there is a growing realization that greater production efficiency will only be achieved if the labor resource is also seen as a component of flow management. Thus, the mobile cell concept has received strong endorsement as a system flexibility type that enhances the achievement of project goals.

However, a solid understanding of what makes the mobile cells work best in the construction projects is still missing. There are two inherent reasons for the gap in knowledge. First, few studies have been undertaken to assess the policies, practices and assumptions supporting this system flexibility type in different project production systems. Earlier works on the topic usually focus on one or two dimensions of cell implementation at a time, such as workforce management strategies. Second, the mobile production cell concept still lacks a proper underlying theory describing the discipline necessary for its effective operation. Not much is known about cell theoretical building blocks, except for the propositions coming from manufacturing literature. Both weaknesses in knowledge have led the mobile production cell concept to be misunderstood and very often described as just a work arrangement in which a group of multi-skilled workers is assigned to perform an entire set of closely affiliated tasks.

Without any doubt, the lack of a theoretical framework for describing the discipline of mobile cells is the most worrying weakness. Such theory would be most useful in providing guidance to cell implementation in different contexts. Nevertheless, it is important to note that the mobile cell is part of an emerging project production model. As observed by Sacks and Goldin (2007), the implementation of a project production model cannot be superficial. It requires fundamental changes in many aspects. Thus, the adoption of a broader perspective is needed. An exploration of the other initiatives causing changes to the organizational pattern is likely to reveal the fundamentals of the new project production paradigm and thereby the building blocks of mobile cells.

Under the new paradigm, the project production systems are being founded on an integrative discipline that has yet to be fully understood. The mobile cells and other system flexibility types arising within these systems are evidence of the growing integrality in project production. This cause-effect relationship comes as no surprise to those outside the construction industry. In manufacturing, many forms of integration have long been considered primordial for production systems to develop different kinds of flexibility against different kinds of variations (e.g., Buiar 2000, Schmenner and Tatikonda 2005).

Although formal integration between value chain activities is out of question in a highly fragmented industry, interaction and trust issues in cooperative networks have increased the awareness of the need for strategies promoting, as much as possible, the proximity between project participants in terms of culture, organization, technology, and geography. Greater proximity in these dimensions improves the quality of relationships among participants both during and after project execution. It is, therefore, a prerequisite to the active involvement of all project stakeholders, especially to making the labor resource a component of flow management. Alongside project management efforts, the creation of such working conditions is crucial to increasing the probability of project success. As mentioned by Bassioni et al. (2004), what remains in the mind of participants after the project completion is not so much financial success or early completion, but memories of harmony, goodwill, and trust, or conversely, arguments, distrust, and conflict.

Investigation into this subject can certainly bring contributions to the development of a more comprehensive theory for project production. Research along this line is particularly promising because it can bring clarifications to the goals of value generation and waste reduction (e.g., Ballard et al 2001) in project production. The flexible production competences and capabilities arising inside project production systems as a result of the increased organizational integrality are intrinsically linked to the two goals, since they address both production situations and uncertainty regarding costumer requirements (Figure 1). Therefore, if a theoretical foundation is needed to describe the emerging project production model, the fundamentals and enablers of integrality that generate flexibility types within organizations are worth investigation. Research on integrality can be powerfully important to practitioners and academics because it can provide a comprehensive picture of why and when mobile cells work best.

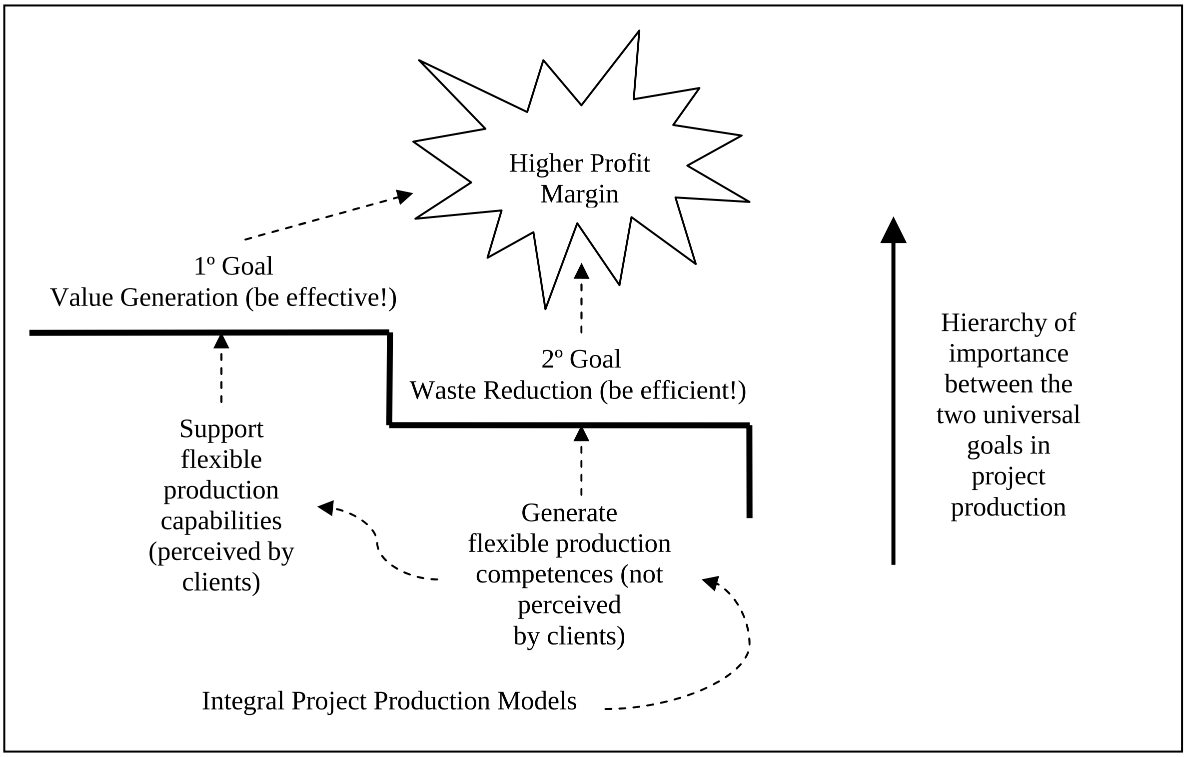

Figure 1 - Flexible production competences resulting from the increased organizational integrality in project production. Source: Miranda Filho (2008)

1.2 - Research Questions

Based on the belief that the mobile cell is more than just a group of multi-skilled workers operating closely together, this dissertation seeks to understand fundamental cell building blocks by exploring the integrative discipline that is also guiding other renewal initiatives in large-scale product developments. In this dissertation, it is argued that the mobile cells and other true “best practices” derive from a considerable number of changes in the design and operation of production systems. Therefore, the research is not intended to propose a definition of the mobile cell concept. Any definition would be too simple and shallow. Instead, it seeks to provide a comprehensive understanding of what is actually necessary for effective cell operation.

However, addressing a new production model requires a broad literature review on many different topics. It also requires a substantial number of field studies to test ideas with the rigor and repetition necessary for solid conclusions. These are the only ways of achieving a comprehensive perspective of the inner workings of a production model and its competences. Thus, this dissertation builds on library and field research in the construction industry to study three broad interrelated research questions:

- What are the changes that allow the emergence of real mobile cells?
- How does this true best practice relate to other successful renewal initiatives in project production?
- How does this system flexibility type contribute to the performance of the project production system as whole?

1.3 – PROPOSITIONS

An understanding of the mobile production cell concept is of great importance to large-scale product developments undertaken by complex project organizations. The interest in knowing what is needed to implement and to make mobile cells work best comes from the perception that there is no such thing as managing complexity, but only organizing the way around it.

However, to adequately understand the workings of a production model and its underlying causes, one must analyse the production strategy both in terms of tangible and intangible attributes. Besides the external context, there are a number of internal factors affecting the emergence of a best-in-class production model in a particular industry. Some are quite unobvious to outsiders. The development of a successful project production model is no different. It is also influenced by strategic choices and many different "soft" factors. Thus, this dissertation proposes that research into "best practice" development needs to address the structural and infrastructural decisions that shape the production system design and the underlying principles and assumptions that influence those decisions. These aspects are rarely taken into consideration by the traditional project management approach.

Furthermore, it is put forward in this dissertation that the same principles guiding "higher" level project integrality are also behind the operational level integrality needed to create mobile production cells.

1.4 – OBJECTIVES

The primary research goal is the proposition of a proper theoretical framework for describing the discipline of mobile production cells in project production systems.

The following specific objectives are also included:

- Explore the fundamental ideas of project production to uncover aspects of the emerging production model;
- Use systems thinking approaches to understand the need for integrality and workforce autonomy in large-scale product developments;
- Provide insights on the inter-relationship between mobile cells and other successful renewal initiatives applied to project production;
- Critically discuss the concept of flexibility, regarding its definitions applied to construction projects;
- Assess the embedded strategic choices, production practices, underlying principles and assumptions enabling mobile cell operation;
- Identify the relative importance of different types of control and buffers after developing this system flexibility type.

1.5 – HYPOTHESES

This dissertation seeks to confirm or refute the following hypotheses:

- The renewal initiatives are shifting the large-scale product developments back to the fundamental ideas of project production;

- The search for integrality and simplicity, in contrast to complexity, is what intuitively guides the successful renewal initiatives in project production;
- A true “best practice” can only emerge from a substantial number of internal adjustments;
- A better understanding of integrality building blocks and enablers gives project organizations an idea of what is needed to implement mobile cells and to make them work best;
- The mobile production cell is a competitive weapon for time-based competition.

1.6 - RESEARCH METHOD

Research formats can vary in terms of nature (basic and applied), approach (quantitative and qualitative), objectives (exploratory, descriptive and causal) and investigative procedures (e.g., Silva and Menezes 2001). Although engineering theses usually refer to a problem to be solved, this dissertation talks in terms of questions to be answered. Thus, this research is categorized as basic because it seeks to generate useful knowledge to the field without attempting to solve any specific problem. Basic research on industrial processes has as its primary objective the advancement of knowledge and the theoretical understanding of the relations among variables.

As for the approach, the research can be defined as qualitative. Besides a broad literature review, a field research was conducted to obtain data from two basic sources. The primary data came from both semi-structured and in-depth interviews. The secondary data came from documents provided by management teams during visits to construction sites.

In terms of objectives, the research can be categorized as partially exploratory and partially descriptive. To support this research format, library research and case studies were chosen as the investigative procedures.

Addressing a new production model is not an easy task because it requires a broad literature review on different, but interrelated, topics. Thus, the library research encompassed earlier works on production flexibility, production system design, project management, workforce management and systems thinking theories. Although the approach to some topics may have been somewhat shallow, the broad literature review was necessary to capture "the big picture". It showed the multitude of variables related to production system design that work together to influence the emergence of a “best practice”. Furthermore, the review allowed a comprehensive understanding of the current state of practice and theory. This helped to identify gaps in knowledge and to formulate hypotheses.

Additionally, this dissertation uses case studies because they help to understand phenomena, to facilitate theory building and to provide directions on what to look at more extensively in future research. The field research was conducted to support the development of insights into the problem and operated on the basis of hypotheses generated through the previous exploratory library research. It was more analytic and aimed at particular factors. Thus, the investigative methods used were non-intrusive and gathered data without any manipulation of the research context. As mentioned above, they involved semi-structured interviews, in-depth interviews and documental analysis.

The case studies were deliberately structured to focus on different aspects of cell design and operation in project-based organizations. Two cross-case analyses were conducted. The first involved five builder-developer firms belonging to the same strategic group. The second involved a contractor and a subcontractor. The case studies portray the strategic choices, production practices and other contextual solutions that have been implemented to introduce cells in the workplace situations. They also highlight the outcomes that have resulted from the changes undertaken. Throughout the case studies, consistent patterns were uncovered from the experiences of different firms, serving to generalize the results and to reinforce the emerging theoretical framework.

1.7 - Research Scope

Like any other system flexibility type, the mobile production cell is by itself a multi dimensional concept. Therefore, the research theme is very broad because the core discipline and various enablers of cell operation are poorly understood. Even if the research was restricted to a portion of the previously mentioned topics, the literature review and field research would still be quite challenging and demanding. However, such path was readily rejected because of the need for a "helicopter view" on systemic relations. This thesis builds its strength on this aspect in order to counterbalance the superficial approach to some topics. Moreover, a special concern is given to the literature on structural and infrastructural decisions because both sets of strategic decisions closely influence production system design and thereby flexibility types.

Furthermore, the scope of this thesis is the project production functions, not design functions. Therefore, the value generation view is approached not in terms of creation but in terms of support provided by flexibility capabilities. Thus, attention is given to flexibility types developed internally. These internal dimensions of flexibility are at the foundations of flexible capabilities perceived by the customers.

In addition, the construction industry in the city of Fortaleza (Brazil) has served as the prime industry for the analysis because of its richness, its complexity of needs, as well as an unusual level of openness to scholarly inquiry. But most important of all, it was chosen because of the high level of implementation of new production practices and philosophies. Moreover, with the exception of the subcontractor firm, this dissertation treats mostly firms that conduct projects belonging to private owners. Consequently, the case studies not only reflect a particular context, but also involve firms that are exposed to relatively high demand patterns.

1.8 - Dissertation Structure

Chapter 1 presents a general view encompassing the research problem, framework, and methods. It also states the research questions that are the basis for this work.

Chapter 2 discusses several barriers to integrality in large-scale product developments. Then, a discussion is made with the purpose of showing the importance of organizational integrality and workforce autonomy in construction projects. The discussion is fundamented on three different, complementary approaches: complexity theory, theory of constraints, and system dynamics.

Chapter 3 characterizes the content of production strategy as comprising tangible and intangible attributes: performance criteria, structural and infrastructural strategic choices, theoretical foundation, and underlying assumptions. It presents a broad review of the literature on these aspects and proposes a conceptual model of their interrelationship.

Chapter 4 investigates the underlying theory of the emerging project production model by looking at aspects of two successful practices: design-build and partnering initiatives. As a result, it summarizes in four principles the discipline of integrality in project production. It also extends the discussion to the reasons why the theoretical framework is applicable to guiding or explaining mobile cell operation.

Chapter 5 presents the findings obtained from a cross-case analysis involving five high-rise building firms. In particular, the chapter explores the strategic choices, production practices and underlying assumptions supporting workforce autonomy in those workplace situations. It highlights the consistent patterns behind the different initiatives with the objective of reinforcing the emerging theory. It also discusses the outcomes that have resulted from cell implementation, especially regarding the relevance of different control and buffer types.

Chapter 6 proceeds with the investigation on cell operation by discussing the workforce management strategies supporting labor autonomy in two very different firms. This chapter presents a more people oriented approach to exploring the similarities between strategies adopted by a general contractor and a subcontractor when developing autonomous teams. The cross-case findings provide further feedback on the hypotheses.

Finally, Chapter 7 provides a synthesis of contributions to knowledge and directions for future research.

CHAPTER 2 - BARRIERS AND OPPORTUNITIES FOR INTEGRALITY IN PROJECT PRODUCTION

In this dissertation it is argued that integrality is primordial for any project production system to develop flexible competences against variations derived from both internal and external sources. Therefore, before moving on to explore the conceptualizations and key strategic decisions behind the creation of mobile production cells in construction projects, it is necessary to take a closer look at barriers to integrality in large-scale product developments.

Initially, this chapter presents a discussion on the differences between types of projects and on the fundamental issues in project production whatsoever. The fundamental characteristics are used throughout this thesis as reminders of what projects are all about before the misinterpretations and labyrinths caused by the layers of complexity that have been added to construction projects. Next, construction peculiarities, business strategies and production paradigms are discussed to show how well-intended responses to new business challenges have worsened the task of building "finely-tuned" organizations for specific missions and have left the construction sector with projects that are ungovernable and underperforming.

This is followed by a discussion using systems thinking approaches to understand the volatile behaviour of large–scale complex organizations. By discussing the challenge of managing complex organizations, this chapter aims to encourage initiatives that address organizational integrality in construction projects and, most important of all, to highlight the importance of workforce autonomy at the level of operations.

2.1 - DIFFERENCES AND FUNDAMENTAL CHARACTERISTICS OF PROJECTS

If production is defined as designing and making things, then a project should be seen as the fundamental form of production system. According to Ballard and Howell (2003), designing and making something for the first time is done through a project. As mentioned by Lim and Yeo (1995), it is essentially a one-off undertaking to fulfil predetermined specific goals, within the constraints of budget, time and acceptable performance standards. Moreover, project management is the aspect of business dynamics that turns vision into results. This aspect reveals project management as the point of departure for management theory, where management manages the behavioural processes of people who manage the activities in product development processes or in the continuous incremental improvement of business processes in the organization (e.g., Van der Merwe 2002). Either way, the projects guide the business process to address the costumers' needs or the change in the strategic direction of the organization.

Because projects aim at solving relatively complex and unique problems within distinct start and end points, temporary organizations need to be established for a limited period of time. Even the simplest projects are installed as distinct organizational units to the base organization and receive from it an appropriate amount of resources and personnel to accomplish specific objectives. As expected, the rigid departmental structure and the formal communication lines are made less important as the people involved belong to both the project and departments. The project team becomes an entity that crosses the departmental boundaries with its own budget, division of work and performance goals. In this sense, the project approach creates less hierarchical and more flexible and responsive organizations inside the base organization. This enables the base organization to undertake missions outside the scope of its on-going operations.

To summarize, a project uses a structure within the structure. But because of that, it is affected to a certain extent by the external setting, which is represented by the bigger structure. The contingency factors herein include the base organization's existing structural and infrastructural aspects.

The number of people and of internal hierarchic layers can vary depending on the project. The project organization can be composed of a single person from a functional unit, a group of individuals from one or more departments or even teams from different firms, like in the case of large scale projects. This diversity in the number of participants can be seen among many types of project-based production systems. Ballard and Howell (2003) provide a list that includes shipbuilding, civil construction, movie-making, software engineering, product development and all forms of work-order systems such as plant and facilities maintenance.

Due to the different possible objectives, projects can be categorized into internal and external projects. The fundamental difference between the two types is that internal projects do not have any external stakeholder while external projects have external stakeholders i.e. the costumers (e.g., Lim and Yeo 1995). The internal projects are applied to business development. These projects serve to improve the firm's overall efficiency and to create more value in the product or services delivered to the costumers. Invariably, successful internal projects improve the performance of the company in terms of financial returns as well as market share. Differently, external projects are applied to industrial development. These projects usually involve the production of a specific service or product. According to Martucci (1990), their specific goals are influenced by two distinct costumers: the final costumer in the marketplace (the buyer) and the organization that is sponsoring it (the developer).

Lim and Yeo (1995) argue that projects in firms can be broadly divided into improvement projects, development projects, product-based projects and manufacturing structure and infrastructure projects. These projects can be operational, tactical and strategic in nature depending on whether the consequential impacts as short-term, mid-term or long-term. According to the authors, strategic level projects can be all-encompassing in nature, which might include some or all of the above four types of projects.

An *internal project* can be strategic, tactical or operational. No matter what the nature, it has to be aligned with strategic guidelines because changes in strategy precede those of structure (e.g., Van Der Merwe 2002). A good example is the implementation of lean production. The principle of Kaizen is a lean pillar that stands for continuous improvement and requires a firm to be constantly challenging the status quo and norms of doing business as well as increasing operational efficiency. Hence, improvement efforts can cover various facets of the firm like quality, cost and cycle-time. Lim and Yeo (1995) add that the goals specified in the upper-level policy deployment must be translated into tactical goals by the middle managers. These in turn need to be deployed down to the first-level as sub-goals (e.g., Müller 2003). So the contribution of each project should not be in a fragmented manner, but driven by the "total programme" strategy. Therefore, the implementation of lean production as an internal project is strategic in nature and requires a total system approach since it involves various levels of plans. It is a long term business level programme represented by a series of projects, which can be developmental, improvement and infrastructural.

The same goes for structure and infrastructure projects exclusively aimed at operational expansions such as plant relocation to another area or commitment to a brand new facility. According to Lim and Yeo (1995), these are also strategic in nature because they are derived from the projected growth in product demand and their life cycle is relatively longer. Moreover, the investment requires huge capital outlay to extend product lines to current new products, acquire major equipment, quality management systems etc. Because of the heavy investment involved, an operational expansions project must have its financial viability critically analysed and assessed. Factors like market for products, selling price, cost of raw materials and labour, government's policies and etc. must be taken into account during the project definition phase.

The lean production implementation and the operational expansions plans are examples of business development projects that require great investments and have long term consequential impacts. Four years is the length of time generally necessary for a company to be able to assess the results of introducing a new strategy (e.g., Acur et al. 2003). However, the duration and cost of an internal project will depend on the type of business development. The project duration can also be in weeks or days when it is operational in nature. In such cases, very often the costs incurred are in terms of allocated labour man hours and there is no money spent on capital equipment.

Regardless of the nature, all internal projects share the commonality of being installed as distinct organizational units to the base organizations using predominately in-house staff with some input by consultants. According to Van Der Merwe (2002), human resources used to manage and execute these projects involve people from distributed cross-functional teams, lateral teams and virtual teams possibly working on many projects concurrently.

Internal projects can be strategic, tactical or operational in nature because requests to improve or even to change working processes may come from management, staff, costumers and suppliers. Each request turned into a project needs to correctly and unambiguously define the measurable end goal and beneficial change of the project. The reason lies in the fact that although a business development project is installed as a distinct organizational unit to the base organization, it provides results that are in one way or the other integrated into the overall company's strategy. Therefore, attention is needed when restructuring existing aspects internal to the organization so that the results support and align changes in both strategy and business processes.

However, a project can also be a vehicle for achieving change outside the existing functional structures and hierarchies. That is, it can be done to fulfil objectives without necessarily bringing changes to the base organization. This is the case of many *external projects*. These are temporary undertakings aimed to successfully deliver a product that meets customer-driven performance specification, on schedule and within the development budget so as to satisfy the corporate business and profit plans. Effective project management meets these interlocked objectives, which form the basic triple constraints in this type of project. In fact, these are a direct consequence of the characteristic of having two distinct costumers in external projects.

Examples of external projects at the work level abound. In a job shop production system, jobs to manufacture customized products can be considered operational projects. The same can be said about a batch type of production system, where the customisation of the process flow for particular customers is in itself an operational project. Except for the experience acquired, these projects do not cause any relevant change in aspects internal to the base organization. On the contrary, they are supported by the existing structure.

But there are situations that do require internal adjustments to effectively perform an external project. This is the case of new product developments, which are described by Lim and Yeo (1995) as being tactical projects in whatever type of production systems. To bring products from concepts to the marketplace, project management will usually involve a multifunctional team in the product development process. Depending on the product and the capabilities required to develop it, the project implementation may use one's own staff or the contractor's staff. Moreover, human resources may be needed in a more dedicated team to work full-time on one project at a time. Clearly, these and other contingency factors may be beyond the control of the project organization because development projects are tactical in nature. Instead, it is more likely that they are under the control of the base organization, since they closely relate to each individual company's requirements, existing organizational framework, and countervailing pressures. Therefore, in some cases the base organization needs to reconfigure its structure to finely support specific development processes, which might reflect a new strategic orientation.

The match between mission, structure and processes generates customized formal development processes within the main project phases, e.g. predesign, design, procurement and installation. Industrial development projects such as chemical plants, power stations, bridges, dams, and production plants, to name only some, are examples of large-scale product developments often operated with customized development processes. Unless the base organization is sufficiently robust to undertake a range of large-scale projects without altering its structure, it will need to be adaptive in order to everytime generate new strategies and/or reconfigure the structure. Thus, in accordance with Qing et al. (2002), a new large-scale product-developing project is often followed by a great business reengineering or great renovations of technology and management.

The link between business strategy, structure and performance is a classical theme in strategic management literature, with the main thesis being that organization strategy determines organizational structure, which in turn influences organizational processes (e.g., Prajogo and Sohal 2006). The organizational performance is the result of their alignment. The discussion in this section is conducted inside this model with the intention of clarifying the relationship between strategy, structure, processes and projects (Figure 2).

Given the above discussion on project characteristics, when a firm initiates various projects to achieve its goals, two important issues have to be considered by its management (e.g., Lim and Yeo 1995, Ebbesen, 2004). The first issue involves the interdependence of the projects and with the base organization. The second issue concerns the learning aspects of the base organization in regard to the projects. These are critical issues to both internal and external projects, regardless of them being operational, tactical or strategic in nature. The two issues highlight the importance for the base organization to consider what needs to be done to perform successful projects and what can be gained from each project.

Interdependence is an issue that requires consideration at all times, even in the simplest project. For example, a worker responsible for leading the Total Quality Management (TQM) programme in a particular department still needs to satisfactorily perform his/her other routine activities. However, this issue becomes more important in a multi-project environment, where resources may be shared between projects and with the base organization. Thus, competition for scarce resources and involvement of personnel may not only affect the outcome of a single project but also the outcome of other projects. This pushes the company to periodically evaluate ongoing projects in order to review and adjust the assignment of personnel and the allocation of other resources. Moreover, it preferably undertakes as many high pay-off projects as can be successfully completed. This way the company limits the number of projects to the critical ones in order to ensure that they are not starved of the required resources.

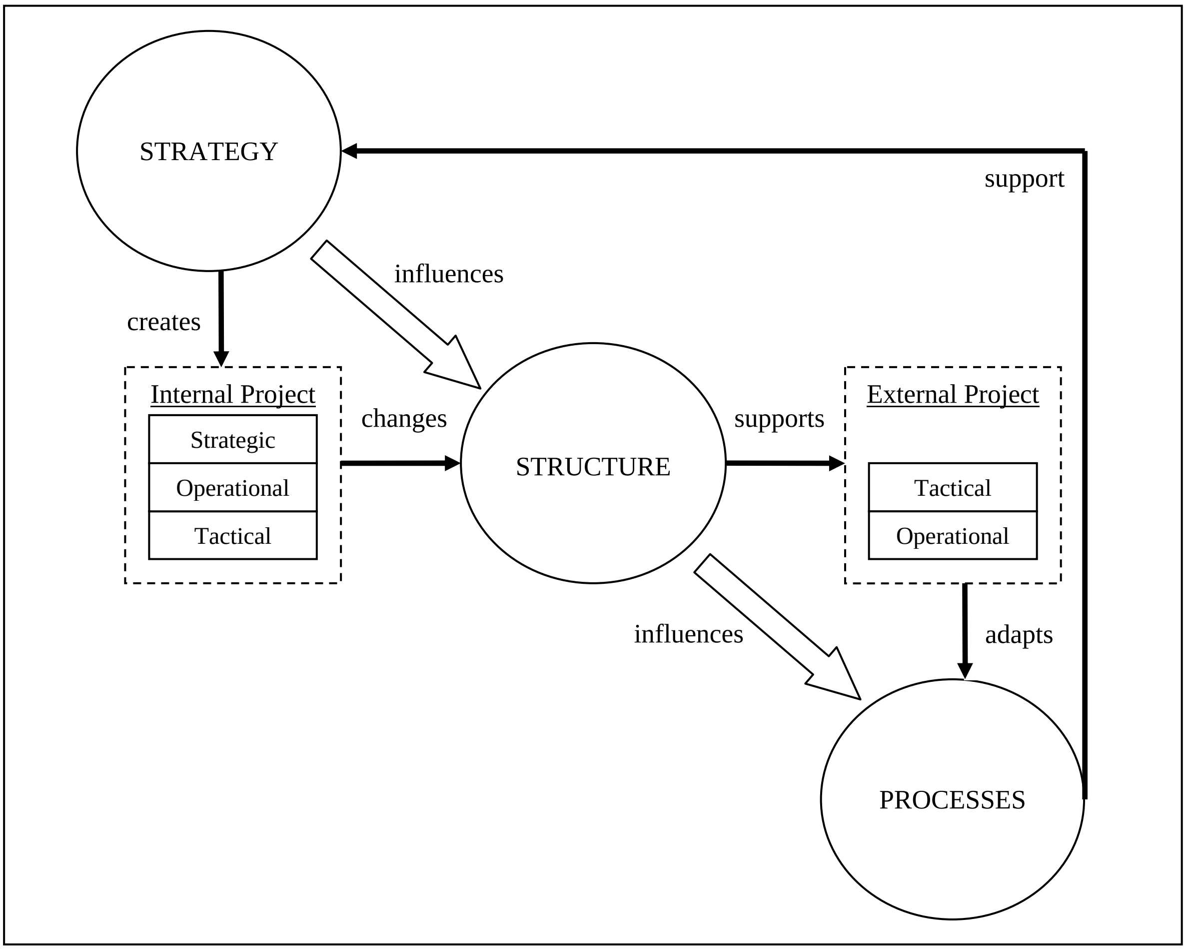

Figure 2 - The relationship between strategy, structure, processes, internal projects and external projects in organizations. Source: Miranda Filho (2008)

Differently, learning is an issue that is sometimes ignored, even though it should be a concern to all sorts of projects. It is important to keep in mind that a project is the fundamental production system where knowledge is acquired on how to make or improve something. Therefore, it is a mistake to perform a project and ignore all outcomes but the product (or service) delivered for an internal or external costumer. As mentioned by Ebbesen (2004), technical knowledge concerning the product, its parts and technologies as well as procedural knowledge concerning producing and using the product need to be accumulated. The base organization has to ensure that the lessons learnt from one project are not dispersed but rather absorbed by it or translated to its other projects.

An interesting observation is that interdependence and learning issues are somewhat interrelated. Besides the above mentioned types of project knowledge, another project outcome is organizational knowledge concerning communication, collaboration and acting in a project, which can actually help to improve the management of interdependencies in similar projects. The other way around is also true. Because both are pretty much a consequence of how the project is supported by the existing structure, it can be argued that an improvement initiative taken to cover one of the issues will probably positively affect the other. If the strength of the projects approach lies in the use of systems thinking applied to the entire organization (e.g., Lim and Yeo 1995), management should take advantage of it to develop solutions for dealing with the two issues and thereby enhance the probability of fulfilling specific goals.

Despite all the prevailing definitions and because organizations are processing systems (e.g., Rummler and Brache 1994), the discussion presented allows to visualize a project as a temporary process to achieve something different from what is already achieved through the existing processes in the base organization. It can be less hierarchical and more flexible because it does not follow the same rigid paths of routine processes. But like other processes, it crosses the existing structure consuming resources from different functional areas, which altogether form what is known as the project organization. It can also superimpose and interact with other processes in ways that are not clearly defined. And just like the rest, it is subordinated in its own particular way to frictions caused by structural features, both good and bad.

This understanding of a project allows thinking through the commonplace interpretations and bringing two fundamental ideas that will guide this research. First, every project must belong to a base organization. Second, every temporary process, like any other, is influenced and constrained by the structure. These aspects are understood as fundamental to all sorts of projects and the attention given to them influences the way interdependence and learning issues are dealt with within organizations.

2.2 - THE CAUSES OF COMPLEXITY IN LARGE-SCALE PRODUCT DEVELOPMENTS

The organizations formed to conduct large-scale product developments are, like other large organizations, by nature complex (e.g., Hansen et al. 1997). Ashkenas (2007) mentions that the causes of complexity tend to fall into one of four categories: product proliferation, structural mitosis, process evolution, and managerial habits. Organizational complexity is the cumulative by-product of changes, big and small, in these four categories. To improve business results, a careful look at organizations can provide areas of opportunity in each of these categories. However, the success in countering complexity takes a lot of hard work and a vigilant attention over time. Managers need to address the causes of complexity in a multidimensional, ongoing strategy, because attacking them separately may actually worsen the problem (e.g., Hansen and Rush 1997, Ashkenas 2007). Thus, understanding the external and internal factors contributing to complexity in each business and their interrelations becomes a prerequisite for effective decision-making.

2.2.1 - The Impact of Construction Peculiarities

The architecture, engineering and construction (AEC) industry is a project-based industry where time and space-related aspects determine the way transformation processes and supply chains are organized. As mentioned by Voordijk et al (2006), each construction project has a temporary character and takes place on a different location. Because of this, Koskela (1992) has long advocated for the need to understand the peculiarities of construction and their implications for the structuring and management of construction projects. After conducting an overview on construction peculiarities, Koskela (2003) stated that it is convenient to group the significant peculiarities into three major categories: one-of-a-kind nature of projects, site production and temporary organization.

According to Koskela (2003), *one-of-a-kind production* is caused by differing needs and priorities of the client, by differing sites and surroundings, and by different views on the best design solutions. Because all organizational structures are influenced by various aspects of the environment and mission, the author mentions that this is not a unique feature of construction, since a major share of output in manufacturing industries are actually of one-of-a-kind products. Another aspect mentioned is the fact that projects are quite often roughly similar, so the materials, components, product design options and skills needed are also usually the same or similar. Thus, it has to be stressed that the problems associated with one-of-a-kindness affect only certain aspects in any project (e.g., Koskela 2003).

Interestingly, these observations create the awareness that problems with one-of-a-kindness in construction relate more to the project's organizational realm than to its product realm. Indeed, the changes undertaken in the production system to customize everytime the development process for each new project are a major source of problems. Moreover, it is the intensity of changes on the level of system design from project to project that differentiates the one-of-a-kind production feature of construction from that of other industries.

In accordance with Koskela (2000), it makes sense to describe construction as a prototype production system requiring improvements, but being overwhelmed by the task of debugging errors in designs or production plans. As a matter of fact, uncertainty from the organizational realm, alongside with changes in costumer orders, is what makes so difficult the accurate development of project plans for large-scale product developments that are often operated with a certain amount of business process reengineering.

It comes as no surprise that several kinds of dynamic and static modelling methods including Extend+BPR, Crystal Ball Pro, STROBOSCOPE, IDEF3, ARIS, RAD and DFD have gained the interest of construction academics over the years (e.g., Al-Sudairi et al. 1999, Horman 2001, Qing et al. 2002, Alves et al. 2006), even though reengineering as a generic approach to radical reconfiguring of processes has lost much of its fashionability towards the late 1990s (e.g., Koskela 2003). The methods' capabilities to model processes for new projects are being useful to support project management tools (e.g., Qing et al. 2002) and thereby one-of-a-kind production.

As for *site production*, unlike the previous it is a construction peculiarity shared by only a few other industries. Koskela (2003) argues that the concept of site production refers actually to a bundle of features that add to uncertainty and complexity of construction in comparison with stationary production. The author provides a list of the features: site as a necessary input resource; lack of shelter against elements; use of local resources and conditions; creation of production infrastructure; and space needed by mobile workstations. These features also influence the degree of one-of-a-kindness in construction. However, it is the spatial flow of workstations and the need to coordinate them that has the most special implications for the management of construction.

Because construction production typically takes place at the final site of the product to be constructed, the construction layouts are much more dynamic. As the product takes shape, the construction site layout suffers several big alterations and also a number of small alterations on a daily basis (Figure 3). Consequentially, not only the material flow to the site changes, but also intermediate flows because work areas move around and crews and materials come and go based on the start and finish, and throughout the execution of an activity (e.g., Choo and Tommelein 1999, Koskela 2003). This implies that very often the process flow is not superimposed to the physical flows of materials, equipment, and labourers moving about the site. Thus, a remarkable feature is that space has to be treated as an explicit resource like any other allocated to a work package (e.g., Choo and Tommelein 1999). For this reason space is an important constraint in the great majority of construction projects, being constantly considered in all decision making and even changing the schedule when its availability is inadequate.

Oppositely from the steady state operation of manufacturing facilities, the dynamic nature of a construction site layout is characterized by variation in terms of space use, speed of travel and activity duration. The combination of features from site production with those from the other two major construction peculiarities turns the network structure too complex, creating a high degree of variation in the flows and making probabilistic inference a difficult task. Hence, the use of data resulting from simulation provides the basis for generating production system design, schedule, and layout solutions that remain effective for a limited period of time, since uncertainty increases dramatically for work to be done further in the future.

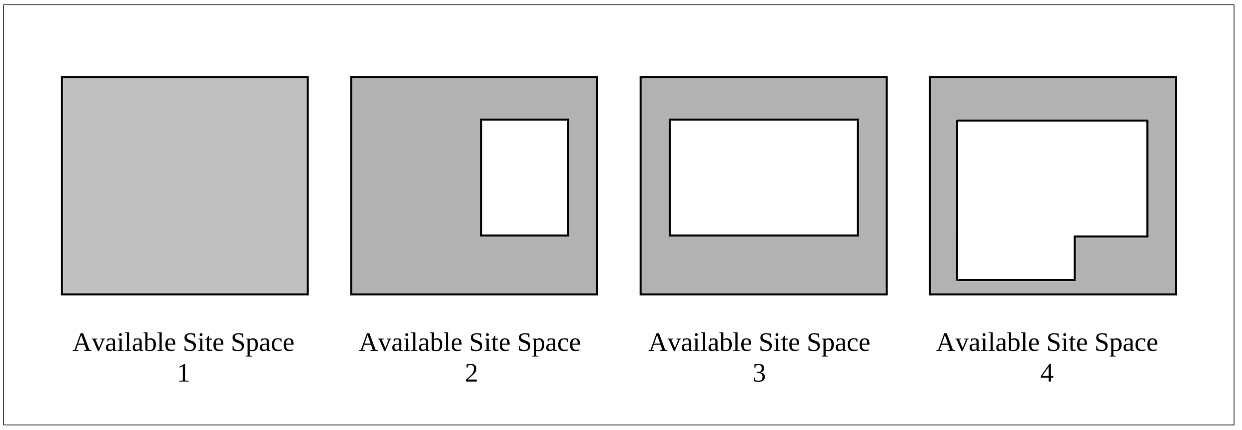

Figure 3 – A representation of changes in the proportion of land occupied by the tower block that lead to big alterations in the construction site layout. Source: Miranda Filho (2008)

This means that work load control becomes necessary in small time intervals in order to periodically adjust and limit the number of jobs in the system according to the interdependencies and work space constraints. Of course, the decisions are subordinated to the project schedule and are commonly implemented through weekly work plans, which is the most detailed level of scheduling in construction (e.g., Choo and Tommelein 1999). However, more than specifying work and space use along different assembly phases, what is done is an ongoing redesign of many aspects of the production system (Schramm et al. 2006). Site production implies that the project production system not only has to be redesigned every time for a new product development, but also redesigned many times during the project life cycle. Thus, a certain degree of one-of-a-kindness in production is needed for the specific mission parameters of each assembly phase.

The *temporary organization* peculiarity relates to the fact that a temporary production system is designed and assembled for the purpose of the particular construction project (e.g., Koskela 2003). Each temporary production system is linked to multiple, enduring production systems from which the project is supplied materials, information and resources (e.g., Ballard and Howell 2003). As mentioned before, this feature is common to all projects and reflects the one-of-a-kind nature of a constructed product. The difference, however, lies in the fact that in construction projects, as in other large scale product developments, the temporary organization is usually not constant throughout the entire project life cycle. The product's large scale in combination with its one-of-a-kind nature requires a higher number of participant firms and of hierarchic layers within the project organization. As cited by Sacks (2004), some of the reasons are: increasing sophistication and specialization of trades, increasing prefabrication off site, and fluctuating demand for the services of general constructions contractors.

This greater division of work generates organizational complexity and an extreme case of temporary organization, where specialists come and go because they are only involved in one or few phases of the product development process. The site production peculiarity also plays its part in aggravating the temporary nature of the organization. Because of the economic necessity of using local labour or subcontractors, participants who might not have worked together before and whose practices and cultures are somewhat unknown to one another are tied to the project by means of varying contractual arrangements (e.g., Koskela 2003).

The resulting organizational structure resembles a matrix structure, which superimposes a product or project structure onto existing function based structures (e.g., Van Der Merwe 2002). However, in this case the function based structures belong to different firms and not to one single base organization. Depending on the project and on each participant's role, resources from vertical units (participant firms) are assigned to horizontal units (hierarchic layers), based on the need in each unit. Hence, these project structures are derived from the role of differentiation and integration in organizational theory (e.g., Baccarini 1996, Van Der Merwe 2002). As discussed, the differentiation is not only in terms of different occupational specializations but also of authority in the organizational structure. Authority is split up into horizontal layers so that each layer has more authority than the layer below it. At the same time, as an organization differentiates itself, it must also integrate activities into sets of tasks performed as a co-ordinated whole. The span of control in management theory refers to the number of immediate subordinate positions that a superior position controls (e.g., Van Der Merwe 2002). Therefore, in large scale product developments the matrix is split, not only horizontally, but vertically as well, creating the challenge of integrating work across contracted functions in the project organization.

As expected, an extreme case of temporary organization creates several disadvantages for the matrix structure regarding both interdependence and learning issues, especially under time stress. First, as the multidimensional organization is constantly changing in terms of participants and space use, fluidity through time causes more intense and problematic redesign of the project production system throughout the project life cycle. Second, explicit authority differentiation between the matrix managers and the contracted functional heads is less clear, making people under the matrix unsure to whom they are accountable for what and for what time period (e.g., Van Der Merwe 2002). Rather, an effective matrix structure would require project managers to work co-operatively with the functional heads in order to clarify priorities and handle conflict of interests. Third, the lead firm in the matrix structure has trouble in providing proper work conditions to support higher productivity and to alleviate the behavioral trauma that commonly affects the relocated, assigned personnel. Forth, and perhaps the most critical of all, the firm in charge finds difficulty in implementing improvement opportunities and in keeping project knowledge from being dispersed both during and after the project execution.

What stands out from the problems above is the need to devise distinct strategies for product suppliers and service suppliers within the construction matrix structure. Although the efforts in both types of firms need to be coordinated for the sake of the project, the latter are clearly more severely affected by the one-of-a-kind nature of projects and site production. During the assembly phases, product suppliers respond for the material flows to the site, which are usually composed of interchangeable, loosely coupled, and individually upgradeable modular components (e.g., Voordijk et al 2006). In contrast, the service suppliers respond for the intermediate flows at the construction site, which generate integral products that perform many functions, are in close proximity to each other, and are highly synchronized. The hybrid characteristics of the construction output highlight the mistake of maintaining with both types of firms an indiscriminate outsourcing relationship commonly based on a low relational or hierarchical character. But far more than establishing distinct practices for what goes on inside the construction site's boundaries during the assembly phase, the delivery of integral products requires building closer relationships between participants in integral supply chains and integral processes across all project phases (e.g., Ballard and Howell 2003, Voordijk et al 2006). This will be further discussed in the following topic.

2.2.2 - The Impact of Governance Structures

It is paradoxical that designing and making something for the first time under a tight schedule cannot be done by a fully integral organization when common sense says that it should. It is clear from the discussion so far that the need for integral supply chains and processes is created by the one of a kind nature of the construction product and the fact that its production is typically carried out at the final site of use. Ironically, at the same time both peculiarities from the product realm present features that, together with governance structures and economic necessities within the organizational realm, counterbalance the integrality needed, leading to extreme cases of temporary organizations in construction projects.

In this section construction projects are conveniently sliced into different dimensions in order to allow an initial discussion on the implications of the construction peculiarities and other environmental factors for the organizational integrality needed in large scale product developments. To begin with, according to the three-dimensional modularity concept proposed by Fine (1998), integral products tend to be developed and built by integral processes and supply chains, whereas modular products tend to be designed and built by modular processes and supply chains. The three dimensions of integrality tend to mutually reinforce each other. Obviously, the product dimension relates to the one-of-a-kind nature of construction and site production peculiarities while the process and supply chain dimensions relate more closely to the temporary organization peculiarity.

As mentioned before, an *integral product* includes components that perform many functions, are in close proximity or close spatial relationship to each other, and are highly synchronized. According to Voordijk et al (2006), normally, a change made to one component requires a change to other components for a correct functioning of the total. The author adds that in a *modular product* architecture, components are interchangeable, autonomous, loosely coupled, individually upgradeable and interfaces are standardized. For a modular product, two factors are thus of major importance: independence of components and interfaces. Hence, the building as a whole can be described as an integral product made upon some modular components.

As for process architectures, a highly *integral process* is one integrated in both time and space while a highly *modular process* is dispersed in both time and space (e.g., Fine 1998). Of course, the process architecture can also be integrated in either time or space. When the coupling between the process components decreases in time (production spread over multiple time intervals) or place (production takes place on dispersed locations), the so-called modularity increases. Voordijk et al (2006) analysed three types of building techniques following this logic. A discussion on these different project delivery processes is presented next:

- In the traditional building technique, the degree of prefabrication is low. The process architecture is dispersed in time but tight in space. The major activities adding value take place on the construction site. Time buffers need to be placed between activities in order to avoid over load in space use. Strong emphasis is given to planning and coordinating activities at the construction site;
- In assembly building, large prefabricated elements are manufactured in factories and assembled on the construction site. The prefabrication degree is high. Tuning the design, manufacturing, and assembling stages to each other takes a lot of preparation time. The process architecture is dispersed in space but tight in time. Emphasis on planning and coordination is distributed throughout different project phases;
- In the closed building system, components are manufactured within certain dimensions especially for that system. "Closed" means that these dimensions do not fit components of independent manufacturers. Components are manufactured centrally in one factory or in different factories that are part of one firm or a conglomerate of firms. Closed building systems are assembled on site within a tight schedule. The process architecture is highly integral and strong emphasis is given to planning and coordinating activities in early project phases.

The three types of building techniques result from characteristics of the market place and strategic choices in production strategy. No matter what are the specificities, they present process architectures that are unavoidably integrated in both time and space, or integrated in either time or space. Therefore, even though the design of the macro process and the control emphasis can be changed through strategic choices in production strategy, a certain degree of process integrality will always be necessary due to the uniqueness of construction products and to the feature of site production.

In the case of supply chains, an *integral supply chain* is determined by the degree of proximity between the set of entities that produce, distribute, and/or sell items along the path that a product takes from raw materials to delivery to the final consumer (e.g., Fine 1998, Blackstone 2001). Consequently, a *modular supply chain* presents a degree of non-proximity of participant entities. The degree of proximity is measured along the following dimensions (e.g., Fine 1998, Voordijk et al 2006):

- Geographic proximity can be most simply measured by physical distance;

- Organizational proximity deals with ownership, managerial control and interpersonal and inter-team interdependencies;
- Cultural proximity captures commonality of language, business mores, ethical standards and laws, among other things; and
- Electronic proximity can be captured by email, electronic data interchange (EDI), intranets, video conferencing, etc.

It is important to notice that supply chain integrality is not the same as vertical and horizontal integration (e.g., Hitt et al. 2003), although both types of ownership and control schemes can help to improve the degree of proximity of participants in some dimensions. Therefore, integrality has a much broader meaning.

In the real world the high proximity between participants engaged in the production of more complicated products is more likely to happen in industries where the final assembler leads the chain, establishing quality standards, information flow and technical specification. The automakers are a good example of final assemblers with a significant domain over product design sales, production and supply chain. This competitive advantage affects their sourcing strategy and allows them to develop manufacturing capabilities to support more favourably the important competitive criteria. In accordance with Wu (2003), such large manufacturers have a better chance in achieving “lean logistics” than their suppliers do, as it is more likely for large firms to have resources and bargaining powers.

Large manufacturers create for themselves some conditions that are close to the ideal and are hard to be achieved by most organizations. If all participants in a supply chain could become closer in terms of geography, technology and information system, the lower lead times and information delays would allow production to be regularly adjusted to the updated real necessities of clients. This ideal situation between supply chain agents would enhance flexibility across the supply flow while simultaneously reducing the dependence of programming based on forecasts. Consequently, wastes in information and material flows among supply chain agents would also be reduced, increasing the overall efficiency. This would truly represent an application of pull and flow principles throughout the entire supply chain. Moreover, even if such integration brought eventual losses to some supply chain agents, one could easily argue that these would be compensated by the enhanced competitiveness of the whole chain due to higher value aggregation to the final costumer. At least, this is the belief of Womack and Jones (2003), which is very much influenced by the automobile industry.

Unfortunately, the argument of higher competitiveness in the whole chain does not always find sustainability outside the production sphere. There are many barriers to it. The proposition of a pull system between all supply chain agents ignores their different bargaining powers and perhaps even individual needs, such as for economies of scale. Besides, the firms must constantly balance between the needs of customers and shareholders. Firms with higher bargaining power and open to the stock market may be more compromised with their shareholders than with partners in the supply chain. Under certain circumstances, during negotiations they may even be compelled to take advantage of this to try to quickly expand profit margins. Thus, some firms may behave opportunistically, trying to gain at the expense of other firms. These “outside” constraints to integration and cooperation are usually overlooked by the majority of studies in operations management.

With a restricted focus on manufacturing, it would seem natural to think that the firm's sourcing strategy is only affected by the degree of component independence or product modularity (e.g., Voordijk et al 2006). One can even be tempted to conclude that Just-in-Time (JIT) production and pull platforms should be applied to components that are either modular or present limited functions. At a first glance this is not absurd, since breaking a complicated product into smaller and simpler pieces means finding more components that are interchangeable, autonomous, and individually upgradeable. However, the discussion so far shows that, depending on the industry, there are more factors that need to be considered when deciding the sourcing strategy and the way of mobilizing components and resources through pull or push. Hagel and Brown (2005) mention that designers of resource mobilization systems need to think through carefully at what levels in the system or under what circumstances push models may be more appropriate than pull models and how these two models intersect. The authors add that it is best to think of push and pull models along a continuum rather than a set of binary choices.

Regarding construction projects, the reality is far from ideal. There are hybrid modes of governance within construction projects that, together with the site production and one-of-a-kind product peculiarities, also impact the degree of proximity between project participants. Fontanini and Picchi (2004) describe construction as being a highly fragmented industry, with leadership shared among developers, contractors, designers, and sometimes with suppliers with higher bargain power than downstream players. The authors add that the supply flow involves a complex chain of diverse products and services (material, components, rented equipment, etc.) coming from several industries. This characteristic results in higher coordination problems in the supply flow in construction, comparing with other industries (e.g., Fontanini and Picchi 2004).

Voordijk et al (2006) describes three modes of governance that can often exist inside the same construction project:

- Market governance: corresponds to a low proximity of supply chain elements, since parties are autonomous and deal with each other by market contracts;
- Hierarchical governance: corresponds to an integral supply chain architecture with close proximity among its elements, since activities are integrated into one organization;
- A modular production network: corresponds to a vertically disintegrated governance structure where there is less frequent and intense interaction than in relational networks, but with rich streams of data flowing across highly formalized inter-firm linkages, such as the transfer of digital design files.

In a way, the construction industry defies Fine's three-dimensional modularity concept, even though the delivery of an integral product would ideally require integral processes across all project phases and closer relationships between participants in the value creation chain. Of course, the great number of components and participants required for a new large-scale product-developing project provides a partial explanation. But it should be reckoned that the choices in business strategy and production strategy also play a part in aggravating the hybrid aspect of the governance structure in the project organization and thereby worsen the degree of integrality needed.

For example, a general contractor that performs a wide range of projects needs to have a more robust structure than a specialized contractor. Either that or outsource a great part of the activities in the projects. In the second case, flexibility stems from the local concentration of specialized small firms within the same sector that can be recombined into multiple configurations according to changing market demand and the requirements of the lead firm that is embedded in the matrix structure (e.g., Voordijk et al 2006). In accordance with traditional project production paradigms, these specialized participants supply/build components with a single or only a few functions (product modularity). Moreover, the outsourcing relationships are maintained without an intensively relational or hierarchical character (supply chain modularity), which makes easier the substitution of different functional components or project participants. But this also enhances the uncertainty within the project organization. Consequentially, the same low relational logic is applied to the process steps as their activities are dispersed by using time and space buffers in and off site (process modularity) to protect participants from different sources of variability, including internal ones. Hence, although obliged to be integrated in both time and space due to construction peculiarities, traditional project production methods try to contradictory create a more modularized project delivery process.

More recently, this product, process and supply chain architecture is being pushed to a new alignment due to external market press. Through the years competition has made products increasingly complicated in terms of parts and functionalities. Very often an individual component cannot be upgraded or innovated without considering changes in interrelated parts developed by other parties. Not only that, the growing time-based competition in project production has further contributed to the importance of carefully interlocking project stakeholders in order to enhance the reliability of project plans.

The discussion in this section helps to understand that integral processes and integral supply chains in project production have a better chance of being created under the "umbrella" provided by the general contractor. Although Fine's (1998) three dimensional modularity concept is not clear on the system's boundaries, the discussion suggests the general contractor's scope of activities as the boundary. Beyond it there are too many factors that lower the degree of proximity between participants. Therefore, products manufactured in multiple factories and from there taken to the construction site are modular products tended to be designed and built by modular processes. Oppositely, integral products are the parts resulting from design and construction activities concentrated under the general contractor's responsibilities.

2.2.3 - The Impact of Production Paradigms

Perhaps the most critical barrier to enhancing integrality in project production is not an outside factor, but rather an internal one. To begin with, when two people experience the same event, their mental images of that event will not be identical (e.g., Gillard and Johansen 2004). Thus, each of us lives in a world built upon numerous assumptions, many of which result from everyday experience. These encompass a body of hypothesis, beliefs and principles used to explain phenomena. As mentioned by Werther Jr. (2003), our lives are built upon a foundation of assumptions that are seldom questioned. In fact, they tend to be reinforced whenever events occur in ways that corroborate their validity. Together, these assumptions form each individual's assumptive world. Werther Jr. (2003) adds that underlying all strategic actions and changes are the explicit or tacit assumptions held by leaders. Thus, before dealing with stakeholder resistance, leaders need to be aware of their own assumptions and how those assumptions shape their actions.

Ideally, the use of a multi-perspective approach to capture different “worldviews” would be very appropriate for decision-making (e.g., Checkland 2001). It would lead to finding accommodations and taking purposeful action in the situation aimed at improvement. Methodologies for such an approach have been developed to support organizational improvement efforts. One example is the Soft Systems Methodology developed by Checkland (2001), which learns by comparing pure models of purposeful activity with perceptions of what action is going on in a real-world problem situation. The author describes the Methodology as an articulation of a complex social process in which assumptions about the world – the relevant myths and meanings as well as the logics for achieving purposes which are expressed in the systems models - are teased out, challenged, tested. It is thus intrinsically a participative process because it can only proceed via debate.

Unfortunately, everyday adaptive decision-making cannot be done on the same basis, since it very often needs to be done in real-time. In situations with higher time pressure or increased ambiguities, individuals use intuitive decision making rather than structured approaches. This helps to understand why sometimes conflicts occur between the design and operation of a production system. It is not unusual for a production system to be designed following a set of conceptualizations, but operated according to different assumptions. This problematic situation is also common when structuring and managing other organizational functions and provides a partial explanation to systemic inefficiencies.

Nevertheless, organizations find different ways to deal with this matter. Current benchmark companies such as Toyota have built an exceptional workforce by striving to maintain people’s jobs, at every level. This has been one of Toyota's secrets to creating a sense of unity, to improving work, and, most important of all, to making employees at all levels embody through time the same values and vision that founded the world famous production model known as the “Toyota Production System”. The same strategy is applied to outsourced operations.

With respect to authority flows, this aspect of Toyota’s production strategy is well in accordance with Mintzberg (2003), who studied missionary organizations and concluded that the decreasing formality in the division of work increases the importance of coordination through the shared values and beliefs in a given group. Morgan and Hunt (1994) acknowledge the shared values as extensions of the common beliefs people have about the behaviours, goals and policies that are important or not important. The authors add that shared values are prerequisites to trust and commitment. Thus, as organizational structures become flat and characterized by decentralization and delegation of responsibility, the procedural patterns tend to be substituted for behavioural patterns. This shows the importance for modern organizations to define and make explicit what they expect from employees in terms of profile and behavioural patterns. Such information becomes a useful guideline to both staff selection and training processes.

Regarding change management and continuous improvement, Spear and Bowen (1999) argue that the common goal or vision of what an ideal production system would be is believed to inspire and drive further improvements to existing production systems, from the highest to lowest levels of the organization. Continuity among personnel and their ever blending assumptions has led Won et al. (2001) to mention that the difficulty in replicating Toyota’s successes lies in articulating a system that grew naturally and largely unwritten over the course of decades, particularly by rigorously implementing the scientific method.

As for traditional project production and management, in spite of individual “worldviews”, perhaps the most widely diffused is the assumption where a project can be broken down into parts that can be improved separately or managed independently towards the established goals (e.g., Bertelsen 2003, Ottosson and Björk 2004). It is believed that the parts can then be subsequently reassembled in a logical sequence to form the original totality (e.g., Howell 1999). As a consequence, conventional construction management practices have focused on variances from project objectives for quality, cost and schedules. The prevailing managerial mentality has been to allocate responsibility to internal and external work parties, which are then controlled against schedule and budget commitments. That is, in many aspects more attention is given to the process output than to the process itself and its interconnections (e.g., Koskela 1992). Koskela (2000) calls this theoretical foundation the transformation model.

The decomposition of specialists and steps becomes even more significant if the product is characterized by having a high cost, an intense use of engineering and information technologies and a rich array of customized subsystems and components. The process of subdividing a project into smaller parts makes it easier to track progress of the project and maintain accountability for various tasks (e.g., Lim and Yeo 1995). Hence, the explanation lies in the human mind, which, according to Mawby and Stupples (2002), can only predict behaviour in the case of simple systems with two or three interconnected decision areas. Friend (2001) defines a decision area as nothing more than a description of any area of choice within which people involved in decision making can conceive of more than one possible course of action that might be adopted, now or at some future time. Mawby and Stupples (2002) add that with more decision areas, computer models are required for accurate comparisons of the impact of alternative project strategies and combination of strategies. Friend (2001) came to the same conclusion when developing his Strategic Choice Approach method for structuring interrelated decision problems under pressure. He observed that in practice it is rarely advisable to select a focus of more than three or four decision areas as a basis from which to proceed to closer exploration. Because the origins of the Strategic Choice Approach are more empirical than theoretical, the author’s advise provides evidence that the human mind is in fact behind the reductionist thinking and, probably, of many transformation model concepts.

Although it should be reckoned that the process of subdividing a problem into smaller parts is a natural human phenomenon, a revision based on complexity theory shows that it is wrong to assume that the sum of the parts equals the total (e.g., Bertelsen 2003, Leite 2004). Even so transformation model concepts and tools have become widespread by being passed on through generations of scholars and practitioners. The focus on parts and outputs has dominated management thinking throughout most of the twentieth century and can be traced back to production models that share a reductionist view to solving complicated problems, such as those nowadays known as Taylorism and Fordism. While seeking for renewal initiatives, construction firms have arbitrarily incorporated to project production much of the traditional cultural, structural and managerial paradigms that worked well for industries characterized by high production volume and a low product variety. In these industrial environments, organizations possess high division of work, vertical communication and tall hierarchic structures. In construction, transformation model concepts are also quite evident in the use of project management techniques like PERT/CPM and manufacturing strategies like specialized work force, just to mention a few.

For a long time, solutions inspired by this conceptual base were successful in many sectors for allowing efficiency gains in the fabrication of relatively simple products. However, over time the lively competition in free-market economies has turned products increasingly complicated and innovative, forcing the design and production of components to be highly fragmented between various participants. This is mostly evident in mature industries where networks of specialist firms are well developed and activities are commonly outsourced (Hitt et al. 2003). The major result has been the increased complexity and difficulty of coordinating organizations. This is also the case in the construction industry, which is one of oldest industries in history. As a matter of fact, in construction projects most problems arise exactly from the interconnections between participants, both inside and outside construction sites.

Of importance to note are the numerous contradictions and implications the traditional paradigms have for the design and operation of project production systems. As if it were not hard enough to create integrality with construction peculiarities and contingency factors in the market place, the division of work fundamented on the transformation model is also characterized by a low relational level between participants. Commonly, similar criteria are adopted for the selection of material suppliers and subcontractors, reflecting the option for a procurement strategy based on low relational contracting with both types of project stakeholders. Therefore, as discussed in previous topics, little distinction is made between the particularities of supplying a tangible, modular component that can be stocked from those of providing a service with unique results that cannot be stocked.

Consequently, as the contractual chain grows longer, the relationship between the various sublevels of contractors and the client grows weaker (e.g., Sacks 2004). From the subcontractors' point view, the poor relationships with the contractor contribute to demand uncertainty and lack of trust in project plans. This leads specialty-contractors to try to achieve full capacity utilization by distributing and shifting resources among different construction projects. As service suppliers, they aim to keep resources busy at all times. Moreover, construction projects tend to be resourced for minimal uncertainty because their costs are a function of the cost of the resources allocated. Thus, subcontractors believe that high resource utilization will maximize their competitiveness and their returns. The local optimization is done even though it is difficult to accurately determine the capacity required for a project due to its uniqueness.

As observed, the subcontractor's attempts to achieve full capacity utilization turn the production system vulnerable to disturbances. This approach to project resourcing, while common, leaves little room to accommodate difficulties when things become variable (e.g., Horman 2001). Variations in the rate at which work is supplied from upstream trades leads to degradation in the performance of the downstream trades and thereby to extending the project duration. But even worse, the negative impacts on workflow are not limited to a single project. Because subcontractors engage multiple projects, a disturbance in one economic system may trigger harmful dynamics that can easily spread beyond its borderlines (e.g., Rodrigues and Bowers 1996). Consequentially, the temporary organizations established for the missions are open systems and activities within a particular project are not independent processes (e.g., Bertelsen 2003a).

Therefore, uncertainty brought upon subcontractors from the use of transformation model concepts turns them into sources of uncertainty internal to the project organization. From the project point of view, it is a self reinforcing cycle. As discussed by Sacks (2004), a schedule that is unrealistic for one or more parties can be a disaster for all who plan on it. This is unavoidable in an environment of poor relationships, because only the subcontractor can plan its own operations to create a schedule that is realistic economically (e.g., Sacks 2004). In each project the lack of transaction transparency together with the substitution of subcontractors with different work methods make it difficult to elaborate trustworthy plans for tasks and resource allocation, which are many times based on data provided by subcontracted parties or extracted from previous projects. Hence, the high subcontracting and substitution rates transform the subcontracted work into a considerable source of uncertainty for project managers.

As a consequence, the low level of confidence shown by project participants towards workflow reliability, project plans and allocated work capacity is reflected by the protection they individually seek through the application of time buffers. Instead of deliberately providing a modest excess of capacity, subcontractors prefer to achieve full capacity utilization and to place time buffers between steps in response to the lack of confidence in fulfilling the established goals. Although this is contrary to the notion of time being an important competitive criterion in project production, subcontractors are more concerned with ensuring their own survival than in helping the general contractor fulfil project goals. Thus, the local optimization works against flow because of time buffers placed between steps by participants in each hierarchic layer. In all cases, the redundancies respond for the overall organizational inefficiency and are a direct consequence of the deficient interrelationships.

Even though organizational complexity is pretty much a consequence of the product's large-scale and uniqueness, it is clear from the discussion that transformation model concepts used in designing and operating production systems contribute to increasing uncertainty in commitment, methods and goals (e.g., Koskela 2003). Although this may not represent a major problem for suppliers of highly modular components, it does enhance the challenge for those involved in the production of unique parts, whose efforts require high integration and synchronization. Therefore, the use of transformation model concepts and practices are contrary to the design and construction of highly complicated products that require better interactions between all those involved (e.g., Koskela 1992, Koskela 2000). Interestingly, this shows that not only do individuals have assumptions that naturally differentiate each one of them and their actions, but contractors also make it worse by structuring and managing project organizations based on the assumption that a difficult undertaking can be accomplished with a low relational level.

Moreover, the transformation model seems to be the "mother" of many wrong assumptions in large-scale product developments. To begin with, the traditional paradigms create the assumption that work should be benevolently driven from above. Unlike in manufacturing, where the work released moves down the line based on the design of the factory, in construction the work is released by an administrative act, planning, so that the teams can move around the product (e.g., Howell 1999). The project manager breaks the mission into smaller objectives, which are then passed on to the work teams. Because of this, it is quite common for the manager to wrongly assume that it is up him to make decisions at all times instead of getting decisions made.

Of course, this would not be a problem if the manager was close enough to the subordinates who are actually performing the tasks. After all, projects are temporary processes and thereby project managers are supposed to be process leaders. In theory, to have ownership of the process, besides proficiency, all that a manager needs is to stand in a spot that gives a proper overview and sufficient information, allowing him to know the process, exercise leadership and implement changes (e.g., Harrington 1993). However, in practice this has to be done by someone else closer to the workers because construction peculiarities together with the high division of work and tall hierarchic structures puts the manager to far from where all the action is happening.

Consequently, construction projects can either have managers get overwhelmed with micromanaging many aspects of production or organizational charts showing many authority relationships in the chain of command, formal channels of communication, formal work groups and formal lines of accountability. These are the two most probable ways of managing large scale product developments under transformation model concepts. But both show negative side-effects in complex environments. In the first case, high technique and experience is needed for planning and controlling, because of the complexity of the work breakdown structure and the dependency among activities (e.g., Qing et al. 2002). Moreover, experience shows that centralized decision-making in complex environments can actually turn managers into informational bottlenecks, leading to more frequent and worse interventions (e.g., Maani and Li 2004). As for the second case, superimposed on the relationships are informal or de facto relationships that are not necessarily sanctioned by the organization, although they might be perceived to actually exist, and are thus considered by some, to be the real structure (e.g., Van der Merwer 2002). The way people actually perform tasks or relate to each other bears only limited similarity to how formal organization structures and plans says they should behave. In both cases, there are unknown internal factors causing dynamics that lead the totality to be greater than the sum of the parts (e.g., Rodrigues and Bowers 1996, Bertelsen 2003). This pretty much contradicts the fundamental assumptions of the transformation model.

In closing, the reductionist approach and thereby transformation model concepts, which propose handling problems by decomposing them into simple parts, become inefficacious when applied alone in a complex, unstable, adaptive system. What this means is that in some circumstances, complex systems should not be broken down in parts, but rather looked at in a holistic manner. Thus, a more comprehensive view supported by other theoretical conceptualizations will sometimes be more appropriate for a fuller understanding of the situation and even for decision-making. But this also means that the holistic characteristic, although important, should not be entirely separated from reductionism, since up to now a pure holistic procedure that is truly effective, quantitative and realizable remains inexistent. Borges (2006) argues that both schemes must be applied cooperatively according to the “glocal” paradigm, which states that people should think globally but act locally. This is aligned with the recommendation made by Bertelsen (2003) regarding the need to consider the interconnections between participants as important as the work to be done by the participants.

However, the challenge remains on when to apply the holistic view or the reductionist view in project production. New insights are required to change managerial habits and to keep managers from exacerbating complexity, even though they may have the best of intentions. Such knowledge would be very useful in helping contractors understand how to balance and articulate both schemes for the sake of organizational integrality and, thereby, of project success.

2.3 - The Challenge of Handling Complexity in Project Production

The discussions in the previous topics show that the same factors representing barriers to integrality are also the sources of complexity in project production. But no matter what the cause, complexity is a phenomena manifested in the organizational realm. In other words, complexity arises from the consequential heterogeneity of the project stakeholders and from the difficulties of interlinking them in different dimensions (e.g., Tunzelmann and Wang 1997, Baccarini 2003). As mentioned before, the problems associated with complexity are most obviously perceived through the non-linear interactions between the different entities that have an interest or a gain upon a successful completion of a project. Whenever these interactions occur, the amount of effort put into a task is not proportional to the results achieved.

2.3.1 - Distinguishing Complicated from Complex

Inside the project organization, the non-linear interactions are behind what construction researchers (e.g., Koskela, 1992, Howell 1999, Ballard et al. 2001) call the variability of systems and subsystems. This means that the variation seen in productivity rates, rework and other performance measures is nothing more than the final result of non-linear dynamics between project participants. Therefore, regardless of having been started by an external or internal event, the dynamics are aggravated by flaws in the interconnections within the organizational structure.

This notion leads to a review of the common understanding of project complexity. To begin with, Snowden (2003) defines products (engine, refrigerator, car, airplane, house, etc.) as complicated systems, since their components are stable with time and can be improved by optimization. In this case the total is equal to the sum of the parts. Differently, complex systems are complicated and unstable, which means they change shape and pattern with time (e.g., Ottosson and Björk 2004). As discussed, a business organization is a good example of a complex system where small changes expressed through opinions, decisions and actions are amplified by others and disproportionately cause large effects (e.g., Goldoff and Jay 2003). The more people involved the more probable it is that completely uncontrolled dynamic changes will occur. The non-linear interactions among them make the total differ from the sum of the parts.

For a long time, the common assumption was to interpret projects solely as complicated systems, as demonstrated by the use of transformation model concepts and tools like PERT/CPM and Line of Balance (e.g., Assumpção 1996, Mendes Jr. and Heineck 1999). More recently, there has been a tendency to interpret projects exclusively as complex systems (e.g., Bertelsen 2003, 2003a, Bertelsen and Koskela, 2003). However, this dissertation proposes that both approaches be reconsidered and combined so as to visualize each project as a blend of complicated system (product) and complex system (organization) (Figure 4). The two realms must be dealt with in different but complementary ways.

A product is characterized by a set of attributes like purpose, criteria, functionalities, components and value. These attributes not only establish the product’s cost and quality standards, but also its degree of constructability. Changes in the attributes affect how simple or complicated will be the product. On the other hand, an organization is characterized by the policies, strategic choices, resources, capabilities and core competences that generate its robustness and constraints. Changes in these characteristics alter the system’s robustness and transform the way the various subsystems interact routinely or when submitted to sporadical events.

There is no direct relationship between the product’s level of complication and the organizational complexity. A complicated product can very well be entirely designed and built by a small number of people if there is sufficient time and skills. This was a remarkable aspect of the craft production of the early automobiles, which was later supplanted with the advent of mass production due to the growth in market demand, time-based competition and product proliferation (e.g., Womack et al. 1990). This corroborates the notion that organizational complexity is not just a consequence of the product type, but rather the cumulative by-product of decisions regarding business selection, structure and management (e.g. Gröbler et al. 2006, Ashkenas 2007). Therefore, a small project can be more complex than a large one if there is a great amount of uncertainty, either in product goals or in organizational methods, added to time and cost constraints (e.g., Williams 2002, Liu and Leung 2002).

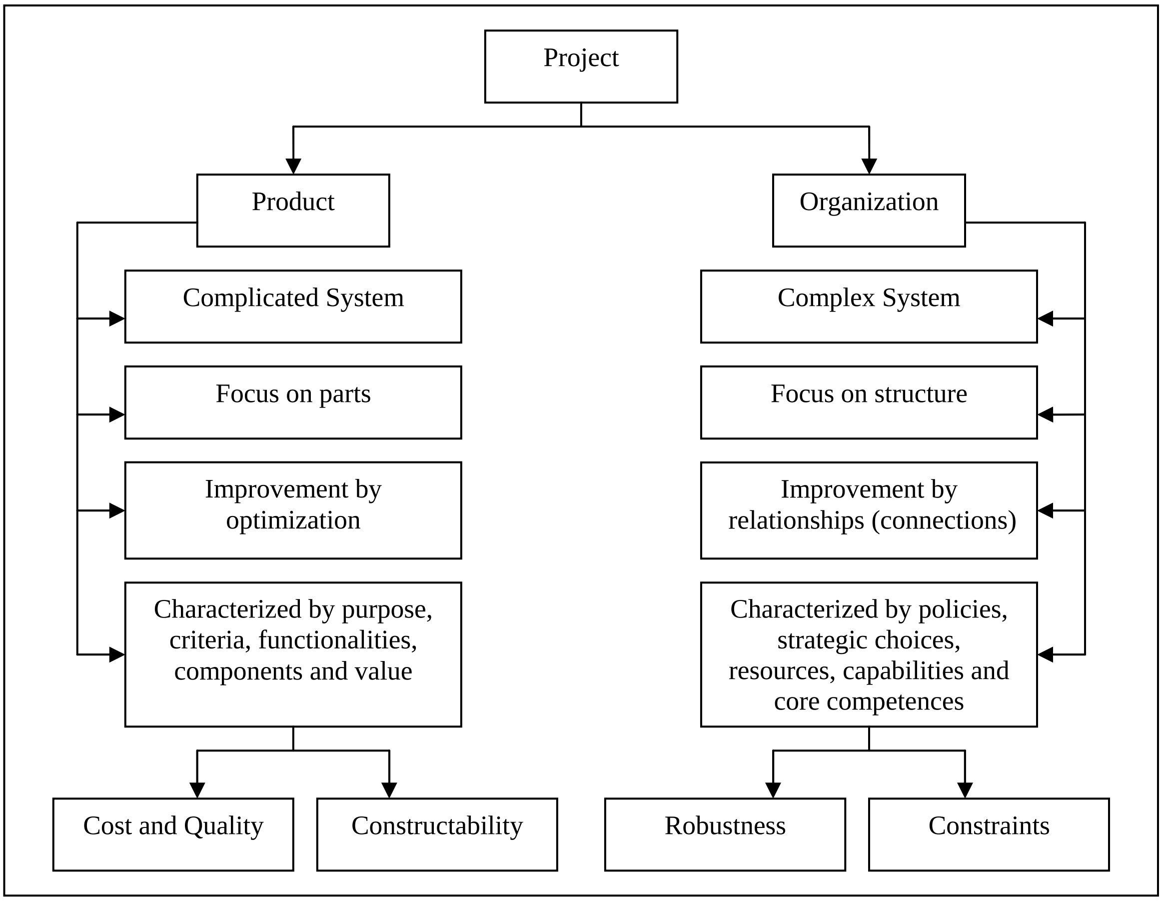

Figure 4 – A model for project realms, where complexity is directly derived from the organizational structure and not from the product. Source: Miranda Filho (2008)

Distinguishing a complicated system from a complex system is an important step to guide improvements in project performance. Ottosson and Björk (2004) observe that traditional management and research practices can deal well with complicated systems, i.e. systems consisting of many components that are stable with time. Complex systems, on the other hand, cannot be dealt with in the same way as stable systems, because the changes are greater in each chosen time interval. The non linear interactions in complex systems cannot be predicted by traditional budget and schedule tools, as they are the results of relationships inside and among the various subgroups in the structure. Thus, countering the harmful effects of non-linear interactions requires paying careful attention to the design of the organizational structure and managing complex systems in real time as much as possible.

2.3.2 - The Sources of Non-linearities

Understanding the non-linear dynamics and how they are aggravated is a prerequisite to devising solutions for structuring and managing large organizations. When facing a management problem, project managers tend to assume that some external event caused it. Indeed, Thomas and Napolitan (1995) have reported in quantitative terms the impact of disruptions during construction and shown the importance of avoiding them, since they are the root cause of loss of efficiency. But not every management problem is caused by an external event and secondly, the way external events evolve and are dealt with pretty much depends on the organization's internal capabilities. According to Kirkwood (1998), from the viewpoint of systems thinking, the internal structure of the system is often more important than external events in generating problems.

Moreover, the problems faced over and over by the management team are, very often, symptoms of an underlying cause in the organizational structure. Looking at symptoms, not at the underlying cause, leads to corrective interventions that may amplify the problem or generate other deviations. For this reason, Toyota's Just-In-Time inventory strategy says "ask why 5 times", which is its way of pointing out the need to find the underlying cause. Therefore, uniting the traditional event orientation with a focus on the internal system structure can help improve the possibility of improving project performance. However, perceiving how non-linear dynamics originate, propagate and affect the systems requires combining ideas from different systems thinking approaches like theory of constraints, system dynamics and complexity theory.

The application of theory of constraints in construction projects has gained increasing attention and has been very much about project scheduling and buffer management. For instance, Rand (2000) explored the ideas contained in theory of constraints to make recommendations for project management using the PERT/CPM approach. Steyn (2002) illustrated the application of theory of constraints to manage resources shared by concurrent projects. Complementarily, Wei et al. (2002) discussed several drawbacks of traditional project management and of existing theory of constraints project-scheduling techniques. Additionally, Yuan et al. (2003) proposed a generic inventory buffer management procedure.

Differently, the system dynamics approach is still a relatively rare technique and perceived as being too costly and of little value until a contract has been awarded (e.g., Rodrigues and Bowers 1996, Watt and Willey 2003). Therefore, it tends to be employed to modelling and refining a project when a special concern arises (e.g., Mawby and Stupples 2002). The dynamic modelling of construction systems with local contextual factors has been adopted to simulate the implications of strategic policies and resource management decisions (e.g., Ogunlana et al. 2003, Park 2005). System dynamics simulation modelling has also been proposed to support the negotiation of a disruption and delay settlement by showing what would have prevailed if the events had not occurred (e.g., Eden et al. 2005). But because any model of project dynamics requires the modelling of hard (quantitative) and soft (qualitative) variables, academics have described this approach as being only complementary to the traditional practices and as requiring itself the support of other approaches like Soft Systems Methodology (e.g., Rodrigues and Bowers 1996, Checkland 2001, Ulloa and Caceres 2004).

For the exact same reasons, some authors consider it to be more useful in showing tendencies than in providing accurate data (e.g., Rodrigues and Bowers 1996, Mawby and Stupples 2002).

In construction projects, the two systems thinking approaches described above have been mainly applied from a project management perspective. Moreover, the applications and analysis were conducted under traditional production paradigms, tending to dismiss current structural and cultural changes in project production. The exceptions are the papers based on complexity theory (e.g., Bertelsen 2003, 2003a, Bertelsen and Koskela, 2003), which have brought greater clarifications to the systemic behaviour of large-scale product developments by discussing it from a more organization-wide approach and in the light of new production philosophies. In accordance, a comprehensive understanding of the non-linearities in complex organizations also requires the adoption of a wider perspective and, most important of all, the combination of ideas from different systems thinking approaches.

To begin with, Kirkwood (1998) states that many business processes are nonlinear, especially when pressed to extremes. For example, while it may be true that if an employee works ten percent longer hours he will accomplish ten percent more work, it is probably not true that if he works twice as many hours he will accomplish twice as much work. By trying to increase even further the amount of overtime the employee soon suffers from fatigue, which leads to a reduction in his working effectiveness. Similarly, despite the efforts and goodwill of the sales team, if the degree of customer demand grows too rapidly the available production capacity of a manufacturing plant may limit the amount of a product that can be sold, making costumer satisfaction give way to costumer dissatisfaction. These are both practical examples of nonlinear responses encountered by business organizations.

These problematic situations can also be replicated inside classrooms. For instance, a common exercise in organizational behaviour courses is one that begins with a short story containing specific details being told to the first person in a line. That individual has to tell the exact same story to the next person. This goes on until the end of the line and is done under a certain time stress. It is observed that the larger the number of individuals involved, the larger the amount of information being passed on and the shorter the given time, the more distorted and incomplete will be the story told to the last person in the line. This exercise allows students to perceive how non-linear dynamics originate and spread in an organizational environment. Moreover, it shows that the degrees of geographic and cultural proximities between the participants, although important, are not enough to counteract non-linearities. The participants are simply overwhelmed by the amount of information that has to be memorized and transferred in such a short time.

What stands out from all these examples is that the non-linear behaviour of the interactions is aggravated by constraints in the systems. Although in each case the variables representing constraints to the goals may be different, they are of similar nature because all relate to the capacity of the resources involved. Indeed, resources are defined as things that have a limited capacity to bear loads; e.g., labor, tools, equipment, space, and time (e.g., Ballard et al. 2001, Ballard and Howell, 2003). Even though systems are nowadays being mostly constrained by organizational policies (e.g., Goldratt 1990), it is common knowledge that rules can be broken while resources are often physical entities that cannot. This shows the importance of considering the impact of overloaded resources in cause-effect chains.

A visual representation of the aspects herein discussed can be made using causal loop diagramming from the system dynamics approach. In a causal loop diagram, the arrows represent influences between the different factors (e.g., Park 2005). Moreover, the plus or minus sign indicates whether a positive change in the preceding factor has a positive or negative effect on the next (e.g., Rodrigues and Bowers 1996). Considering the first example described, the smaller causal loop is represented by variables like overtime, task progress rate and adjustments to schedule (Figure 5). Under schedule pressure, the project manager may try to catch up the delayed schedule by adopting overtime as part of the production strategy. To a certain extent, this managerial decision works well and the increased work hours are successful in neutralizing the perceived schedule slippage. The loop has an odd number of negative relationships, which suggests a complete balanced cycle with the system stabilizing itself. However, increasing the overtime even further is likely to cause fatigue, which possibly lowers work quality and subsequently counteracts the construction performance enhanced by the increased work hours. Thus, the previous dynamic becomes dominated by a larger dynamic comprising these variables. The new dynamic has an even number of negative relationships, which stands for a self-reinforcing loop. That is, the system keeps on perpetuating the problem, with more work generating more errors and more rework in turn. The final result is quite different from what was originally intended.

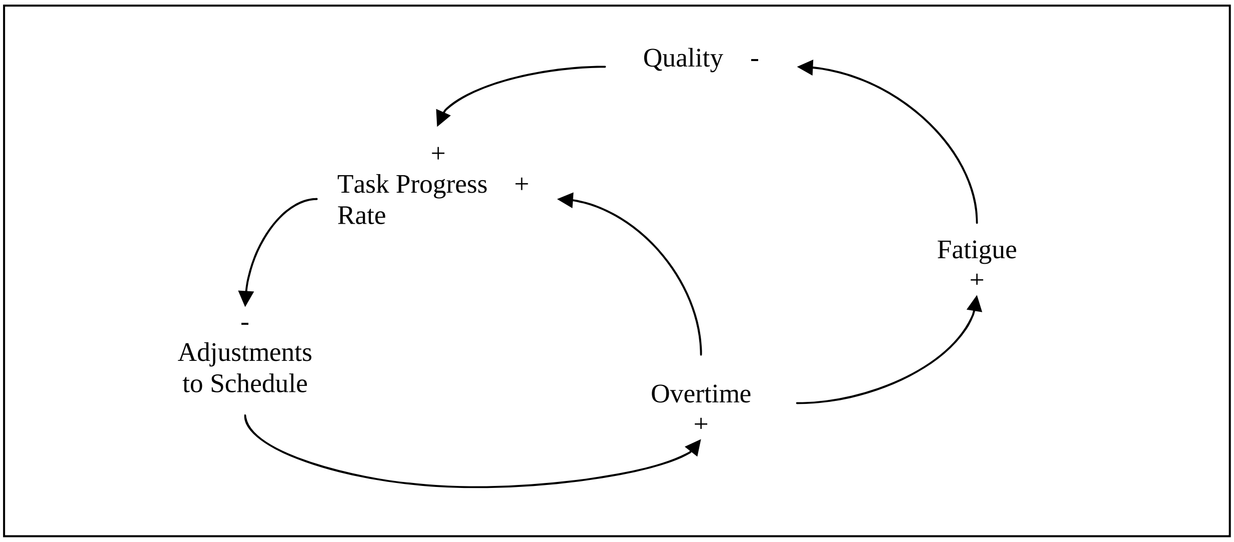

Figure 5 – Causal cycles before (smaller loop) and after (larger loop) exceeding the load capacity of the workforce. Source: Miranda Filho (2008)

Regardless of having been started by an intended or unintended event, the dynamics originated after exceeding a constraint’s load capacity will always be harmful to business performance. As a matter of fact, if the desired state of a subsystem is characterized by specific values for a relevant set of variables, an event causing one of those variables to change beyond a tolerable limit alters the state and is, thereby, considered to be disturbing the course of the subsystem (e.g., Corrêa and Slack 1994, Campagne et al. 1995). For this reason, Van der Merwer (2002) mentions that often the optimal operating point of a subsystem is against one of the constraints of the operating window. Hence, many control applications employ a strategy that pushes the subsystem against the closest active constraint.

However, the closest currently active constraint typically changes with time and situations. This is especially true for construction projects because the statistical or spectral properties of these systems are not stable. Even though theory of constraints considers a constraint to be a focusing point around which a business can be organized or improved (e.g., Goldratt 1986, Backstone 2001), there may be little time to identify and exploit internal constraints in complex adaptive systems that have a continuously changing structure (e.g., Meijer, 1998). To make matters worse, in large project organizations the work is accomplished through a structural mitosis that has created many hierarchic layers (vertical differentiation) and different occupational specializations (horizontal differentiation) (e.g., Baccarini 1996). As previously discussed, the high level of differentiation within the organizational structure added to the peculiarities of site production has a negative influence on the degree of operational interaction between the project elements. This implies that there can be not one, but many unknown constraints that are being pushed to the limit as the dynamics propagate throughout the organization all the way to the frontline workers. Consequently, what may seem like a simple decision or request to a project stakeholder can turn into a major exercise for hundreds of other people. The lack of sufficient information regarding the existing constraints and the interconnections between the components of a large system explains why a series of outputs may appear random to an outside observer.

The dynamics caused by an event can lead to a phase transition, where the system undergoes a change to develop substantially different properties. In construction, managerial interventions to absorb environmental dynamics or to initiate planned activities also start dynamics that rapidly create intermediate states or move the production system from one project phase to another (e.g., Bertelsen 2003a). Alterations in product specifications or scope, hand-over of activities to different specialists, addition of workforce, and changes in the construction site layout are just a few examples of events resulting from active interventions. Like in any other complex system, collective properties emerge everytime the production system is redesigned during the project life cycle, strengthening the one-of-a-kind nature of construction. But the notion that the dynamics of both intended and unintended events can have positive and negative influences shows that it is paradoxical that a project is itself a process of continuous change, but within the project every change may be hazardous (e.g., Gabriel 1997, Love et al. 2002).

Knowing that dynamics causing positive and negative influences co-exist throughout a project's life cycle implies that appropriate solutions need to be devised to maximize the positive influences and minimize the negative ones. This volatile systemic behavior is a source of concern that can be prevented if addressed early in the process of production strategy formulation. The decisions made when designing the production system can not only create capabilities that reduce the negative influences of harmful dynamics, but also induce a project to undergo less intersecting phase transitions. Underlying the production system design and operation should be the philosophy that a system cannot achieve management goals nor be improved if it is not stable. "Stability" means the system can produce repeatedly the required quality, mix, quantity, delivery time, and cost in spite of sources of variation (e.g., Won et al. 2001). Even though construction projects need to pass through a series of phase transitions, it is necessary to place emphasis in understanding how particular project organizations can be designed and operated to deal with the dynamics that cause a process to vary from the expected or desired state during a phase transition.

2.3.3 - Opportunities for Stabilization

There are two main observations that can be made based on the previous discussions. First, the non-linear interactions between project stakeholders naturally arise from their non-proximity in terms of geography, organization, culture and technology. Second, the non-linear behaviour of the interactions is considerably aggravated by overloaded resources in cause-effect chains. These notions are particularly important to appreciate the difficulty of making decisions and interventions in a temporary organization characterized by high division of work and many hierarchic layers.

As discussed previously, the only way to have a more complete view of a system before intervening is by capturing the different assumptions, knowledge and values of project stakeholders (e.g., Liu and Leung 2002, Werther Jr. 2003). In other words, the essence of a problem is tackled by extracting as much information as possible from the people involved or affected and by spending some time studying the options. However, in general, firms can only afford this holistic approach when they are committed to reengineering or improving the organizational structure. Similarly, in the construction sector the factors representing barriers to organizational integrality turn difficult the early involvement in a project, the creation of an open and trusting environment, and the interaction in all levels on a regular basis. These aspects keep a general contractor from applying a satisfactory holistic approach to project plans or in everyday problem solving.

Consequently, decision-making is mainly fundamented on the reductionist approach, where the focus is on a smaller number of events, decision areas and possible outcomes. This is especially true for time-stressed situations, like when dealing with the problems that arise during project execution as a result of poor integrality. The deliberate, conscious part of the cognitive process leading to the selection of a course of action is quite limited for managerial decisions in such circumstances. In accordance with Gladwell (2005), this leads the rational aspects in rapid cognition to operate more mysteriously within each individual's subconscious. For these reasons, Meijer (1998) affirms that hierarchical decomposition will continue being the principal solution for managers even in highly complex organizational settings.

Reductionist thinking causes managerial decisions to be commonly taken from a macroscopic perspective. A large project observed macroscopically is characterized and evaluated based on few variables, which creates the illusion of a predictable behaviour. Hence, managerial decisions are made considering a relatively small number of variables, such as the match between resources and tasks to accomplish the project schedule. However, as mentioned by Ottosson and Björk (2004), decision-making from outside or centralized in upper hierarchic levels will have serious problems in grasping the small things that are totally independent of the rules, goals, visions, business and project plans. These things, which include interrelationships and constraints, can actually change development processes. Thus, in a particular project the different interventions are either done: optimistically, with unknown constraints being overloaded and starting harmful dynamics; or pessimistically, with unknown constraints being dealt with by buffers placed in the project plans. This is a partial explanation to why detailed long-term planning, detailed income budgeting and detailed business planning are rather meaningless in practice.

Oppositely, from a microscopic viewpoint, even though the scope is narrower, there are many quantitative and qualitative variables interacting. For instance, when observed from inside and up close during a particular time interval, the construction site is seen as being packed with specialist teams, each with a different cultural background, moving around the product, colliding with one another, and communicating through both formal and informal channels. It is, therefore, a chaotic system that becomes even more confusing with the disturbances caused by interventions taken from a macroscopic view. Thus, Borges (2006) argues that what may look in order from one point of view may be seen as chaotic when analysed through another perspective. According to the author, this is the idea that interlinks the concepts of chaos and order.

The combination between reductionist thinking and macroscopic perspective illustrates the problem with strategies that allow the occurrence of many events and that foster centralized decision-making in complex organizations. The high probability of occurring uncontrollable dynamics that cause deviations indicates two main guidelines for a better stabilization of large project production systems. The first guideline relates to system operation and is concerned with the need to reduce the number of intended and unintended events to be handled by a production system. Intense and overlapping managerial interventions to absorb environmental dynamics or to initiate planned activities are most likely to overload some resources and thereby start harmful dynamics. For this reason, over-intervention, which is quantified by the magnitude and the frequency of changes, is counter-productive (e.g., Maani and Li 2004). Complementarily, the second guideline relates to system design and, in accordance with Pocock et al. (1996), is concerned with finding solutions that improve the production system's integration by increasing the quality and quantity of interaction between project stakeholders. Designing a production system in a way that enhances the degree of proximity between participants improves their interactions and allows them to help in keeping the subsystems operating optimally against the closest active constraints. This reduces the non-linearities in the system and consequently enhances the project performance. In summary, the idea behind the two guidelines is that managers should not try to manage complexity, but rather to organize the way around it (e.g., Meijer 1998).

To do so, it is important to perceive that product proliferation, structural mitosis, process evolution, and managerial habits reflect a bi directional influence to organizational complexity that can be minimized. The first influence comes from external drivers of complexity that force the organization to internally build-up complexity in order to cope with demands from the outside. The main drivers can be found in a firm's costumer base and the type of products demanded by the market place. In other words, the external environmental complexity in which the firm will compete is established by the business strategy. As a result, the complexity of the organization's internal structure tends to match that of the external environment. Of course, firms that have outsourced many of their fabrication tasks are likely to experience a lower level of internal complexity than a firm that manufactures the same goods with its in-house service functions (e.g., Gröbler et al. 2006). But even such firms still need to simultaneously take into account a number of aspects and to emphasize control on the interrelations with the different outsourcees (e.g., Meijer, 2002, Isatto 2005). This is especially true for the lead firm in a large-scale product development characterized by site production and performed under a tight schedule.

Fortunately, business organizations are able to select to a certain degree the external environment they want to "live" in depending on its complexity (e.g. Gröbler et al. 2006). Although the product requirements and contextual factors that influence internal aspects are established by the market place, it is up to top managers to decide about the specific strategic orientation or particular geographic area in which the firm will compete. Complexity is considered lower for firms with a higher degree of concentration or focus on certain customer segments. The choice to create value for a limited, well chosen, set of costumers helps to reduce the overall complexity and interactions to a level that can be successfully dealt with by the organization. The deliberate limitation reduces the number of aspects and interrelations that need to be taken into account simultaneously and the bandwidth and randomness of these relations (Meijer, 2002). Therefore, focusing the business proposition can not only reduce the internal complexity but also the exposure to events and unplanned changes that cause dynamics. This is well aligned with the two main guidelines for improving systemic stability.

Regarding the second influence to organizational complexity, it is important to recognize the internal drivers that largely contribute to the heterogeneity of participants, functions, and processes performed within the system and to the difficulty of interlinking them. These are of particular interest to the present thesis due to the notion that the internal structure of the system is often more important than external events in generating problems. As discussed throughout this chapter, how project organizations are structured also shapes the level of complexity they possess. Therefore, despite the influence of contextual factors in the market place, at least to a certain degree, organizations are able to reduce the complexity of the internal environment (e.g. Gröbler et al. 2006).

The importance of reducing the internal complexity is justified by the need to counter the non linearities. The notion that decisions taken from a macroscopic viewpoint can start harmful dynamics highlights the importance of developing capabilities to correct inconsistencies from upper level decisions and to shield downstream activities from upstream problems (e.g., Mawby and Stupples 2002, Ballard and Howell 2003a, Buch and Sander 2005). As mentioned by Isatto (2005), organizational structuring in civil construction requires a considerable attention to adaptive management schemes. However, this very much depends on implementing strategies and practices that reduce the internal complexity by limiting the degree of differentiation and improving the interconnections between participants. In other words, initiatives to promote simplicity and to enhance integrality are needed to reduce complexity. A production system designed to enhance the geographic, organizational, cultural and electronic proximities between participants improves their interactions and allows them to help keeping the dynamics from over loading the closest active constraints.

The higher degree of proximity of project participants eliminates intermediate barriers to the flows, including layers of authority relationships in the chain of command, and empowers the people at each level to make decisions and solve everyday problems. Integrality is, therefore, a prerequisite to decentralization and delegation of responsibility. Decentralize is to make the decision process less bureaucratic and quicker by reducing the number of hierarchic levels and other intervenients. Delegate is to trust the work parties and make them responsible for micromanaging different aspects of production. Fostering integrality makes total sense to a large project organization because the dynamics that need to be controlled propagate vertically, horizontally and diagonally across organizational lines all the way to the frontline workers. Hence, the initiatives supporting integrality can make the organization flatter and simpler.

Structural arrangements that support integrality and thereby workforce autonomy create a production system design dominated by self-stabilizing cycles. A system dominated by self-stabilizing cycles tends to posses a systemic resistance against disturbances because the variables within the negative loops will stabilize over time (e.g., Toole 2005). In contrast, a non-self-regulatory system does not achieve another steady state without additional external intervention once the first external occurs (e.g., Van der Merwer 2002). The system is more unstable and harmful dynamics are likely to arise and keep on reinforcing themselves until more interventions are made. But taking corrective action from a macroscopic perspective can always make matters worse. For this reason, implicit adaptation processes creating emergent strategies are highly needed in complex environments. In other words, under complex conditions the self-regulating mechanism of emergent patterns is of more relevance than explicitly crafted policies and plans (e.g., Mintzberg and Waters 1985, Gröbler et al. 2006).

Furthermore, it is true that in some circumstances self-stabilizing cycles within a system can be undesirable. For instance, systemic resistance can occur even to well-intended perturbations within the system, including to management actions taken to improve project outcomes (e.g., Toole 2005). This improperness can be explained by the fact that an existing organization has an attractor which locks the organization in its existing structure, patterns of interaction, ideas about the market, its costumers etc.. Meijer (2002) argues that changing means moving the system to the edge of this attractor and providing a new attractor. But the problem with most reorganization processes is that the intervention is carried by top management. If the attractor is not communicated or simply does not exist, the organization will most likely fall back to the old attractor but with the loss of people in the process (Meijer 2002). This is why discussions on new strategies are often frustrated with constraints from the existing structure. A successful implementation of changes in such a system may therefore require introducing change in several aspects within the structure (e.g., Toole 2005).

A production system design that supports workforce autonomy seeks to create the same systemic behaviour, but with the purpose of using it to increase the stability needed to achieve management goals. A flexible, motivated, autonomous work team becomes the attractor that ensures that a subsystem will move to the desired state during a phase transition or that it will remain there when disturbances occur. In construction projects, this is a particularly important competence because of the different changes the production system undertakes during the project life cycle. Thus, every ounce of intelligence has to be mobilized to control the dynamics in a complex temporary organization.

The advantage of achieving stability through decentralization and delegation comes from the fact that a change in one element takes several iterations to cause changes in the other variables within a feedback loop. That is, the causality around the loop typically occurs over time (e.g., Toole 2005). A system design that supports workforce autonomy allows a quicker response to harmful dynamics that otherwise would probably be detected only after the closest active constraints became overloaded. This operational proactivity reduces the trade-offs between project goals like time, cost, quality and safety.

2.4 - Conclusions

Project management as an engineering discipline in architecture and production is commonly described as a mature issue (e.g., Qing et al 2002, Van der Merwe 2002). However, the layers of complexity that have been added to construction projects have placed project managers too far from where value is being created to the final customer. Thus, even though projects are temporary processes, construction managers should not be seen as process leaders because of their macroscopic perspective of what is going on. Their frequent interventions may exacerbate complexity or cause greater deviations. Instead, the process leader must be someone closer to where the transformations are actually occurring. This insight shows the need to change managerial schemes and habits, because organizational complexity is a cumulative by-product of decisions regarding business selection, structure and management. Therefore, complexity leads to revaluating traditional paradigms about system design and operation in construction projects.

In a large-scale product development, an effective effort to create stability during the project's short life cycle requires managerial actions by people at all levels of the temporary organization. However, the proactive behaviour of all participants is very much dependent on structural arrangements made by the general contractor to create integrality in terms of geography, culture, organization and technology to the value creation chain under his command. Despite the influence coming from external drivers, internal adjustments that foster a higher proximity in those four dimensions can reduce to a certain degree the organizational complexity and improve interactions within the system. As a result of the increased integrality, different stakeholders, including frontline workers, become empowered to reduce the number of events to be handled by the production system and to help in keeping it operating optimally against the closest active constraints. This reduces the non-linearities in the system and consequently enhances the project performance.

The discussion so far suggests that the removal of barriers for the integrality of participants and processes responsible for delivering the integral parts of the construction product requires the general contractor to look back to the fundaments of project production and assume the role of the base organization. Although fundamentally every project must belong to a base organization, in large scale product developments very often the project developer or owner is not the agent responsible for creating the structure that supports temporary processes neither is interested in acquiring organizational knowledge to continuously improve performance. These are all aspects of interest to the general contractor. Therefore, the new insight indicates that the general contractor must step in to perform the role of base organization, seeing as "internal projects" the temporary processes performed by all internal and external specialist teams under his scope of activities. This is well aligned with the need to consider as process leaders people who are actually closer to the operations. More than the traditional management of interdependencies and resource allocation, this implies in providing to the work parties in charge of the "internal projects" the best conditions for autonomy and ensuring that their contributions are driven by the base organization's overall objectives. This hypothesis will be verified empirically in this dissertation. Furthermore, it is put forward that the search for simplicity and integrality, in contrast to complexity, is what intuitively guides the successful renewal solutions in project production and is, to a certain extent, causing the construction industry to shift back to the fundaments of project production.

CHAPTER 3 – THE CONTENT OF AN INTEGRAL PROJECT PRODUCTION MODEL

Although project management is considered a developed technology, system design in project production is still a developing topic, lacking a comprehensive understanding. Making a temporary complex organization more integral and simple represents a challenge not only to firms in the construction sector, but also to firms in different industries that focus on high added-value customized products. As different from one another as business organizations might appear on the surface, the underlying goal of stability is the same.

However, to understand stability and the workings of a best-in-class production model in a particular industry, one must analyse a top competitor's production strategy both in terms of tangible and intangible attributes. While a myriad of factors can affect the emergence of a production model, understanding a successful model and its underlying causes requires a careful look at a number of internal aspects, some of which may be somewhat unobvious to outsiders. For instance, the notion that integrality in a large-scale construction project requires, in the first place, the general contractor to perform the role of base organization, reveals that the roots of an innovative production system design may contain both strategic decisions and a paradigm shift.

Different from the narrow description of the content of production strategy commonly made in operations and industrial management literature, this points to the importance of also considering the underlying principles and assumptions that align the strategic choices in production strategy with one another and with those in other functional strategies. Best practices like mobile production cells arise from coherent, innovative organizational arrangements and can only be well understood if these tangible and intangible attributes are captured alongside with external factors. Therefore, it is proposed here that integrality begins in the foundation of a production model, through the shared principles and underlying assumptions that create coherence between design and operation decisions. The present chapter explores in detail this extended view on the content of production strategy, which becomes primordial to understanding the changes made for the implementation of mobile production cells in construction projects.

3.1 - THE DIVERSITY OF PRODUCTION MODELS

The discussion on construction peculiarities, governance structures and traditional production paradigms highlights the natural complexity of industry environments faced by organizations. It provides a basis to understanding the failures in transplanting contextualized methods to new environments. Moreover, it explains why the uptake of some conceptualizations has not been widespread. Boyer and Freyssenet (2000) argue that business strategies and the subordinate functional strategies are not equally adequate everywhere, at all times. This includes the production strategy. The reason lies in the fact that companies control the emergence of production models only to a certain extent. The emergence of the models can escape their control because it is partially the result of non-intentional processes. As well as the external context, there are many contextual factors within organizations responding for the complexity and evolution of a production model. For instance, there is tacit knowledge, which is dificult to imitate and is originated from everyday problems and experience.

In accordance with Contingency Theory, this implies that there is no best way to make decisions, to lead a group, or to organize a company (e.g., Chiavenato 1999). In fact, there has never been a one best way, neither in the past nor today (e.g., Boyer and Freyssenet 2000). In other words, the effectiveness of a production model is contingent upon various internal and external constraints, some of which have already been discussed in the previous chapter:

- Macro economic context;
- Local economic and social contexts;
- Competitive strategy;
- Technologies available;
- The size of the organization;
- Differences among resources and operational activities;
- Assumptions of managers and employees;
- Local and organizational cultures;
- etc.

This has generated the notion of equifinality, which states that there are multiple, equally effective ways in which an organization can achieve environmental or internal fit to compete within a particular industry (e.g., Christiansen et al. 2003). Thus, the plurality of production models inside a project based industry is not only a reality to be accepted but also a necessity. Boyer and Freyssenet (2000) point two main reasons: (1) firms have to find original solutions because of market and labour instability in their own areas and (2) when they find themselves in the same areas different strategies are developed to differentiate or avoid competing directly with one another. It is also important to remember that they may be using other sources of competitive advantages, rather than competing only through their production capabilities. And this is not just a matter of maintaining the competitive edge through brand or trade secrets, to mention a few. Besides different functional strategies, in a business environment there can be many unlawful tactics or relationships involving both public and private institutions. All this has to be accepted as a fact of life, even though it contradicts the disseminated idea that firms should primarily compete through their production and service capabilities (e.g., Voss 1995, Voss 2005). Therefore, caution is recommended when pursuing a single best practice model in the different spaces. Firms are more likely to initially amalgamate ideas from different production models considered to be best-in-class and start evolving from there.

3.2 - The Content of Production Strategy

As mentioned above, companies have only partial control over the emergence of production models. But even the aspects supposedly under control can be quite confusing and misused. To begin with, there is no generally accepted definition of production strategy (e.g., Acur et al. 2003). In industrial management literature, researchers agree that it involves the identification of competitive criteria that should be prioritized, based on a balance between business strategy and internal competencies (e.g., Voss 1995, Acur et al. 2003). They also agree that it encompasses a number of key decision areas such as vertical or horizontal integration, workforce, capacity, technology, facilities and organization. It is understood that there needs to be a relationship between these two aspects because the assurance of environmental and internal fit is a pre requisite to good performance. In other words, the competitive criteria serve as a reference to strategic choices in production strategy, that need to be aligned with one another and with other functional strategies in order to make the whole organization capable of supporting the business strategy (e.g., Wheelright 1984). Despite the two above mentioned aspects and the notion that the key decisions have a direct effect on production system design, there is still much to be uncovered and agreed upon by academics in the field.

Knowing that both conjunctural needs and internal characteristics influence the specific key decisions does not explain how top competitors rationalize when shaping their organizations internally. Indeed, little is known about the methods they use to make the specific content decisions that originate the production system. However, at least in the case of top competitors, there has to be guiding principles or assumptions creating an alignment between decisions and thereby a first line of defense against organizational complexity. This is corroborated by the idea that, due to the existence of contextual factors that vary from firm to firm, the focus of production system design should not be on the tools of best-in-class production models. Instead, the focus should be on their underlying principles. In the following topics, arguments are presented to propose that a production strategy, including one aimed at creating mobile cells, can only be fairly understood if its content is seen as comprising the performance criteria, structural and infrastructural strategic choices, theoretical foundation, and underlying assumptions.

3.2.1 - The Content Comprising Important Performance Criteria

The common definition of a project as a temporary organization established with the predetermined purpose of developing and executing a unique product under budget and schedule constraints gives an initial idea of the strong relationship between time and competitive success in project production. In fact, Steyn (2002) has discussed this relationship with further detail and provided a few reasons for identifying project duration as the major constraint of projects in general.

First, the product life cycle as opposed to the project life cycle has to be considered. Very often the project itself is considered as an end on its own while in reality the project only exists to create another system or product. If the focus is on the product life cycle, then it often makes sense to reduce project duration in order to reduce the time between development and commercialization. A quick achievement of the “breakeven point” improves the revenue. In some cases, this may even justify a greater expenditure during project conception and execution. This is very appropriate from the sponsor’s perspective. It is common sense that in a constantly changing world, innovative things may only make sense or be important for a limited period. Some opportunities can only be exploited inside that particular window of time. Beyond it, new ideas need to be devised.

Another issue is that project costs often escalate as a result of extended duration. As the schedule of a project with a fixed scope increases, costs usually increase especially because of the fixed costs. From the subcontracted parties’ point of view, revenues are often reduced as a result of delays. Not only that, things only seem to worsen when project duration and project budget are sometimes traded off with the assumption that reduced project duration would be possible only with an increase in project costs. Of course, this apparent discrepancy is highly influenced by the widespread use of techniques such as Critical Path Method (CPM), which ignore the minor trade-offs with the new conceptualizations applied to project production and the fact that the project often only exists to create another product.

Moreover, market share could be lost if a project is delayed. This is true for both the developer and project participants. As mentioned before, if a project takes too long the sponsor or developer might miss the best opportunity to release the product. Similarly, project participants having resources stuck in a particular project might be impeded to engage in other ongoing projects. But this is not all. Poor delivery reliability will affect the selection of contractors, subcontractors and suppliers in future projects and thereby worsen their loss of market share. In fact, in a study involving lean and non-lean suppliers in manufacturing, Wu (2003) found evidence that delivery performance plays a critical role in the supplier selection decision.

Additionally, extended project duration leads to scope changes because stakeholder needs could be expected to change over time. This is especially applicable to the development of products where changes in market needs or in technology could be addressed by subsequent product generations. Not only do the changes keep on reinforcing the project delay and all sorts of related problems, they also imply that more flexible capabilities will be expected from the project organization.

From the discussion above it becomes clear that although the project duration is every project's major constraint it should not be allowed to become the constraint limiting each project participant's business performance. There are important reasons for welcoming improvement initiatives aimed at reducing project duration or at enhancing the reliability to fulfil the planned schedule. First of all, it should be kept in mind that projects are temporary undertakings using resources lended from participants, so interdependency problems are a constant concern at the firm level. Moreover, projects are used by organizations to achieve different internal and external objectives, like business process improvement, product customization, and new product development. Therefore, compressed project times are important to many aspects of competition other than just delivery speed.

In fact, the use of time as a competitive weapon has already been shown in a research conducted by Rohr and Corrêa (1998). The authors found that many manufacturing companies use time not to be able to compete with shorter lead times but to improve performance in other competitive criteria. From what has been discussed here, the same can be said about time in project production. Hence, time can be pointed as an important competitive criterion in project production whatsoever.

There are different nomenclatures for competitive criteria in literature: competitive objectives, competitive priorities, competitive factors, performance goals and performance criteria (e.g., Hayes and Wheelwright 1984, Gerwin 1987, Slack 1993). Regardless of the nomenclature, the following list presents the most common competitive criteria, which are all affected in one way or the other by time-based competitiveness:

- Cost: to provide products and services at the lowest possible price and with favourable payment conditions;
- Quality: to satisfy the client's explicit and implicit requirements through better processes and products;
- Flexibility: to adapt the system to changes in the environment or to changes in client orders;

- Delivery: to reliably hand-over to the client what has been agreed upon, especially in terms of time;
- Innovativeness: to devise and introduce new ideas to both processes and products in order to gain competitive advantages.

Each competitive criterion has important variables belonging to different dimensions. Just to mention a few, innovativeness can be measured in terms of frequency or degree while delivery can be in terms of reliability or speed. It is important to capture the variables clients value the most and to share with them the same perception on their level of importance. Furthermore, it is important to identify the ones that may or may not be directly supported by time improvement programs, which are aimed at reducing value added activity times, eliminating non value-added activities and better coordinating activities.

The fact that project duration is the major constraint of projects in general implies that in all cases time will either be the most important criterion or amongst the important criteria in project production. In other words, time is either an order winning competitive criterion or at least a qualifying criterion. Hill (1993) established this terminology to distinguish the particular criteria that win orders from those that an organization must meet if it is to be in a market, even if they do not win orders. One useful methodology for identifying order winning and qualifying criteria is the Importance-Performance Matrix developed by Slack (1994).

The notion of which competitive criteria should be prioritized is particularly important for any organization to decide how to compete. In each market in which the firm operates it should identify those criteria that win orders against competition. Only then it can structure itself properly to support the processes that are critical for achieving the important competitive criteria (e.g., Harrington 1993, Rummler and Brache 1994, Voss 1995). The same logic applies to project production, since projects are developed for various reasons. The mission parameters established by the base organization must guide the making of a suitable temporary production system, which is structured under the existing contingency factors.

At one extreme, a project may be a brief critical process adequately supported by a temporary structure built to undertake a mission outside the scope of the base organization's on-going critical processes. An example is the customisation of the process flow for particular customers. It becomes critical for a limited period of time and is thereby supplied with the necessary resources in order to give a quick and satisfactory solution to the problem encountered by one of the firm's permanent critical processes. In this case, an operational project is conducted with the specific performance goals of delivery and flexibility.

At the other extreme, the project itself can be the base organization's main critical process. This is the case of project-based organizations, where the projects' performance goals and the firm's own competitive criteria may confound. For every single project it chooses to engage, the organization needs to match its structure and processes as closely as possible to the specifications of the product being developed. In such cases, as the product's scale and uniqueness increase, so does the division of work throughout the development process. Consequently, the management of knowledge and interdependencies is no longer just a problem between the projects and the base organization, but also a problem inside each individual project. Here the challenge of improving delivery time and other particularly important order winning competitive criteria encompasses the design of an appropriate structure for dealing with interdependencies and learning. Time overruns and cost overruns are important variables concerning how the two issues are handled in projects.

3.2.2 - The Content Comprising Structural and Infrastructural Strategic Choices

In an attempt to bring further clarifications, Wheelright (1984) proposed that the key decision areas in production strategy be split into two sets of strategic choices. One set relates to structural decisions, such as resource capacity, facilities, equipment, and technologies to be used. In manufacturing, these decisions create the physical part of the production system design and are usually seen as onerous, long-term and difficult to reverse (e.g., Barros Neto 2002). The other set relates to infrastructural decisions, like relationship with suppliers, managerial philosophy, production planning and control, workforce management, quality control and so on. These are less obvious decisions and are behind the creation of intangible capabilities and competencies that cannot be copied by the competition (e.g., Hitt et al. 2003). The two categories are the most commonly accepted in industrial management literature.

In the context of construction, in general, attention is mostly given to the set of decisions relating to facilities, resource capacity, and technologies. The other set has been usually taken for granted or has been mainly limited to misaligned initiatives at the level of operations. Therefore, the development of project production models has been very much restricted to the construction phase. Moreover, it is a subject that has been mostly approached from a project management perspective and not really from an organizational one. This is quite clear in construction management literature, where the concept of work structuring has been confoundingly used to refer to production system design (e.g., Martucci 1990, Ballard et al 2001, Alves et al. 2006, Schramm et al. 2006).

It is not hard to understand why the focus has been on the set of decisions regarding facilities, resource capacity, and technologies. The concern with these structural aspects of the production system has a direct relation to construction peculiarities. Not only there is the influence of site production, but also of the product’s one of a kind design, location and specificities. Moreover, when designing project organizations many mission parameters may be inaccessible a priori or poorly defined, making the initial decisions to be very broad (e.g., Williams 1999, Levchuk et al. 2001, Liu and Leung 2002, Schramm et al. 2006). Once the mission scenario unfolds, decisions become more detailed and the actual specifications and values of the parameters may require adaptations in the structural aspects of the production system in order to achieve the desired performance. Furthermore, Levchuk et al. (2001) mentions that throughout the course of the mission, various causes (operational resource failures, over estimation of productivity rates, regulation changes, bad weather, etc.) may trigger unexpected alterations in either mission environment or in organizational constraints.

With so many sources of uncertainty, the confidence in schedules established optmistically using static models is low (e.g., Monostori et al. 1998, Watt and Willey 2003). Alves et al. (2006) adds that all these problems make simulation models have limitations when applied to large scale product developments. Some models are even simplified because of the lack of precise data on the activities modelled (e.g., Alves et al. 2006). The bottomline is that these manifestations of uncertainty can cause deviations in performance and force some decisions to be made at the last minute possible (e.g., Bertelsen and Koskela 2003, Navon 2005). Consequentially, unlike in manufacturing, the production system design in construction cannot be an isolated activity but an ongoing one because of construction peculiarities and uncertainties, specially the ones related to the product design (e.g., Schramm et al. 2006). This pretty much explains the importance of the approach from a project management perspective, though it should not be the only one.

In fact, the structural aspects focused by project management are only a part of the production system. There are other aspects of production system design in construction that stay more or less constant over a longer period of time, like the set of infrastructural decisions concerning the relationship with suppliers, production planning and control, workforce management, and quality control. These comprise the strategic choices and production practices organizations use to attain higher performance. Because infrastructural decisions may involve construction executives and stretch well beyond project boundaries, one can only speculate that these might be some of the reasons to why they have been frequently neglected by traditional construction management literature.

However, the interest on infrastructural decisions is necessary in order to take advantage from the benefits of a formalized production strategy. Although this functional strategy is generally less formalized than business strategies, Acur et al. (2003) presented results showing that a formalized production strategy enhances the translation of competitive criteria into action programs. Whether it is done in a written or explicitly expressed manner, the formalization of production strategy establishes guidelines to actions taken at all levels. Companies with a formalized production strategy tend to have a more decentralized structure as the policies that establish the limits are well known. It contributes to reducing the level of improvisation in production sytem design and operation, which is in conformity with the need to first focus on uncertainty management and from there move on to risk management (e.g., Ward and Chapman 2003).

More than the definition and sharing of important competitive criteria, the formalization of production strategy is very much about making explicit the infrastructural decisions. Although commonly overlooked by construction management, the policies, philosophies, strategies and practices applied are all manifestations of infrastructural decisions that if carefully chosen and made explicit can help create a production system where methods and goals are less uncertain. In accordance with Barros Neto (2002), these will not only have a top-down effect over other infrastructural decisions, like “best practice” implementation, but also over structural decisions concerning resource capacity, facilities, equipment, and technologies. The hierarchy between the two sets of key decisions clearly indicates the importance of paying more attention to infrastructural decisions when developing project production models. But as interesting as it may seem, the need to expand the focus from structural decisions to one that also encompasses infrastructural aspects is not a new issue. Goldratt (1990) has long argued that nowadays sistemic performance is more constrained by organizational policies than by production resources.

In spite of that, infrastructural decisions seem to be the least understood aspects of production models. When analysing the content of production strategy, Harris (1997) reported the existence of interactions between strategic, tactical and operational factors and argued that consistent decisions at all three levels would give returns over and above the benefits obtained from particular levels of any one factor. Although the alignment of fundaments and subsequent decisions is made somewhat easier with the formalization of strategies, academics still have difficulty in capturing all the strategic choices and even the underlying rationale used by decision-makers when structuring organizations to support business strategies. Practitioners offer little help, since few put effort into analysing and understanding why they do what they do. A good example is the relationship between strategic choices in production strategy and production practices implemented at the operational level. Voss (1995) mentions the link between strategic choice and “best practice” programmes, such as Just-in-Time (JIT) and Total Quality Management (TQM), as being quite unclear. Not only there is little information on the infra structural strategic choices needed to support the practices, the reasons to why they are chosen and how they align are usually not explicit. The poor understanding causes doubt on the efficacy of infrastructural decisions. And this is true in both manufacturing and construction literature. The only certainty, however, is that the strategic choices in production strategy and the production practices effectively implemented or developed internally by top competitors are in some way aligned with one another and with the companies’ business strategies.

A further discussion on “best practice” implementation offers a more comprehensive view of the problem. For instance, if “best practice” programmes are implemented alone, some companies may not obtain satisfactory results. First, as discussed by Voss (1995), a “best practice” will not by itself guarantee improved performance because it cannot solve all problems. Second, “best practices” usually come in small isolated pieces. Third, their most obvious characteristics can be easily imitable. Therefore, they are unlikely to give sustainable competitive advantage. But even worse, some may only bring the best results under certain circumstances or are applicable only in specific contexts. And like other aspects of functional strategies, they may not be relevant for all companies. In fact, some production practices may be of interest and even appropriate only to companies belonging in the same strategic group, which are those following a similar strategic orientation and sharing the same geographic area. Thus, different strategic groups emphasize the implementation of different bundles of production practices, resulting in different operational performance (e.g., Christiansen et al. 2003).

This shows that regardless of what many consultants like to say, a “best practice” is not a technique that can be easily taught and transplanted from one industrial or market environment to another. On the contrary, similarly to other aspects of production models, true “best” practices are the final results of the combination between contextual factors and organizational arrangements. It should be taken the position that “best practice” must be what best performing companies do within a market sector (e.g., Laugen et al. 2005), but knowing that there is much more than meets the eye. Thus, the implementation of a successful production practice in a new context requires an organization to recreate and match the main strategic choices that have made it so effective in the original environment. But even this may not be enough, as there are many other external and internal factors that are not fully understood nor replicable. As mentioned by Alarcón and Ashley (1996), in a dynamic environment like the construction sector, it is difficult to understand the implications of individual or combined construction strategies on project performance. This explains why some best practices fail to provide the alleged positive results. For example, Alarcón et al. (2005) perceived organizational elements to be one of the main barriers to the more complete implementation of the Last Planner System and other lean construction practices. Mohan and Iyer (2005) have also presented results showing a small amount of lean principles and practices effectively used in construction companies and an even smaller amount of major benefits realized.

A well known example in the construction industry is the implementation of the ISO9001, which is one of the standards in the ISO9000 (International Organization for Standardization) family of standards for quality management systems. The standard does not guarantee the compliance of end products and services with the costumer’s needs. Rather, it certifies that the organization is applying consistent business processes. Consistency means that the set of procedures established for all key processes in the business are being effectively followed. Because the procedures need to be adjusted to the particularities in each case, they are written according to the organization's belief on how the processes are actually performed. This is where the problems begin for construction organizations.

The ISO9001 has not been successfully implemented outside offices and auxiliary processes partly due to the high labour turnover and outsourcing strategies in construction projects. Although both decisions are originated by constraints in the external environment, the decision to conceive contracts exclusively in terms of transactions, which is very much influenced by transformation model concepts, has become an internal constraint to the full implementation of the ISO9001 in project organizations. The substitution of subcontractors with different work methods makes it difficult to elaborate trustworthy procedures for operational processes. Not only that, the weak relationships turn the data collection effort at the level of operations almost useless to feeding back improvements in activities carried out by subcontracted parties. With this, the quality system looses one of its most important purposes and exists only for the fulfillment of commercial requirements, having as the main focus the measurement of process outputs.

Furthermore, this standard was originally conceived to help relatively steady organizational systems to control and continuously improve their own performance. For instance, Spear and Bowen (1999) realized that rigid procedures actually stimulate flexibility and creativity at Toyota. It seems that rigid procedures in a stable environment support learning and evolution by becoming a basis for improvements. Hence, procedures are allowed to change because other systemic aspects are stable. Oppositely, procedures in an unstable environment need to be truly rigid because they are among the few constant aspects of the system. They become a reference to the firm's purpose that needs to be checked upon or even re-learned during changes. Therefore, in temporary organizational systems, like the ones in civil construction, the quality system becomes a doctrine that needs to be relearned everytime by the newcomers in each project. Ironically, it is practically turned into a constraint for the new ideas necessary to organizational improvement.

To sum it up, the failure of understanding the underlying conceptualizations and of replicating the contextual factors that made quality management systems so effective in manufacturing industries has turned the ISO9001 into a source of disappointment to many people in the construction sector. It is not unusual to hear people in the field complaining that they are consumed by paper work and data processing, but at the same time feeling unmotivated for not perceiving the benefits of such effort. This has lead the standard to be considered by many practitioners as just another fad. All this is quite unfortunate because it is important to overcome the problems of implementing the ISO9001, since its robustness provides support to other standards such as ISO14001 (Environmental Management), OHSAS18001 (Occupational Health and Safety Assessment), and SA8000 (Social Accountability).

The discussion points to the need of critically perceiving the various internal and external contextual factors that may hinder an organization from satisfactorily applying or developing certain practices and competencies. It also serves as a reminder to the construction sector for a better understanding of underlying strategies and their impact on the emergence of production models. Under the existing contingency factors, like any other successful organization, effective project-based organizations should not only seek a proper fit with the surrounding environment, but also between its subsystems. Although challenging, the strategic choices in production strategy, be they structural or infrastructural, must be aligned with one another and with those in other functional strategies like marketing, financial and human resources. There must be horizontal coherence inside and among functional strategies in order to support the vertical coherence with business and corporative strategies.

3.2.3 - The Content Comprising a Theoretical Foundation

In free-market economies, the existing top competitors in each market sector are most likely to be organizations showing the best environmental and internal fit. In accordance with Ballard et al. (2001), the production systems in these firms have been successfully designed to achieve the purposes of both their costumers and those who deliver the system, the producers. Such organizations were capable of strategically making changes to reduce the external and internal constraints that kept them from attaining better results (e.g., Blackstone 2001). They have learned that, despite the biggest barriers being in the market place, many problems can be relatively well surpassed through the revision of different functional strategies and infrastructural decisions in production strategy.

But the way top competitors find different, effective designs to achieve the same customer needs within a particular industry is poorly understood. A route to better comprehending the production strategy is by looking at it from two perspectives: content and process (e.g., Acur et al. 2003). As mentioned before, the content of production strategies comprise the specific key decisions which set the production system's competitive criteria, production practices and activities. As for the process of production strategy, it is defined as the method to make the specific content decisions that originate the production system. The focus on the content is concerned with what the organization is going to compete while the focus on the process is on how the production strategy is developed. Although the focus of the present thesis is on production strategy content, some aspects of the content may be clarified by understanding the process of production strategy formulation, since both perspectives are perceived to be interrelated.

The process of production strategy has been the subject of many academic debates and has even lead to the proposition of heuristics, principles and methodologies (e.g., Meijer 2002, Müller 2003, Won et al. 2001). Porter (1980) proposed a top-down approach where the implementation of functional strategies, including the production strategy, should begin with the analysis of the five competitive forces in the market. Oppositely, Wernerfelt (1984) proposed a bottom-up approach where the formulation of strategies should depend on the organization's resources, capabilities and core competences. Nowadays it is commonly agreed that the two approaches are complementary. There is strong evidence that both strategy and structure influence each other (Hansen et al, 1997) (Figure 6).

It is important to notice that because the need for a change can only be justified by the external press, the top-down approach, with priorities driving programmes, is in fact stronger. Acur et al. (2003) found results corroborating that it is apparently easier for business and marketing goals to influence production than the other way around. The authors also observed that if a formalized production strategy is present it is more likely that the firm has employed a top down than a bottom-up approach in the design of the strategy. These aspects explain why the changes in production system design to support the competitive criteria are primarily concerned with the effectiveness of the chosen solutions and secondly with their efficiency.

Following the firm's directives, the production system is initially designed to meet the costumer's expectations and only thereafter to look for ways to eliminate waste in processes. This leaves no doubt that production is a secondary consideration in strategy formulation and a derivative of business strategy.

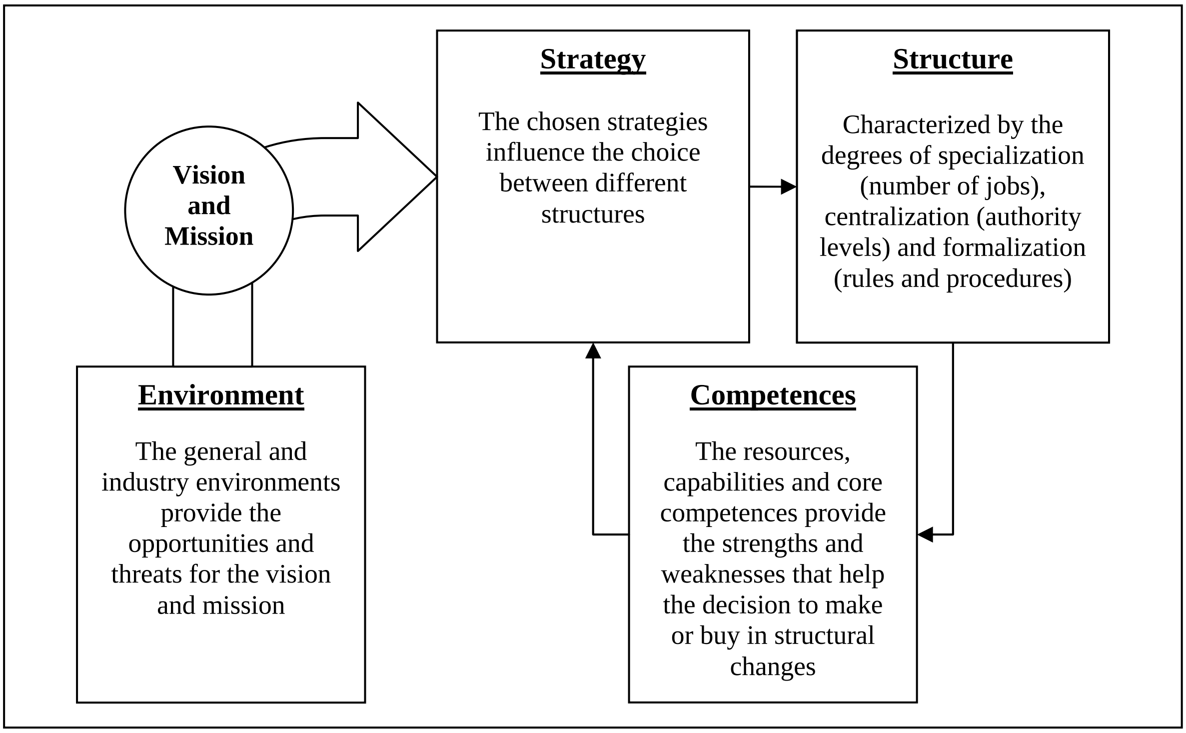

Figure 6 - A model where the selection of a new strategy calls for changes in the organizational structure, which in turn influences the strategy. Source: Miranda Filho (2008)

Even so, it cannot be ignored that the alignment between competitive priorities and action programmes may actually work both ways, with competitive priorities driving key decision areas and programmes, but programmes limiting priorities (Acur et al. 2003). This two-way communication is best explained by Hitt et al. (2003), who affirm that although the strategy influences the structure, it is the effective alignment of the organization's tangible assets (machines, facilities, etc.) and intangible assets (people's skills, procedures, relationships, etc.) that facilitates the implementation of strategies. To summarize, there is a constant effort in balancing what needs to be done with what actually can be done.

Furthermore, the affirmation made by Hitt et al. (2003) points back to the importance of unveiling the rationale used to align structural and infrastructural decision areas. It shows that the discussion on the top-down and bottom-up approaches, although clarifying to a certain extent, is too broad to provide further answers to what actually goes on during the process of production strategy formulation. The lack of understanding on how top competitors rationalize leads the outside observers to see an apparent lack of order in the way those organizations are shaped internally. For instance, when discussing lean construction practices, Barros Neto (2002) mentioned that the sequence of implementation can vary from firm to firm, since both content and process are influenced by internal characteristics and conjunctural needs. Although this is true, it does not mean that there is not a rationale or a theoretical foundation creating an alignment between decisions, at least in the case of top competitors.

Once again, Toyota provides important lessons. Quite often, companies fail to implement the Toyota Production System (TPS) because they do not understand or articulate the functional requirements that this production model is meant to solve. In other words, companies see TPS as a collection of tools to solve local optimization problems defined by conventional finance-driven management concerns, and not the systemic optimization envisioned by the original architects of TPS (e.g., Won et al. 2001). Under different contextual factors, the linkage between higher-level needs and lower-level means may require those interested in applying Toyota's production model to de-emphasize the tools associated with TPS. The main idea is that the focus of production system design should not be on the tools of TPS, but on its underlying principles.

Spear and Bowen (1999) believe that the workings of the Toyota Production System can be captured by four rules: (1) high specification of work content, (2) direct connection between every customer-supplier, (3) simple and direct pathway for every product and service, and (4) improvements made in accordance with the scientific method. The rules inspire the creation of practices that give support to many current, interrelated production objectives, such as increase of process transparency, reduction of non-value-adding activities, reduction of cycle time, increase of output value, and benchmarking (e.g., Koskela 1992). Moreover, they are believed to create a nested, modular organizational structure - a structure that allows Toyota to introduce changes and improvements to its operations while remaining stable at the same time (e.g., Won et al. 2001).

But there is more to it. The four rules are really all about placing emphasis on the relationships between people and the enterprise community. The more direct interactions and collaborative attitude of stakeholders are just a few of its facets. In fact, finding effective ways to achieve environmental or internal fit requires proactivity at all levels of the organization. For this, Toyota relies on knowledgeable, motivated individuals and, as discussed before, on the common vision of the ideal production system to drive and inspire further improvements (e.g., Won et al. 2001). By adopting a more humanistic view-point than the traditional Taylorism, Toyota sees continuity among personnel as important to blending assumptions and creating the common vision. Thus, it has taken organizational integrality to the next level by conceiving ways to enhance the degree of proximity between participants in all dimensions mentioned by Fine (1988). This is another facet of Toyota's emphasis on relationships.

The common vision has been an important part of Toyota's success because the format taken by organizational policies, practices and leadership styles pretty much depends on the existing paradigms. Spear and Bowen (1999) believe that the four rules, aligned with a common vision of the ideal and not any specific practices and tools, form the essence of Toyota's system. Indeed, it seems to be the presence of a common vision and principles behind initiatives in all levels that allows, to a certain extent, the acceptance of a bottom-up approach to system design. Otherwise, the usual top-down approach manufacturing design methods use to link higher-level system objectives with lower-level means would also have prevailed in Toyota.

There are anecdotal accounts from different industries of changes implemented in production to have required, at some point, bottom-up changes in other functional areas and in upstream phases of the value creation chain that kept the reviewed production strategy from effectively following the strategic direction of the organization. In accordance with lean proponents like Womack and Jones (2003), the teachings of TPS indicate that in such cases it is important to consider the same theoretical basis in all business processes and even in the company's business strategy (Figure 7).

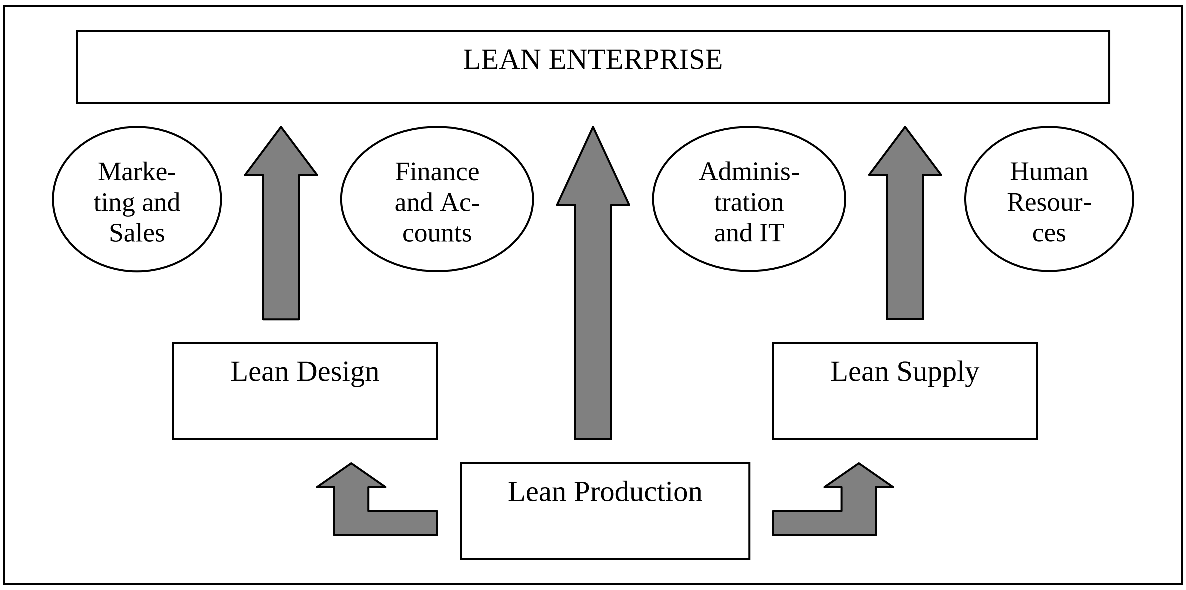

Figure 7 - Representation of gradual bottom-up changes with lean principles. Source: based on Womack and Jones (2003)

All this highlights the need to rely on explicit theoretical foundations for decision making when designing and operating production systems. A good understanding of the theoretical models behind the well-known "best practices" is much more important than simply attempting to copy them to a new context. The reason lies in the fact that explicit theories can support the development of more adequate methods and tools under the existing internal and external contingency factors. In other words, the comprehension of the theoretical foundations used by the best competitors helps different organizations to develop their own contextualized solutions.

However, caution is recommended to outsiders trying to unveil the underlying theory or to propose rules that describe the discipline necessary for effective replication of successful production models. Although such efforts may indeed come up with the description of valid underlying principles or rules, the danger lies in their simplicity. This can be exemplified by the heuristics proposed by Won et al. (2001) for the selection of the best possible design parameters: (1) simpler designs are better than complex designs; (2) the design alternative with the highest probability to meet the functional requirements, within tolerances, is the best; and (3) when multiple functional requirements of design exist, a solution that satisfies each functional requirement without affecting the other functional requirements is superior. First of all, these and other propositions might miss important fundamentals like Toyota's humanistic view-point discussed above. Moreover, the simple statements to describe complex systems, such as rules, may invite casual readers to confuse the simplicity of ideals with easiness of implementation. Although rules may provide guidance to strategic decision making, they do not provide a process as to how to physically implement and achieve the goals of a production system design. (e.g., Won et al. 2001). Additionally, in accordance with the discussion in the previous topic, they do not give upper and middle management important insight into the contingency factors that truly drive and enable the production model.

But even so, it is important to continue placing emphasis on the need to know why, not just how the system works. Efforts in this direction are important because of their individual contribuitions to expanding the body of knowledge on production system design. Without the capability to identify and evaluate the impact of all contextual factors, it is crucial to focus on better understanding the content of production strategy, because that is where companies have a partial control over the emergence of production models. For this, the ideas herein discussed indicate that the content must be seen as encompassing more than the set of decisions regarding the competitive criteria and the structural and infrastructural strategic choices. The content's formalization will be incomplete without understanding the theoretical foundation behind those key decisions.

Interestingly, it is noticed that the underlying principles are not only the most fundamental elements in the content of production strategy, but also the guidelines applied to strategic choice alignment in the process of production strategy formulation. Hence, the theoretical foundations seem to represent the link between content and process in production strategy, which explains why both perspectives are strongly interrelated. In closing, this calls for more basic research with the primary objective of understanding the relations among strategic choices in the different contexts and thereby advance the knowledge on the theoretical foundations used in their alignment.

3.2.4 - The Content Comprising Underlying Assumptions

Recently, the need for revision of project management methods from the late 1950's has become urgent as firms from different industries in developed nations are being forced to focus on high added-value customized products due to increasing competition from mass production and mass customization in emerging economies. In this sense, traditional project based industries can provide a significant contribution from the experience of handling complexity inherent to project production. Moreover, since the early 1990's an international group of construction academics and practitioners has been developing conceptualizations and practices beyond the world famous Toyota Production System and challenging the common belief that it would be the production model into which all organizations would converge in the twenty first century. The name ´lean construction` was adopted to encompass the developments made by the group, which has grown considerably through the years (e.g., Ballard and Howell 2003). Although the group's initial efforts were aimed at translating the lean manufacturing paradigm to the construction environment, it is now reckoned that the two research disciplines have, in some aspects, parted ways due to the characteristics of projects and the consequent need to encompass other disciplines (e.g., Bertelsen and Koskela 2004).

In accordance with the notion that the act of conceptualization is the act of thinking through and seeing beyond existing ideas (e.g., Sedgeman 2007), the constructs and practices proposed by the lean construction group have defied and changed basic assumptions within the ruling project production theory, especially regarding the time-cost-quality tradeoff paradigm. It is important to mention that much of the paradigm shift owes to the emergence of a theoretical model known as the transformation-flow-value (TFV) model (e.g., Koskela 2000, Bertelsen 2002). It not only has provided academics with a theoretical basis to understanding why some practices have become very successful, but has also served as the foundation to the development of many contextualized solutions for project-based production systems.

A better understanding of this theoretical model requires, as a starting point, to break away from the traditional view of construction as comprising a sequence of activities representing transformation processes. Instead, organizational processes need to be simultaneously viewed using three complementary conceptualizations: transformation, flow and value. In the TFV model, a process should be seen as consisting of flow activities and buffers between transformation activities (e.g., Koskela 1992). Moreover, the meaning of value is not associated with monetary quantification, but rather with esteem and recognition. Value is the perceived difference between the benefits gained from purchasing a product or service and the costs of its acquisition. It is a concept applied to the characteristics of the output as well as to the activities in the process that originated it. Hence, transformation activities are the ones perceived as adding value to the business, since they use resources to convert raw materials, components and information (inputs) into what is desired by customers (outputs). Differently, flow activities, such as waiting, transporting, inspecting and correcting, also consume resources, but without being perceived as adding value to the business. Therefore, efforts must be made to reduce them because clients neither whish to wait for the time nor to pay for the resources they consume. Additionally, both transformation and flow activities can be found in all processes crossing departmental borders (marketing, sales, manufacturing, maintenance, etc.), which indicates the importance of a systemic approach to actions aimed at organizational improvement.

As mentioned above, this more comprehensive theoretical model has been the basis to understanding many successful initiatives in the development of tools, procedures, and behaviours for both designing and producing. Although the main objective continues to be the creation of a complete new theory for production in construction (e.g., Koskela 2000), the initiatives seen through the lens of the TFV model have individually added contributions to the formulation of a conceptual framework for project production. The framework is simultaneously oriented to waste reduction and exploration of value (e.g., Ballard and Howell 2003) and is constituted by a set of interrelated concepts, such as:

- Integrate design and fabrication;
- Stimulate delegation of responsibility, commitment, cooperation and learning in the organization;
- Improve products and increase output value to maximize return to clients;
- Organize processes in a stable continuous flow;
- Increase transparency and focus control on the complete process;
- Reduce the share of non value adding activities and inventories;
- Size resource and time buffers to absorb variability.

These concepts are the results of ideas originally formulated in the construction sphere that have been expanded to design and supply in order to align strategic choices in production strategy and thereby create a better fit between organizational subsystems. Solutions inspired by the concepts have proven to deliver better performance. This can be explained by the fact that the conceptual framework reflects, in many ways, the concern with the quality and amount of interactions within the project organization, which have implications for the goals of waste reduction and exploration of value. Therefore, despite construction peculiarities and barriers in the market place, integration is being sought through the framework. This is the fundamental linkage between lean production and lean construction.

However, the concepts are more clearly stated than holistically applied. In practice, there has been a partial use of the conceptualizations to support the development of methods or the alignment of strategic choices under the existing constraints. It is not hard to find reasons to why the uptake of the conceptual framework has not been complete or widespread. First, lean construction as an academic discipline is still a developing field and requires greater diffusion, especially in civil engineering courses. Second, as discussed before, the practical diffusion of the concepts through contextualized practices is out of question. With few exceptions, methods and practices are unsuited for a more general application outside of the context of their origination. Third, lean construction is an ever evolving topic. Despite the unquestionable contributions brought by the TFV model, it should be kept in mind that Koskela (2000) looked at the ideal production system embodied in the Toyota Production System to develop his model for project-based production systems, which consequentially turned the three complementary conceptualizations (TFV) too robust to address the specificities of production in construction. Thus, the TFV model is just one way of recognizing the existence of non-linear dynamics and, thereby, the need for better interactions within project organizations. The conceptual framework for project production cannot be considered definite because it will continue to be revised and enriched as more conceptualizations arise from insights offered by other research disciplines like complexity theory (e.g., Bertelsen 2003a, Bertelsen and Koskela 2003).

But despite all of the above reasons, the main cause of the poor uptake seems to be the misunderstanding of the concepts and of the underlying assumptions from which they have evolved. This comes as no surprise, since the conceptual framework is not a recipe for success but rather the result of a paradigm shift. Although the TFV model is the common explicit theoretical foundation of the framework, the concepts have evolved from changes and experiments undertaken. Organizations aiming to develop contextual solutions inspired by these concepts will also need to undertake changes, especially in assumptions of decision-makers, during the process of production strategy formulation. Otherwise, the framework's potential will not be reached.

For instance, the development of solutions aligned with the cited interrelated concepts inevitably involves a revaluation of project management's attributes using the transformation-flow-value model. This is a primordial step to implementing changes in traditional construction, since it requires changing assumptions regarding the importance of the management function. Although the TFV model is just one way of looking at the project production phenomena, it is important to maintain coherence by conducting the revaluation with the same theoretical model behind the conceptual framework.

Therefore, based on the TFV model, the activities inside the construction site that add value to the final client or project developer are the ones performed by the work teams at the level of operations. From the final client's point of view, these are the activities worth waiting and paying for because they actually make the building arise. Under the same perspective, all other activities at the construction site are flow activities that must be preferably eliminated or at least reduced in terms of incidence. Not only can they disturb the transformation activities if not performed right, they also consume time and resources from project participants without being valued by the final customer.

On the other hand, the transformation activities performed by work teams at the level of operations are supported by material and information flows consisting of activities like planning, transportation, storage and inspection. This demonstrates that even though flow activities are not valued by the final client, some may be valued by the "internal clients" when being efficacious. This duality in the role of flow activities within project production demonstrates the importance of project management and other supporting functions to simultaneously seek a greater:

- Efficacy in attending the needs of internal clients, represented by the work teams;
- Efficiency through the reduction of undesirable times and costs to the final customer.

The first point implies in inverting what is seen as the most important amongst the jobs in the organizational hierarchy. The upper hierarchic layers in the organization should be seen as of secondary importance when compared to the lower, operational layers. In accordance with Orr (2005), the traditional command structure shifts into a structure aimed at supporting the jobs that are mostly valued by the final client (Figure 8). All managerial efforts converge to the provision of the best work conditions for the work teams in charge of the actual transformations. This is a crucial aspect in the new production philosophy and is behind many of the most successful renewal initiatives.

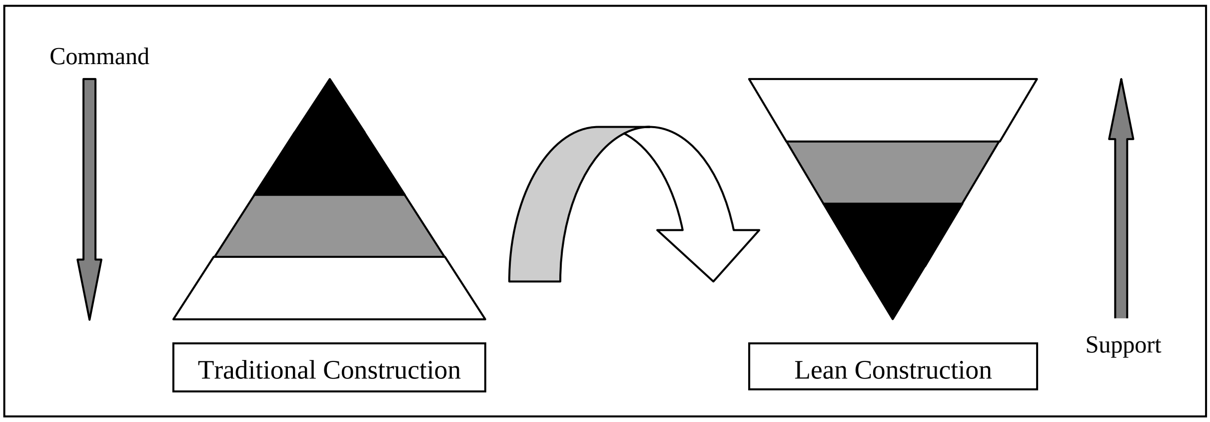

Figure 8 - Comparison between organizational paradigms. Source: based on Orr (2005)

The second point requires the creation of a steady production pace. However, its achievement is strongly dependent on the success of fulfilling the first point. It is important to remember that a considerable part of the value to the client has already been created in the product definition and design phases. Thus, during the construction phase all that remains for the general contractor's project management function is the creation of value by delivering the product in the shortest possible time and cost, without harming its quality specifications. At least this is the case of project production models that separate design from construction. In such models the general contractor cannot bring value to product design because his participation only begins in the construction phase. Therefore, the general contractor's management activities will only be valued by the final customer if they increase the efficiency of the production system. However, as mentioned in the beginning, this will pretty much be a consequence of the strategies and practices the general contractor adopts to support the various participants in the project.

Although an assumption can be something believed to be true without proof, corroborating evidence to backup the notion of management activities as auxiliary to operational processes is found when looking at competition in the Construction Industry. Typically, after the selection of candidates that meet certain requirements like the requisite number of years in the business, the award is made to the lowest responsive or responsible bidder (e.g., Forbes 2001). It is worth mentioning that for a particular project, the price charged by each contractor candidate is, in a final analysis, a consequence of the resources, practices and methods used. Thus, in a marketplace characterized by high levels of subcontracting, candidates submitting for qualification under the general contractor category need to be aware of the cost of management activities and their inefficiencies because it just might make the difference between win or loose. It is common knowledge that if the total price exceeds or fails to lower the established budget, the general contractor candidate will be rejected in the selection process in favor of a rival firm or of a firm who would otherwise be one of its subcontractors. This clearly shows that the project owner/developer will much faster try to cut costs from managerial activities than from operational activities.

Of course the final client or project developer could pay a premium price for the contractor's project management, but only when recognizing his experience as essential for the success of a specific type of project. In this case the contractor candidate would be competing with a differentiation strategy (e.g., Porter 1980, Hitt et al. 2003). However, this type of competitive advantage is very unlikely to be sustainable or even to exist in a mature industry with many equally qualified, established competitors. In such industry environments the selected contractor will most likely be the one perceived as being capable of creating a higher overall efficiency. Although this still reflects a differentiation strategy, the contractor is now primarily competing with a cost leadership strategy (e.g., Hitt et al. 2003, Prajogo and Sohal 2006). In this case the contractor's project management cost is perceived to be compensated by the fulfillment of the project's order winning performance criteria. But once again, this will pretty much depend on how well the general contractor candidate supports the work within the temporary project organization.

In closing, this discussion exemplifies the need to change assumptions throughout the development of a best-in-class production model. A firm that understands the assumptions in which the industry is built upon is the one that might establish a strategy that changes them. Indeed, underlying all structural and infrastructural strategic choices of a top competitor are different assumptions that may have evolved without supporting evidence, even though their origins may lie in one solid, explicit theoretical foundation. A conceptual framework based on the practices of top competitors is no different, since it is the end result of a paradigm shift supported by one or more theoretical models.

The discussion also suggests that, when proposed alone, a conceptual framework presents a limited prescriptive character. The same goes for simple statements like principles, policies, and rules. They all leave out many underlying assumptions that are either influencing or being generated from them. Thus, it is important to be aware that the description of a set of strategic choices or the proposition of a conceptual framework does not entirely cover the paradigm shift that fosters the development of "best practices". Although conceptualizations based on successful production practices contribute to creating a more ample theoretical basis to cover situations encountered in project based production systems, it should be accepted that they will not capture all assumptions held by decision makers. Even so, efforts to better understand the content of a top competitor's production strategy must try to capture as much as possible details like contextual factors and underlying assumptions.

3.3 - Final Observations on the Emergence of a Production Model

As discussed throughout this chapter, there are many internal and external factors influencing the emergence and evolution of a production model, many of which lie beyond managerial control. Therefore, it is important to recognize that an understanding of the competitive criteria, structural and infrastructural decisions, managerial assumptions and theoretical foundations can provide only a partial perspective on the workings of a best-in-class production model. Thus, it is most unlikely that such model can be fully replicated in a different context. Nevertheless, a proper underlying theory can provide a good starting point for the development of adequate solutions under different contextual factors (Figure 9).

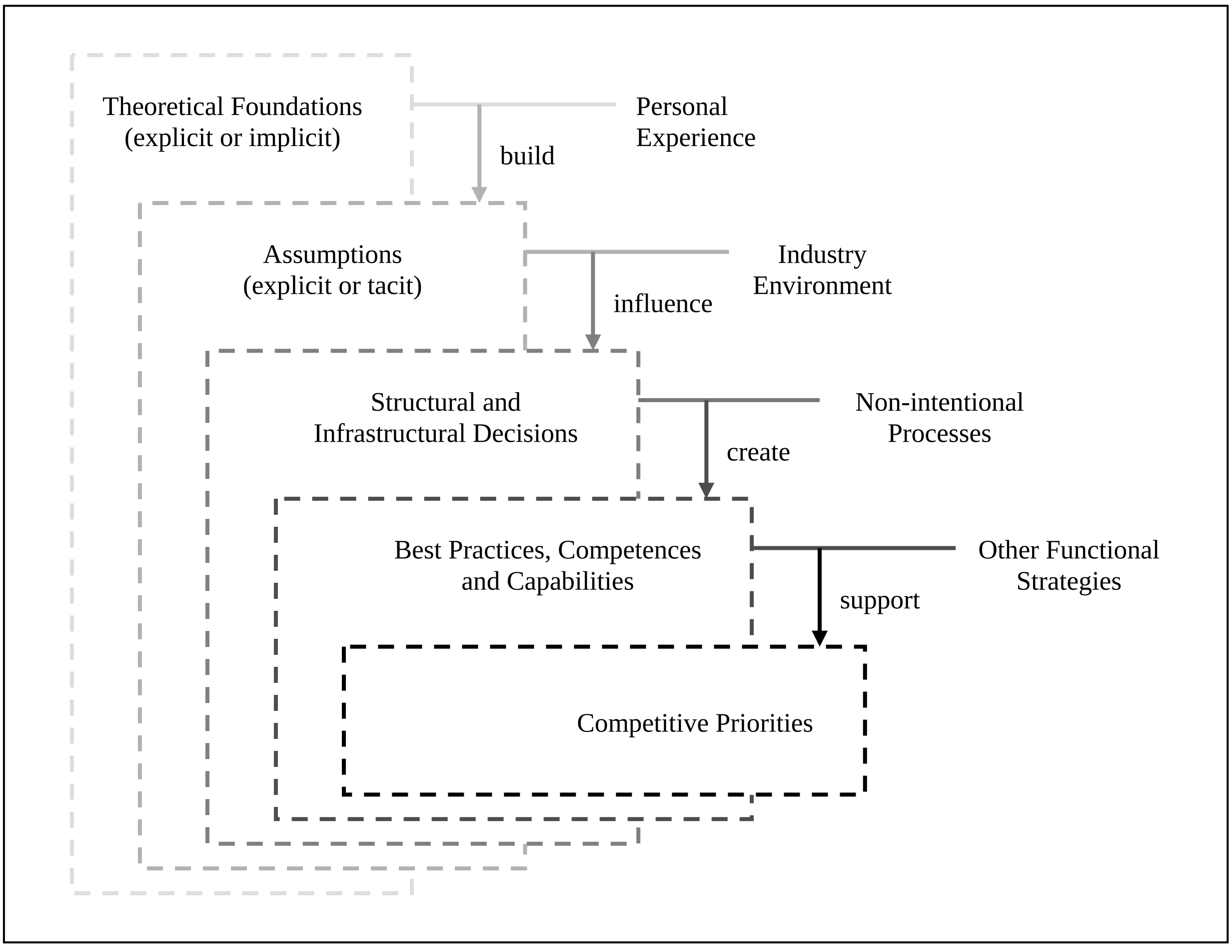

Figure 9 – A conceptual model showing that proper theoretical foundations are the first step towards the development of a successful project production model. Source: Miranda Filho (2008)

3.4 - CONCLUSIONS

In the context of construction projects, construction peculiarities cause the physical part of the production system to be redesigned for every new project and even many times during a project life cycle. This has led the concept of production system design to be misinterpreted by many academics and practitioners. The great concern with the match between resources and tasks to accomplish the project schedule has made production system design an issue mostly approached from a project management perspective and not really from an organizational one. Consequently, the development of project production models has been very much restricted and deviated to structural decisions, such as resource capacity, facilities, equipment, and technologies to be used.

On the other hand, the aspects of production system design that stay more or less constant over a longer period of time, like the set of infrastructural decisions concerning the relationship with suppliers, production planning and control, workforce management, and quality control, have been frequently neglected by traditional construction management literature. The reason lies in the fact that these are less obvious aspects that may stretch well beyond project boundaries and involve decision-making from top executives. However, infrastructural decisions have a top-down effect over structural decisions and, of course, over other infrastructural aspects. The notion of a hierarchy between the two sets of key decisions shows the importance of paying more attention to the infrastructural aspects when developing project production models.

The true “best practices” in each context, including mobile production cells, mainly emerge from infrastructural decisions and other related “soft” factors. These strongly contribute to originating the intangible competences that cannot be copied by the competition and that really make a difference in a successful production model. Hence, besides the competitive criteria and structural strategic choices, the content of a successful production strategy can only be fairly understood if the infrastructural decisions, theoretical foundation and underlying assumptions are explored. This understanding is needed because there exists somewhat of a hierarchy between them. First, the theoretical foundation comprises a set of rules or principles that might have been written or explicitly expressed. Some can be implicit, but well known by the people in the organization. Second, the assumptions are the explicit or tacit conceptualizations held by decision-makers that have been built on personal experience and theoretical foundations. Third, the structural and infrastructural decisions are the key strategic choices based on the underlying assumptions. Making explicit the guiding theoretical principles and sharing assumptions as much as possible represents a first step towards integrality and a first line of defense against organizational complexity. This can influence the decisions that shape a production system design where methods and goals are less uncertain.

CHAPTER 4 – EXPLORING THE RATIONALE BEHIND INTEGRALITY IN CONSTRUCTION PROJECTS

Koskela (1997, 1998, 2003) has long argued that advances in construction are often related to the elimination of certain peculiarities. But evidence to support his affirmation can be more strongly found in the organizational realm of construction projects. Regardless of the building technique, peculiarities related to the product realm, like size and site production, continue to be accepted as aspects that naturally contribute to complexity in construction. Differently, the renewal initiatives within the organizational realm are aimed to bypass the problems created by the peculiarities from the product realm and by other contingency factors in the external environment. In other words, there is a realization that the project organization is the key to success because that is where all problems from the business strategy materialize and where all need to be dealt with.

Despite the existing barriers to integrality in the architecture, engineering and construction industry, the project-based firms in the industry creatively devise solutions to enhance organizational proximity in different dimensions. Such initiatives aim to strengthen the linkages between participants in temporary organizations. Some have even gained widespread acceptance thanks to their applicability in different settings and modest success in helping firms to fulfill mission parameters. In fact, the successful practices devised within this project-based industry are worth a closer look because of the strong likelihood that they, alone or combined, share common theoretical principles that suit well project organizations in construction whatsoever.

As mentioned by Shimizu and Cardoso (2002), an effective cooperation is unlikely to be possible without fundamentally rethinking the current inter-organizational relationships and dynamics that exist within the construction industry. Thus, it makes total sense to try to understand the rationale or the underlying theory of best-in-class project production models by looking at aspects of the successful practices they use. In this chapter, design-build and partnering initiatives applied to create integrated project delivery are discussed in detail to unveil the rationale used by the best competitors when managing and structuring project organizations. Understanding the rationale behind successful renewal initiatives that cause structural changes to the organizational pattern may provide useful insight to what needs or is actually being done to support workforce autonomy at the level of operations. In other words, it is put forward in this thesis that the same principles guiding “higher” level project integrality are also behind the operational level integrality needed to create mobile production cells.

4.1 - ANALYSIS OF RENEWAL INITIATIVES IN PROJECT PRODUCTION

Hansen et al. (1997) sustains that the intricate technological aspects of large-scale products has been the major force behind the ongoing changes in organizational structures and controls. As discussed previously, the production of integral products should not be based on the same assumptions that underlie the production of products with modular architectures. Contractors participating in a project-based industry characterized by technology-, time-, and quality-based competition need to establish long-term, mutual trust relationships with suppliers and costumers in order to stay competitive. Moreover, under time stress the project delivery system must differ from traditional project production systems not only in the goals it pursues, but also in the structure of its phases, the relationship between phases and the participants in each phase (e.g., Ballard and Howell 2003). In response to these issues, different practices have been put forward to improve the flows of materials and information in construction. Amongst these are the partnering and design-build approaches, which are the generic terms for a range of practices designed to promote supply chain and process integrality.

Design-build and partnering practices help to shape a production system design characterized by better interactions among subsystems. This is particularly important because of the need to make subsystems act as an integrated whole in order to produce the desired result. However, as observed by Koskela (2003), changes at the higher level of the design of the production system solely bring about only modest benefits. Won et al. (2001) adds that the improvement of the system in most cases needs to be accompanied by the improvement of operations. In other words, systemic stability has a greater probability of being achieved if initiatives to improve interactions are implemented at all levels of the production system design. This corroborates the importance of developing mobile production cells at the operational level to reduce the potentially harmful non-linear behaviour of the dynamics in the system and the number of internal events that can start them.

Again, critical to the success of the project are the foundations upon which the production system design is established and the coherent, subsequent decisions made during this period (e.g., Watt and Willey 2003). In order to maximize gains, it is only logical to expect that the strategic choices of a top competitor try to replicate at all levels of the project organization the same benefits achieved with the partnering and design-build approaches. The use of a common rationale aligns the strategic choices in production strategy and improves the internal fit.

In this chapter, a critical analysis of design-build and partnering practices is conducted with the objective of unveiling the underlying principles of organizational structuring for successful project delivery in construction. The topic of integrality is approached from a multi-project and multi-subcontractor perspective, rather than the usual less comprehensive discussions carried out within the conceptual boundary of a single project. Based on a deductive analysis of the author's field experiences and the foundational work of academic colleagues, a theory describing the principles of the integral project production discipline is developed. The development of the theory provides common denominators that distinguish the successful renewal initiatives from other project production constructs.

Even though caution is recommended when coming up with valid, but simple, underlying principles, their description can be useful for a particular organization to devise its own "best practices" under the existing contingency factors, instead of striving to replicate the environmental conditions and practices of others. The description of valid principles or rules to project production is enough to start a critical analysis of the strategic choices, support mechanisms, motivational factors and leadership styles currently adopted by many organizations. All this becomes fundamental to understanding or making the changes needed to implement mobile production cells in construction projects.

4.1.1 - Design-Build

Voordijk et al (2006) suggested that production models that integrate design and execution are less modular and more integral. The design-build model belongs to this category. In this model, the client gives a single contract for the execution of both design and construction to one company (usually a contractor) (e.g., Koskela 2003). The company then performs the role of general contractor taking care of integrating design and execution processes in a suitable way and bearing full responsibility for the project (e.g., Koskela 2003, Voordijk et al 2006).

Bringing design and construction closer gives the general contractor the opportunity to add value to project management activities by allowing it to contribute in more ways than it normally does in the traditional design-bid-build model, where managerial contributions are restricted to the construction phase only. For instance, with the design-build model project management can bring improvements to design processes and product definition by feeding back information regarding the most frequent alterations, difficulties and problems during construction. Therefore, more than enhancing the management of data exchange between specialists, it can also support the continuous improvement from one project to another. In this model, data collecting and processing procedures conducted in construction sites gain a much nobler application because the information acquired becomes useful to improving the projects' product and organizational realms. This increases the probability of successful new product developments, since each project becomes a prototype for improving aspects of future projects.

In fact, surveys show that the design-build model has served well both private and public clients in different countries, regardless of the project delivery process used (e.g., Forbes 2001). The continuity provided from having one firm in charge of both design and construction allows faster project delivery because: (a) the bidding period does not prolong delivery; (b) the owner/client has one point of contact; (c) the time for production planning is greater; (d) the overlapping of design and construction is easier; and (e) the buidability is higher since design problems are resolved internally (e.g., Forbes 2001, Koskela 2003). In accordance, Nielsen and Thomassen (2004) observe that the possibility of designing activities in ways where fewer hand-overs are needed is an important way of gaining time. Thus, the design-build model is well suited for construction projects because of the strong relationship between time and competitive success in project production.

However, when applied alone the design-build model is perceived to be only somewhat better than the traditional design-bid-build model in several respects, especially in saving time (e.g., Pocock et al 1996, Forbes 2001, Koskela 2003). As a matter of fact, the increase of cost and schedule certainty is minor when changing the procurement route from design-bid-build to design-build delivery (e.g., Koskela 2003, Ling 2004). This can be explained by the fact that many of the actual operational relationships continue to be fragmented. Therefore, in order to support project production's important competitive criteria the design-build model needs to be accompanied by other initiatives that further enhance the degree of proximity between participants at different levels of the project organization.

Indeed, the selection process of a design-build contractor reveals the concern with the implementation of such initiatives as it is based on factors other than low bid (e.g., Forbes 2001). Performance is actually analysed on the basis of various criteria. Although some, such as construction experience and financial stability, reflect attributes exclusively relating to the prequalified design-build contractors (e.g., Alarcón and Mourgues 2002), others look at past performance with regard to how well they articulate with the various project stakeholders to ensure successful project delivery. There is an understanding that the most qualified design-builder correlates to the lowest administrative burden (e.g., Molenaar and Songer 1998). This means that the best design-build contractor is the one who takes strategic actions to improve the interactions within the project organization (e.g., Pocock et al 1996) and thereby minimizes his own and his client's administrative burden in the project. Clearly, this involves more than a careful selection of subcontractors in order to transfer responsibilities to them and to keep project managers from having to micro-manage design-build projects. On the contrary, the effective design-builder is aware of his responsibility for creating the proper work conditions to all parties. This is confirmed by Ling (2004), who found the majority of factors that affect design-build project success to be contractor-related variables.

To accomplish this, the design-builder is cautious in reducing sources of external uncertainty. First of all, the effective design-builder seeks to engage in projects that have a high scope definition and concise request for proposals. Additionally, a low level of client/owner design is highly appreciated at the time of being hired. This way the design-builder can have more control over design specifications, cost, and schedule and requires less administration from the owner. However, the owner must be available and participative in order to support the design-builder throughout the critical design phase. For example, if the owner determines that cost is a critical performance criterion, the owner must be involved in the design phase to keep budget growth to a minimum. Cooperation between both sides in this phase is a crucial aspect to project success and requires some ability from the design-build contractor to make it happen. This shows that the design-build model improves to a certain extent the integrality between project phases because it allows at least the lead firm in the temporary organization to become constant throughout the project life cycle. By being empowered to perform a larger scope of activities and to control a greater number of factors, the general contractor can create more favourable work conditions for his own tasks and, to a certain degree, for those under his command.

The design-builder is mostly benefited from the higher predictability created. This is the main reason for the general contractor's interest in becoming involved as early as possible. The early involvement and the greater proximity between phases support waste reduction in subsequent phases. When becoming involved in the definition and design phases, the contractor can try to influence the product's specifications in a way that suits best his own construction methods and the intended production pace. With this, the contractor can anticipate many difficulties and even reduce their harmful effects in the construction phase. Most important of all, there is the gain of time and information for a more accurate planning, which becomes crucial for project production under time stress. In many ways, the design of the production system is beginning at the early project stages alongside with product design. This helps to improve an organization's internal fit and overall efficiency, which consequentially add further value to the general contractor's managerial activities in the eyes of the client.

Of course, as mentioned above, if applied alone in a large-scale product development the design-build model will not be enough to deliver a significant higher performance. The reason lies in the fact that processes become more integrated only inside one hierarchic layer of the organizational structure. Other internal relationships may continue to be fragmented, representing sources of internal uncertainty that impede an even lower administrative burden. Hence, the attainment of a faster project delivery will be limited unless the design-builder is capable of devising strategies that foster similar benefits to the other project participants.

4.1.2 - Partnering

The gains with the design-build model can be even greater if other project participants can also benefit from higher predictability. It is well known that in a product development project, managers must stress the early phases of the project because that is where the leverage is greatest. Moreover, they must facilitate a broad participation of the multifunctional project team members in negotiation of the key product specifications and design trade-offs. Thus, allowing subcontracted firms to also get involved earlier in the project contributes to finding better technical solutions and to further increasing the predictability of the operations. In accordance with Mohan and Iyer (2005), when these parties become involved in design the projects experience less rework and cost savings and are completed in less time.

However, a cooperative relationship between firms in early phases requires the design-build model to be accompanied by partnering initiatives. These initiatives can be categorized according to the duration of the cooperation between partners. If the objective is a short-term business relationship for the benefit of all parties in a specific project, the collaborative-based practices adopted create what can be described as project partnering (e.g., Shimizu and Cardoso 2002). Procurement strategies promoting relational contracting belong to this category (e.g., Toolanen and Olofsson 2006). However, if the goal is not to benefit from a single project, but to benefit across multiple interdependent projects, then the objective is clearly the establishment of what is known as strategic partnering or long-term partnering (e.g., Shimizu and Cardoso 2002, Sacks 2004). In this second type of partnering, the set of practices adopted aims to increase the degree of cultural proximity by creating a commonality of language, business mores, ethical standards and policies, among other things (e.g., Fine 1998, Voordijk et al. 2006). Although more ambitious and challenging, strategic partnering provides a greater support to the benefits sought-after with the design-build model, since it helps continuous improvement and even decentralization within the project organization.

In fact, in cases of long-term cooperation and higher trust, a subcontractor should not only be responsible for performing the service but also for supplying the design of his specialty (structural, electric, hydraulic, etc.). In accordance with Harland et al. (2005), as subcontractors develop capabilities, they may take on the role of “systems integrators” enabling the general contractor to source entire sub-systems of a building. With this, subcontractors can also benefit from higher predictability because they too are allowed to prepare as much design as possible. It is important to reckon that the price charged by each subcontractor very much depends on the general contractor’s capability to reduce uncertainties, support improvements in production processes and provide adequate work conditions for the task to be carried out. Therefore, creating conditions for subcontractors to increase their productivity and reduce waste has a direct effect on the general contractor’s competitiveness. The incapability to do so hinders the general contractor from obtaining more competitive prices and schedules because subcontractors tend to build in safety cushions for unforeseen contingencies. Thus, using partnering to extend the design-build model to specialty contractors is one of the ways to create more integral processes inside different hierarchic layers and to thereby enhance predictability throughout the organizational structure. In practice, the absence of litigation and disputes is an important performance indicator that this model of construction delivery is effectively working, because it reflects a reduction of differing perceptions and expectations of the parties involved.

Once again, this discussion exemplifies the importance of aligning strategic choices in production strategy in order to have a partial control over the emergence of a successful project production model. On one hand, to bring greater improvements to the production system’s performance the design-build model needs to be combined with partnering initiatives. On the other hand, although subcontractors may show goodwill to absorb any extra costs in a particular project so as to develop or maintain a relationship, such an approach is recognized as being unsustainable in the long run. Therefore, as mentioned by Howell (1999), partnering without a change in operational practices and management philosophy typically fails, because the mere act of partnering does not change the way the work is done.

Besides the complementarity between strategic decisions, the discussion also provides insight into the existence of a hierarchy in which partnering should precede design-build for a more beneficial application of the latter. The reason lies in the fact that even when applied alone partnering initiatives can still create a certain degree of predictability, which points them as the fundamental strategic choices for organizational integration. Partnering is, therefore, the underpinning that enables other integral practices and processes to be delivered in project production systems.

This can be further exemplified considering the problem from the viewpoint of project managers. To begin with, from project management's perspective the "core" activities in any project are always those forming the critical path. The reason lies in the already mentioned strong relationship between time and competitive success in project production. As emphasized by Jiang et al. (2006), the logic behind outsourcing initiatives is in allowing firms to focus on their most value creating activities and leaving the remaining activities to be engaged by other specialist firms. Aligned with this logic, firms performing the role of general contractor concentrate their resources on the "core" activities in which they have unique economies of skills or knowledge and outsource the rest. The general contractors prefer to retain in-house the core activities that have a longer duration and that share a similarity in skills required. Like any other service supplier they aim to keep their work capacity occupied for a longer period of time, but with the additional concern of trying to have a greater influence over the project's production pace. Both of these objectives are achieved by performing core activities that have a longer duration. This is a common rationale behind the decision to "make or buy" in the case of general contractors. Interestingly, it sets them apart from firms in other industrial sectors where there are concerns about the greater lack of knowledge relating to the decision-making process on what and how much to outsource (e.g., Harland et al. 2005).

Still, there can be doubts regarding the management of outsource relationships and contracts. In construction, the one-of-a-kind production feature and large-scale products make it unviable for contract-granting firms to perform a wide range of activities because of the need to reduce operations expense and overhead expense. This leads the firms submitting for qualification under the general contractor category to not only outsource activities "closer to core", but also many of the "core" activities constituting the critical path. Thus, if there is one thing to be sure of when it comes to outsource relationships in construction projects, it is the cruciality of making long term, collaborative arrangements with firms responsible for performing activities in the critical path.

In other industries, firms may consider the substitution of suppliers and the use of transactional oriented cooperation forms as essential to support their business strategies. Indeed, among other things, the objectivity of outsourcees can relieve organizations of the constraints of cultures, established attitudes and taboos, providing benefits like flexibility, fresh ideas and creativity for new opportunities (e.g., Harland et al. 2005). But once more, caution is recommended when transplanting practices from one industry environment to another. It is important to notice that firms using such strategies may be looking for benefits that are of secondary importance to the construction sector. In fact, time-based competition requires reinforcing the proximity between project participants in the exact same aspects that those firms reject.

In a large-scale product development project characterized by the peculiarity of site production, strategic partnering allows the firms performing activities in the critical path to know each others work methods and productivity rates. This alone improves the reliability of project plans. Moreover, as a result of the lower uncertainties in the critical path, the parties responsible for the other interdependent activities in the project plan are also benefited with a steadier production pace, which makes them give even more value to the general contractor's project management. This is evidence that partnerships alone enhance the overall predictability, regardless of whether the construction delivery model is design-bid-build or design-build. It corroborates the perception of partnering initiatives as the fundamental infrastructural strategic choices for organizational integration.

Besides the increase in project plan reliability, there are other ways in which the parties are benefited from the predictability created through partnering strategies. In theory, contract-granting firms should only undertake outsource actions if outside producers can provide comparable services better (e.g., Jiang et al. 2006). In practice, as discussed above, construction peculiarities force general contractors to outsource many activities, including the strategic ones comprising the critical path. This can be quite worrisome because even though the most realized benefit of outsourcing is cost savings, empirical investigations reveal no evidence that outsourcing will improve a firm's productivity and profitability (e.g., Jiang et al. 2006). Hence, a more thoughtful analysis shows that the problem of managing subcontracted "core" activities is not just about finding ways to improve plan reliability, but also of being able to influence them towards a higher competitiveness.

Nevertheless, such issue is also best dealt with through strategic partnering, which allows general contractors to help improve the outsourced operations as if these were also their in-house service functions. The long lasting partnerships offer the firms the possibility to experiment together changes in construction processes. More than improving the efficiency of operations, this is particularly important to create internal fit in order to avoid problems regarding the compatibility of work methods. It should be understood that specialty contractors are construction job shops and that the goal of improving the overall performance requires coherency in actions to avoid surprises when the parties come together. In other words, strategic partnering supports the creation of a more effective network under the general contractor's scope of activities so as to ensure competitiveness against other similar networks.

Without any doubt, using partnering to create a collective efficiency involves revaluating the wrong assumption that long lasting partnerships diminish the search for innovations and negatively affect the overall competitiveness. In reality, this truly applies for firms active in low competition markets or possessing some kind of unlawful and privileged relationship with the project developer. But in a free market environment with intense competition, experience has shown that stronger relationships throughout the value creation chain can actually be the source for the development of many competitive advantages, especially intangible competencies (Hitt et al. 2003). Thus, Al-Sudairi et al. (1999) asserts that management has to go beyond its own boundaries in order to establish a lean enterprise, which is an organizational model where a group of individuals and functions are legally separate but operationally synchronized. In other words, networks should compete against networks, instead of firms against firms.

In the role of internal clients, subcontractors also value the higher predictability created by strategic partnerships because it helps them to make decisions concerning the allocation of resources in the short-run. This is perhaps the most important type of predictability sought-after by subcontractors. The partnerships between contractors distinguish the necessities of delivering services that cannot be stocked from the necessities of supplying tangible goods. Service suppliers like the specialty contractors need to keep their work capacity occupied. With strategic partnering, among other things, the general contractor tries at all times to maximize the utilization of the production capacity belonging to the group of allied firms.

The logic is that external uncertainty regarding market demand should not be a justification for the creation of internal uncertainty through an over exaggeration in subcontractor substitution. It is important to perceive the paradox of the growing specialization in an environment of low cooperation. Even when facing the challenge of executing unique, complicated and geographically dispersed products, firms need to devise strategies for creating predictability in critical points of the macro construction process. Partnerships must be established to reinforce the interconnections between contractors in terms of geographic, organizational, cultural, and electronic proximities.

Of course, the continuity of the close relationships must be periodically evaluated according to both quantitative (cost reduction, production schedule completion, investments in technology, etc.) and qualitative (innovation, proactivity, values, etc.) criteria. Most important of all, it should be evaluated the subcontractors' success in creating further predictability and in passing its benefits to their own collaborators. In part, the objective here is to break away from exaggerations in subcontracting and to modify the production strategies towards lesser layers of sub-subcontractors and higher continuity of labor workforce from one project to another. Better interactions are most likely to occur as a result of the continuous learning, the elimination of responsibility gaps, the reduction of organizational complexity, and the diminished flows (e.g., Ebbesen 2004, Buch and Sander 2005).

This entire discussion shows that there has to be limits to outsourcing and substitution, because if applied alone "over-outsourcing" or "hollowing-out" can create many competitive disadvantages (e.g., Harland et al. 2005). Besides the well known argument about keeping core competences and maintaining the ability to learn in order to stay competitive, it is also a matter of identification of any given system because it has to differentiate itself from the complexity of its environment. If not, the organization will lose its autonomy and vanish in the larger system of its environment (Gröbler et al. 2006).

As mentioned by Harland et al. (2005), firms in different sectors need to be aware of the implications of outsourcing. The decision to "buy" instead of "make" must be based on convincing justifications. Outsourcing should not be used as a mechanism to moving responsibility and risk out of the firm, especially due to the failure in solving internal problems. Moreover, the assessment of costs of "make or buy" should include the additional cost burden of managing the outsource relationships. This means that, even when deciding to "buy", outsourcing firms cannot neglect their responsibility to provide the best support possible to the outsourced operations. As discussed, the creation of a more effective network under the general contractor's leadership points back to inverting the traditional top-down hierarchic relations and assuming that value generation should be conceived in terms of costumers as well as producer (internal clients) purposes (e.g., Ballard 2001). The use of strategic partnering supports this paradigm shift by creating predictability to subcontractors. At the same time, it reduces the disadvantages for general contractors brought by the infrastructural decision to outsource. Therefore, in circumstances where vertical integration is not economically viable, it is preferable to devise partnering strategies because they allow to maintain the advantages of subcontracting (vertical disintegration) while at the same time reducing many of its disadvantages (e.g., Shimizu and Cardoso 2002).

Furthermore, the discussion on the benefits of strategic partnering should not make project partnering seem less prominent. Although the advantages of project partnering are not regarded as equal to strategic partnering, the fact that it is considered possible to cause change over the timescale of a single project is indicative of the view that partnering can be engineered and does not have to evolve naturally (e.g., Bresnen and Marshall 2000). Thus, if partnering initiatives in general are the fundamental strategic choices for organizational integration, a more detailed observation reveals the collaborative-based practices creating project partnering as the foundations to strategic partnering.

To understand the inner relationship between project and strategic partnering, it is important to initially look back at the traditional arrangement of design and construction tasks made through the development of a work breakdown structure. According to Ballard et al. (2001), the work breakdown structure divides the total work scope into its elements, and typically is mated with an organizational breakdown structure, which assigns responsibility for delivery of those elements. However, as discussed previously, the assumptions behind work breakdown structures are flawed because project elements are typically interdependent and value emerges from their interdependence. Still, the same assumptions have led to the misuse of the subcontracting strategy in construction projects and, thereby, to further worsening the quality of the interactions between participants.

In accordance with Harland et al. (2005), outsourcing creates the need for a review of the policy issues and for managing the outsource contract properly. Thus, if value emerges from the interdependence between system elements, contracts should be relational and not just conceived in terms of transactions. It should be realized that contracts play an important role in establishing the framework in which the interactions between subsystems will occur in the temporary project system. Conceiving contracts exclusively in terms of transactions leads to neglecting the interdependence between system elements and creates difficulties in adapting to changes in project objectives.

In the case of project-based production systems where changes and tight schedules are frequent, the need to manage the outsource contract properly is greater because contracts link the temporary system to the larger complex of production systems that exist independently of the project (Ballard et al. 2001). Thus, what goes on in a project is very much dependent on the way firms are tied to one another through contracts. Consequently, the paradigm shift must begin with the adoption of procurement strategies promoting relational contracting. For instance, instead of being solely based on measurement of work quantities, the remuneration forms of subcontractors should be changed to promote transparency and the development of trust (e.g., Toolanen and Olofsson 2006). Likewise, contracts should have provisions for creating a stable workflow, rather than the usual extensive provisions for dealing with non-conformance or non-performance on the part of the subcontractor (e.g., Sacks 2004). To summarize, if the correct goal in strategic partnering is the global benefit achievable by multiple stakeholders across multiple projects (e.g., Sacks 2004), it is only logical that this should be preceded by a significant sharing of benefits and burdens in each single project.

As mentioned before, the relational oriented model of contracting, although fundamental, is just one scheme to creating project partnering. Finding process tools and practices that promote communication, sharing of information and cooperation among all stakeholders is also important to project partnering. Morgan and Hunt (1994) hold that trust exists when one part believes in the integrity and security of another. They add that the perceived quality, and not the promised quality, is an important prerequisite to trust. Thus, a relationship will present a high level of trust as long as there is quality in the communication between the parts, which means exchanging relevant, trustworthy and timely information. If the adopted contracting mode and other practices supporting collaborative action prove to be effective in a specific project, then the basis for a long-term partnering between the participants has been established. This is the idea that interlinks project partnering with strategic partnering.

The benefits of partnering, particularly predictability, may not gain much recognition from firms that are both developer and builder, but they definitely should receive attention from firms performing the role of general contractor or subcontractor. In accordance with Toolanen and Olofsson (2006), activities in project production, especially in fast-track projects, are mostly interdependent and the demand on the interaction between activities is often high. The relational environment fostered by partnering initiatives facilitates the concurrent engineering process and, thereby, time-based competitiveness.

4.2 - DISCUSSION ON THE RATIONALE BEHIND THE INITIATIVES

The analysis of the design-build and partnering approaches reveals a production model where the general contracting firm expands its control over different construction phases and shapes the organization under its command into an integrated whole. The discussions in the previous topics show that the general contractor plays a decisive role when it comes to breaking away from the traditional modular design of construction processes. It is up to the general contracting firm to implement initiatives that connect the flows between participants in each phase as well as the processes of design specialists with those of subcontractors at the construction site. The discussions also show that integrality in a large-scale product development needs to be understood in terms of its goals and underlying principles.

4.2.1 - The Goals for Integrality in Large-Scale Product Developments

Regarding the goals, the discussion on both renewal initiatives indicates a project production model formed for the purposes of: (1) increasing the predictability to all participants and (2) empowering them to contribute to project success (Figure 10). In this model, the two purposes appear as "soft" business goals for the strategic choices made by general contractors when designing the structures under their command. In accordance with lean construction's conceptual project production framework, strategies that enhance predictability within the organization relate to the objective of waste reduction while strategies that enhance the insertion of solutions and improvements in all project phases relate to exploration of value. Ballard and Howell (2003) define "lean" projects as those having systems structured to deliver the product while minimizing waste and maximizing value.

The "soft" goals of increasing predictability and getting contributions from all participants are of great strategic importance because together they can help to enhance the value of the general contractor's managerial activities. Both are also interrelated, since they result from the higher integration between project phases and participants. A primary objective of any production system is to sustain its purpose, but having the desirable system performance requires understanding and improving the proximity between the elements within a system (e.g., Won et al. 2001). Therefore, a production system design based on initiatives that enhance the quality and amount of inter and intra level interactions is not only crucial to achieving the important performance criteria but also to creating more value to project management activities.

Still, it should be kept in mind that the value given by the clients will also depend on the management team's ability to take advantage of the structure's potential to generate predictability and contributions.

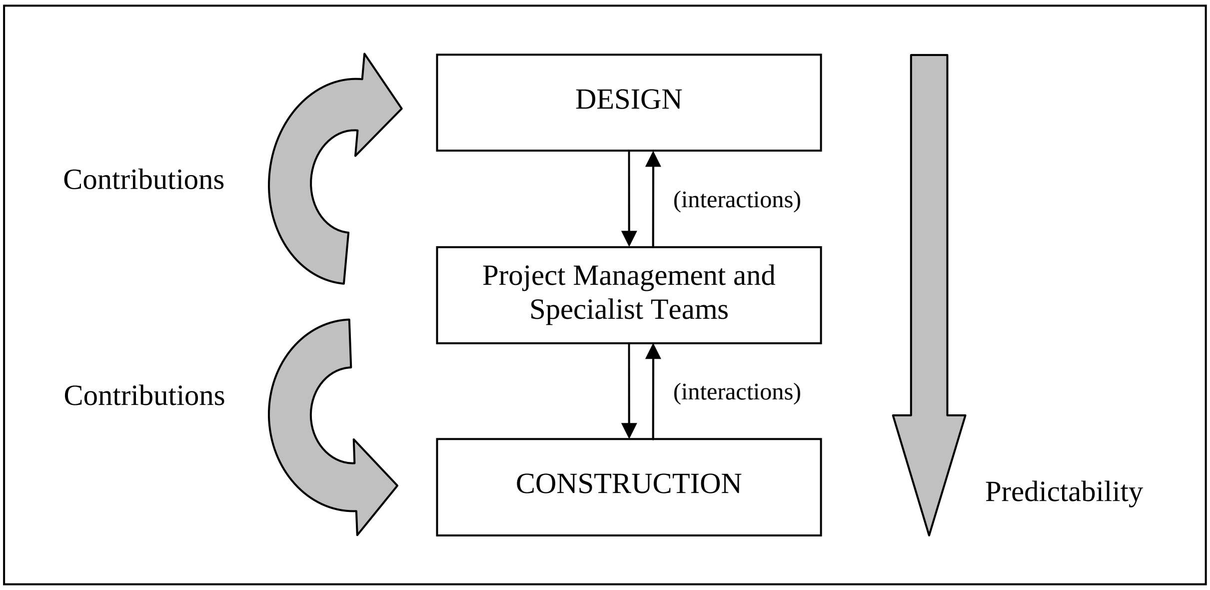

Figure 10 - The goals of an integral production system design for a large-scale product development. Source: Miranda Filho (2008)

4.2.2 - The Underlying Principles of Integrality in Large-Scale Product Developments

As for the underlying principles of integral project production systems, the discussion on the two renewal initiatives shows that they incorporate what seems to be a mandatory rationale for structuring modern organizations. According to Ashkenas (2007), simplification strategies to counteract complexity are being treated as business imperatives by large organizations in many sectors. In other words, the structure adjusted to serve the business strategy has to be made as simple as possible. In the construction sector, the widespread acceptance of partnering and design-build practices in different settings indicates a growing recognition on the part of the construction community that traditional construction strategies adding to complexity are no longer viable and have led performance improvement to hit a wall.

The system design achieved through partnering and design-build practices is evidence that the simplification of the project organization is being used to support the integrality required to perform one-of-a-kind products. Strategic partnering initiatives seek to enhance the commitment, transparency and proximity between firms beyond a single project. Complementarily, design-build initiatives enhance the firms' participation, cooperation and proximity throughout different phases of the product development process. The first group of practices aims to enhance the continuity of factors from one project to another while the second group looks for a higher continuity inside a single project by lowering the degree of horizontal differentiation. Thus, simplification is supporting integrality in different levels of the organizational structure and with different time lengths.

Although simplification strategies creating greater continuity and lesser differentiation within the structure may in fact support organizational integrality, it is important to notice that the other way around is also true. Decisions supporting integrality can also reinforce simplicity. The analysis of the design-build and partnering approaches suggests that the renewal initiatives can actually support simplicity and integrality in more than one way. Four interrelated principles that reinforce one another in terms of generating simplicity and integrality have been identified and are here generalized:

- *Continuity through time*: a particular firm, work team or employee seeks spatiotemporal continuity to reduce the number of potential sources of variation in its/his direct work scope. By creating a work environment with more stable factors, the entity reduces the frequency of interventions it will have to make and thereby the number of internal events that can start harmful dynamics in the system;
- *Influence over upstream factors*: a particular firm, work team or employee seeks to reduce the number of potential sources of variation beyond its/his work scope. By devising mechanisms to avoid uni-lateral decision-making and actions of outsiders, the entity reduces the number of external events that cause inflow variation and the following consequential reactions that start other dynamics;
- *Direct interconnections*: a particular firm, work team or employee seeks to keep under control the variation of variables in the dynamics by improving the linkages with other similar entities in terms of time, space and information. Once a dynamic has started, the quality of the material and information flows in the network will be highly dependent on the existing capabilities to reduce the intensity of the non linearities;
- *Delivery of complete subsystems*: a particular firm, work team or employee seeks to broaden the scope of its/his work in order to try to simultaneously attain the benefits of the three previous principles. The larger work package not only empowers the entity to implement protective measures to reduce internal sources of variation and the intensity of the non linearities, but also makes it easier to shield the inner activities from the inflow variation coming from upstream bordering activities.

The above principles are aimed at reducing the number of events causing dynamics and the non-linearities within the dynamics. In other words, they are aimed at limiting the degree of changes the system undergoes when starting a new project and during the phase transitions in that particular project. The greater systemic stability becomes fundamental to attain the predictability that minimizes waste and the contributions that maximize value. The four principles seem to be guiding, perhaps intuitively, the renewal initiatives and conceptual frameworks in project production. Although not explicitly stated, the conceptual framework for structuring and managing projects proposed by the international group for lean construction is also all about the four principles. In summary, project integrality arises from initiatives founded on four principles aimed to create systemic stability. The nature of these principles is discussed next.

Different from objects that can be disassembled and reassembled to be whole again, spatiotemporal continuity is necessary to build the identity of organizations through time. The continuity of organizational factors contributes to the creation of trust, knowledge and intangible competencies. Therefore, *continuity through time* does not mean rejecting changes. It means that changes should preferably be made in small, frequent leaps rather than in big, discontinuous ones. Work group continuity and cohesion can significantly reduce sources of unwanted variation. It allows management-as-planning and management-as-organizing to gradually give way to management as cooperation and as learning (e.g., Bertelsen 2002, Bertelsen and Koskela 2004).

The continuity of factors will depend on the strategic decisions a business organization makes when selecting the external environment and shaping its internal aspects. The fact that strategic decisions need to be concerned with reducing potential sources of variation makes this, perhaps, the most obvious of the four principles. Furthermore, strategic and tactical level decisions have a wider and deeper impact in reducing sources of variation than operational level decision-making. At least some variation will be reduced if strategic decisions are taken to narrow the level of external uncertainty and organizational complexity to be dealt with by the project management team. Because of this, it seems reasonable to say that each organizational level is responsible for reducing potential sources of variation so as to ensure continuity and improve the predictability for the lower levels and downstream activities.

In this sense, continuity brings a two-way benefit to the parties involved. One example is the effort to reduce waste in the outsourced operations, which also minimizes the cost of “buying” those services (e.g., Ballard et al. 2001). Besides the bargaining power, what determines the cost of acquiring resources is the general contracting firm’s capability to create a less uncertain and more stable environment to the subcontracted operations. For firms in an integral supply chain, a certain amount of inefficiencies and lower profit margin in each project may be tolerated in exchange for long-term relationships and for better predictability and stability in terms of client orders. Likewise, the most cost-effective impact the management team can have on a particular project is to provide to the field crews and other specialists the required working conditions and resources. In summary, a subcontractor will only deliver best prices and full value if upstream uncertainties are removed by the general contractor’s control system. Hence, the cost of acquiring the outsourced resources will depend on how successful the control systems in both sides are in adding value to each other. As discussed by Montgomery (2008), in order to claim value, firms must first create value by providing what internal and external clients want in ways that are better than others. This shows that internal adjustments to create a best-in-class production model need an environment of collaboration, which can be more successfully fostered by continuity in the project organization.

Regarding the *influence over upstream factors*, Meijer (2002) holds that the gain of reducing complexity this way is to provide a future set of states that is sufficiently detailed for individual firms, teams or workers to recognise their own future perspective. This principle reflects the natural desire of stakeholders at all levels of the project organization to anticipate or even reduce possible scenarios. For instance, Maloney (1991 apud Pappas 2003) described results of a survey of 2,000 union carpenters which found that carpenters wanted more involvement in determining “how work was to be performed and how well it was being performed”, and were willing to take responsibility for the decisions they made. In every supplier-client relationship there are expectations from both sides. This is the reason why suppliers try to push some conditions in order to able to effectively deliver what is being pulled by clients. Thus, when it comes to safeguarding the performance of an integral production system, a supplier may have strong reasons to say that internal clients are not always right. However, in the construction sector, the implementation of strategies to reduce uncertainty in the incoming flows and to thereby stabilize work flow at the construction site has been pretty much limited to the project management level.

Of the principles identified, the one concerning *direct interconnections* is by far the most sought-after because of its immediate benefits to the entities. This is clear from the great number of practices and support mechanisms that enable information to reduce flow times, time reduction to improve information flow, spatial proximity to enhance information flow, and spatial proximity to reduce throughput time (e.g., Hyer and Brown 1999). There are plenty of examples in business organizations. At a particular workstation, lights can be used as calls for operator intervention. Similarly, supply chain partners can rely on information sharing such as electronic data interchange (EDI) to have timely and accurate information for quick responsiveness and flexibility. These are both examples that illustrate the role of information as a means in achieving minimal lead times. Inversely, an example of time reduction improving the information flow can be found in initiatives that reduce the number of steps in a process, allowing operators to more easily track the progress of a product. Other examples illustrate the power of moving people, tasks and machines closer together. Spatial proximity successfully enhancing information flow becomes evident when achieving benefits like visibility of co-workers, whole-task understanding and continuous informal communication. Additionally, physical configurations that create spatial proximity between entities have a positive effect on time. The small transfer batches and short setup times that generate shorter throughput times are directly influenced by the spatial arrangement of elements.

The various enablers that improve the linkages between entities in terms of time, space and information contribute to reducing non-linearities and thereby to waste reduction. They support a system design capable of exposing waste, which is fundamental to the elimination of waste (e.g., Won et al. 2001). But most important of all, they empower different stakeholder groups to solve problems or to even avoid them. The stakeholders become equipped to manage the variations in the dynamics against the closest active constraints.

Referring now to the *delivery of complete subsystems*, it is important to remember the fundamental idea that a project, like any other process, is subordinated to the organizational structure and is made more or less efficient according to the variable and uncertain conditions faced by the different functional areas along its path. Structural adjustments that allow different stakeholders to participate in a larger number of production steps create opportunities for them to capitalize on continuity of factors, early decision-making to influence factors upstream, and better interconnections in the current production stage. The more stable and predictable systemic behaviour within the broader work scope permits the reduction of buffer sizes between production steps, which in turn improves the workflow. As shown throughout this chapter, the design-build model is an example of a structural change to streamline the organizational structure.

The four principles of systemic stability in project production interact with each other, and with enablers, to influence project performance. The best way to depict their combined application is through the so-called hierarchic description, which is based on the idea that a particular system possesses different hierarchic levels of complexity (e.g., Gomes 2007). Put differently, a complex system can be broken into different scale levels, each one representing a subsystem. This stratified description is based on temporal criteria or alternatively in terms of behavioural frequency. It allows visualizing a complex system as having both a horizontal structure and a vertical structure (Figure 11). The horizontal structure comprises the subsystems, each defined by a specific set of variables. The horizontal perspective of complexity is, therefore, useful to comprehending large and small-scale systemic properties assigned to the representative subsystems. A system defined by X variables is subdivided in Y and Z fractions. In every single subsystem there are intra level interactions (horizontal arrows) occurring between the entities. But there are also inter level interactions (vertical arrows) occurring between subsystems, which, in turn, make up the vertical structure.

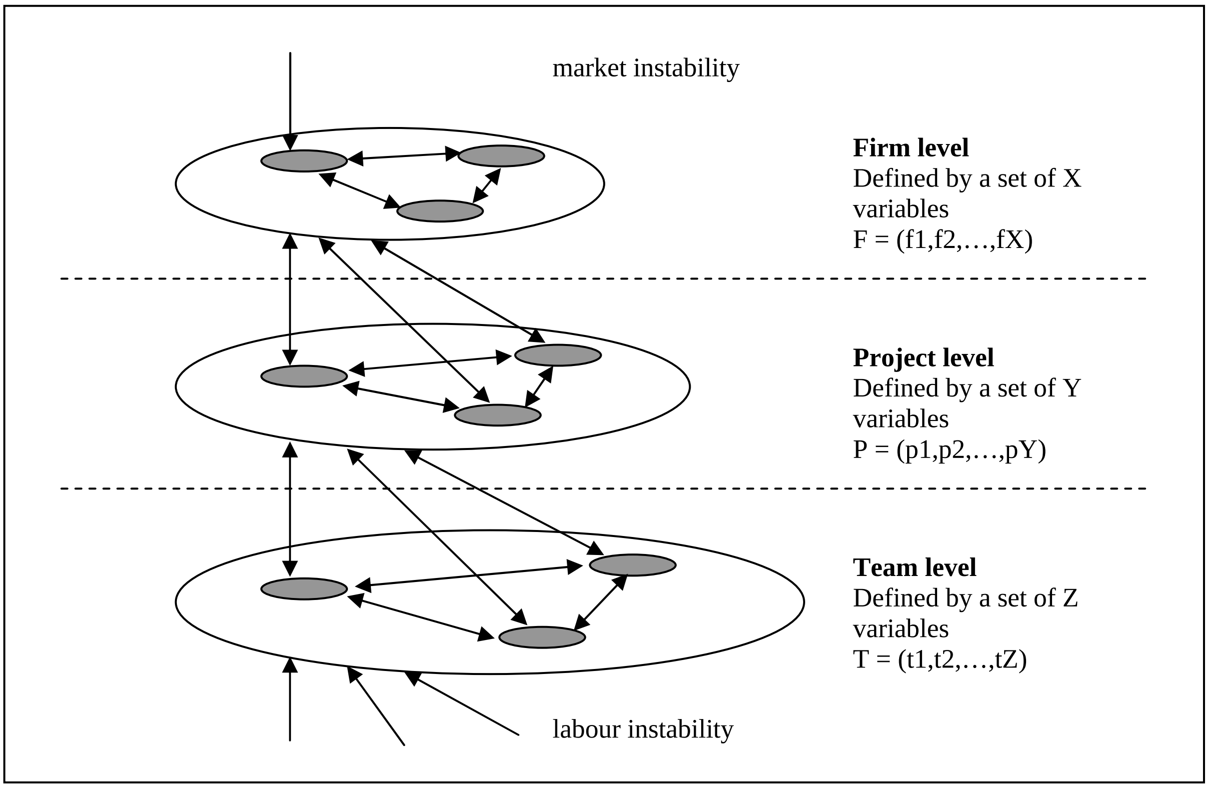

Figure 11 – Hierarchic description of system complexity to depict the workings of the principles of systemic stability in project production. Source: based on Gomes (2007)

The notion of different hierarchic levels of complexity indicates the need for initiatives to promote integrality and simplicity in each one of them. As a matter of fact, strategic choices and practices supporting the continuity of organizational factors and delivery of complete subsystems impact the division of work in different levels of the enterprise. They can improve simplicity and predictability in the project organization in distinct manners and along different time spans. For example, strategic partnering is a firm level strategy aimed at supporting the continuity of organizational factors in the long-term. Complementarily, design-build is a project level strategy that supports the continuity of organizational factors in the medium-term. Furthermore, the use of multi-skilled teams in charge of work packages with a larger number of subsequent activities is an operational strategy to support the continuity of factors in the short-term. As mentioned before, the lower levels and downstream activities benefit from the predictability provided by the upper levels. The enhanced predictability, represented by the downward arrows, helps to reduce redundancies in the lower subsystems. But buffer sizes can also become smaller if arrangements are made to allow entities at all subsystems to influence factors upstream and thereby reduce the number of potential sources of variation. Such influence is represented by the upward pointing arrows and is very much in conformity with the supplier-client role of every entity in an integral production system. Additionally, influence over upstream factors can also be made inside a particular level by entities that closely interact with one another. Practices and support mechanisms that enable the entities in each level to come closer in terms of time, space and information also reduce the dependence on slack or buffers. The enhanced lateral relations in the subsystems are represented by the double-tipped horizontal arrows. In closing, an organizational structure can be made significantly less complex and more stable if initiatives based on the four principles are applied to its different hierarchic levels of complexity.

4.3 - CONCLUSIONS

Different production models can be created for competition in the same marketplace. However, not knowing a more appropriate theoretical foundation for structuring project-based organizations, nor the conceptualizations adopted by the best competitors, turns difficult the task of formulating innovative contextual solutions, coherent with one another and with the business strategy. This is the case of traditional production system design and operation in the construction sector, which has been widely influenced by the Taylor model. As if construction peculiarities were not enough, the linkages in the value creation stream under the general contracting firms' work scope have been further weakened by strategic choices promoting high division of work, excess stratification of subcontractors and intense substitution of workforce. Consequently, performance improvement has been constrained by an organizational context where integrality and simplicity have been left aside.

Based on personal field experience and exploratory library research, a critical analysis of two renewal initiatives that cause structural changes to the organizational pattern has been carried out with the objective of unveiling the underlying principles of organization structuring for successful project delivery in construction. Consistent patterns were uncovered from the observations and literature discussions on design-build and partnering approaches. This allowed the way of thinking about organizational integrality and its underpinnings to evolve, serving to reinforce or reshape the emerging theory. It became clear that, despite the numerous practices to create structural changes, only those meeting certain principles actually support integrality and simplicity. The characterization of the discipline of integrality in project production seems to be summarized in four principles: continuity through time, influence over upstream factors, direct interconnections, and delivery of complete subsystems. Of the principles identified in the analysis, the delivery of complete subsystems is the most supportive, since it allows different stakeholders to participate in a larger number of production steps and thereby creates opportunities for them to capitalize on continuity of factors, early decision-making to influence factors upstream, and better interconnections in the current production stage.

Strategic choices and production practices founded on the principles enhance systemic stability by reducing the number of potential sources of unwanted dynamics or by minimizing the non-linearities within dynamics. However, initiatives to improve the production system design are rarely based on more than one of the principles above. Moreover, the notion that systems possess different hierarchic levels of complexity helps to explain the perception that such initiatives are more effective in improving integrality and simplicity only inside specific hierarchic levels. These are two inherent reasons why a "best practice" programme will not by itself guarantee improved performance when implemented alone. On the contrary, the analysis conducted in this chapter suggests that an organization can only obtain the stability needed to achieve management goals or be improved if different initiatives based on the four principles are applied to its representative complex subsystems.

Therefore, it is put forward in this thesis that with better understanding of integrality building blocks and enablers, project organizations can begin with a solid idea of what is needed to implement mobile cells and to make them work best. This is a particularly promising insight because, in spite of the growing tide of field research in workforce autonomy, the mobile cell construct has not been defined through a proper underlying theory. The discussions conducted under this chapter offer a foundation by suggesting that the rationale guiding the strategies that generate the outermost layers of protection against variation is the same needed to create better interactions in the other multiple levels of complexity of temporary organizations.

In summary, people at all levels want and need a sense of predictability about the future. It is a human behavior that organizations naturally replicate. Unfortunately, the centralized decision-making of traditional construction management practices has relegated workers to being mere commodities, neglecting their needs as internal clients and potential to generate predictability and contributions. As a result, the mobile production cell concept, as a research topic, appears to be the last piece of the puzzle in the creation of an integral project production system. Further investigation on the topic is required involving both field research and exploration of disciplines in the behavioral sciences to agree on a disciplinary theoretical foundation. The findings will not only contribute to filling a perceived void in the implementation of mobile cells in construction projects, but also to building the theoretical foundation of integrality in project production. Thus, in the following chapters the ideas presented herein are tested with the rigor necessary for solid conclusions.

CHAPTER 5 – ENABLERS AND IMPACTS OF CELL PRODUCTION: An Exploratory Field Research in Builder-Developer Firms

Research studies indicate the existence of three generic ways for dealing with variation: control, flexibility and buffering. These are the ways of assuring organizational robustness to support the proactive and reactive management of events that occur during the project life cycle. Traditionally, project management practices have strongly relied on the combined use of control and buffers. However, the growing recognition of problems associated with organizational complexity has been changing paradigms and pushing structural changes towards the development of flexible competences. One such change is observed in the ongoing effort to adopt a more flat organizational structure characterized by delegation of responsibility and decentralization, being its most visible aspect the autonomous, multi-skilled teams working as mobile production cells.

This chapter focuses on system design changes for the application of the mobile production cell concept and its effects on managerial interventions and buffer usages. The ideas expressed here are outcomes of an exploratory five-company case study made to investigate changes related to this type of system flexibility within Brazilian construction firms. Interviews were conducted with project managers from five high rise building firms who adopt different production system designs and a parallel between their distinct production models was established. Thus, the main objectives of this chapter are:

- to highlight the strategic choices and bundles of production practices supporting the mobile cells and verify their relation to the four principles of systemic stability in project production;
- to identify changes in management style and the relative importance of different types of control and buffers after developing this system flexibility type; and
- to provide a further understanding on the inter-relationship between control, flexibility and buffers and propose a conceptual model for project robustness.

5.1 - Theoretical Background

Following the trajectory taken by western manufacturing industries in the 1980s and 1990s, the Brazilian building sector is undergoing a change of paradigms and opening to new approaches for project production. Behind the changes lies the realization that project managers are incapable of planning and controlling all variables in such a complex phenomenon as construction. Therefore, until this point, the focus has been deviated from management-as-planning to management-as-organizing. Far from only meaning the provision of proper work conditions, it is being understood as the creation of a coherent organizational structure and culture. In this new organizational pattern, the vision embodied is that of a production system characterized by delegation of responsibility, commitment, cooperation and learning.

In terms of organization structuring, there has been a significant effort to break away from the conventional hierarchical manner of dividing contracts by functions, sub optimizing for individual benefits and communicating through narrow channels. As mentioned by Monostori et al. (1998), the high complexity environment is leading the firms to decentralize functions and to exploit the creativity, experience and competence of all stakeholders, especially the workforce. The main driver for the change has been the acknowledgement of construction workers as a special kind of structural resource capable of assuming more than the role of sources of physical manpower.

The shift into a flat structure where teams of workers are empowered to control their tasks has also been a process of developing new roles for managers. By holding key positions as the links between top management and workers, project managers are critical to making a successful outcome. In other words, the success or failure of competitive strategies can be explained in many cases by the alignment of strategic choices, production practices and management decision-making and style. Decisions regarding strategic choices and production practices are fundamental to shaping the organizational structure and need to be tailored to an ever changing external context through an iterative process. But they also need to be backed up by coherent tactical and operational level managerial decisions. According to Zuo and Zillante (2005), both leadership and organizational structure impact on the culture developed within a project, which in turn has to be as strong and unified as possible for the attainment of project goals. Therefore, to understand the successful implementation of mobile production cells, the analysis of strategic contents must encompass the strategic choices, bundles of production practices and project management decisions that may affect this type of flexibility, especially those regarding the use of buffers.

In accordance with these aspects, the following topics discuss theoretical issues that form an important background for the research results presented in this chapter. First, the complementary importance of control, flexibility and buffering types is described. Second, the distinction between cellular manufacturing and mobile production cells is drawn.

5.1.1 - Proactive and Reactive Management

According to Monostori et al. (1998), proactive management is a behaviour aimed at fostering anticipation, learning and coherence. It is generally a process of preventing anticipated disturbances as early as they are foreseeable from monitored and sampled performance trends. On the other hand, the authors describe reactive management as a behaviour aimed at achieving an adaptive coordinated response to changes. It is an event-driven incremental repair process to current internal and external circumstances. Both proactive and reactive management decisions should be based on real time monitoring and a continual data-acquisition in the shop floor.

Despite the fact that good management is primordially proactive instead of reactive, both proactivity and reactivity must be combined for the effective fulfilment of performance goals (e.g., Monostori et al. 1998). As Schmenner and Tatikonda (2005) put it, “the study of the Japanese flexible factory has not only led researchers to question whether tradeoffs (e.g. cost versus quality) actually exist, but has also shown the importance of its complementarity with proactive management.” This statement indicates that a firm is flexible in adapting to variation part because it is proactive in controlling it. Among other aspects, it reaffirms the importance of adequately matching types of control and flexibility. It also reminds of the importance of making the proper decisions regarding organization structuring, since all resources contribute to flexibility. Slack (1987) agrees by saying that flexible technology cannot be totally effective without flexible labour and vice versa. Neither can be effective without a set of procedures, systems and controls which are themselves capable of coping with the flexibility of the physical processes.

5.1.2 - Robustness in Project-Based Organizations

Robustness is commonly mistaken for redundancies in task-resource allocation. However, from a strategic perspective, control, flexibility and buffering are complementary ways of dealing with the same problem: variation. Together they comprise the set of strategies, capabilities and capacities that build organizational robustness and, therefore, must be rationally used to support proactive and reactive management during the project life cycle. Despite the major developments in industrial management, most research studies have only examined superficially the mechanisms behind their inter-relationships, especially when used in different organizational structures. Nevertheless, a comparative analysis indicates the importance of carefully applying them according to the conditions because each handles variation in a different manner:

- Control (action): abilities and strategies that identify and influence the occurrence of events with the objective of preventively reducing their effects on the system;
- Flexibility (reaction): capabilities that quickly adapt the system in response to the effects of changes, without inflicting damage to production goals;
- Buffering (conformation): redundancies that allow the system's structural arrangement to accommodate disturbances and variation.

In manufacturing, Corrêa and Slack (1994) found evidence of a hierarchic application in which control mechanisms are used as "filters" that restrict the amount of changes to be dealt by the system. Standardizing, monitoring, advertising/promoting, and focusing are amongst the event control-related managerial actions (e.g., Corrêa and Gianesi 1994). Some changes and their effects that pass through the "filters" will be managed by flexibility types within the system. However, Slack (1987) mentions the control schemes as being incapable of dealing with all variables and flexibility as preferably avoided by companies due to its high development costs. This suggests the use of buffers as the third way of handling the rest of the variations due to their broader applicability. In summary, the three constituents of organizational robustness comprise the layers of strategies, capabilities and capacities that support systemic stability by reducing the number of events that cause dynamics and the non-linearities within the dynamics.

Furthermore, the need to distinguish flexibility from pure and simple buffering is primordial to understanding the results presented in this chapter. While firms may not be able to prevent all problem-causing variations, they can learn to recover from some of them with little, if any, harm to performance. Therefore, flexibility is commonly defined as the ability to respond effectively to changing circumstances (e.g., Schmenner and Tatikonda 2005). It is a strategically important attribute for a firm competing in a marketplace with given variation types. For this reason, Sánchez and Pérez (2005) mention that a comprehensive view of the production function calls for distinguishing flexibility in three ways: (1) basic flexibility types or flexibility of individual resources (flexible competences); (2) system flexibility types or composites of the basic flexibility types at the production system level (flexible competences); and (3) aggregate flexibility types or flexibility of the production system as a whole (flexible capabilities). A flexible production capability is an external dimension of competition that is perceived and valued by costumers such as product, volume, delivery and mix flexibilities. In other words, flexible capabilities have an impact on the relationships with customers. Differently, a flexible production competence, which includes machine, labor, material handling, and routing flexibilities, is a key internal dimension of competition that is invisible to costumers (e.g., Zhang et al. 2006). Both dimensions are interrelated because flexible competences support the system's flexible capabilities.

As for buffering practices, in this dissertation buffers are understood as resource cushions, i.e., money, time, materials, space, etc., used to protect processes against variation and resource starvation (e.g., Alves and Tommelein 2004). Alves et al. (2006) mention the importance of acknowledging the effect of variation in the definition of buffer profiles, which can be described in terms of type, place and size. In highly uncertain and variable conditions, like project production in the architecture, engineering and construction industry, buffers have a role to play in absorbing changes in costumer orders, problems with defective products, variations in production with long lead times, and problems with material shortages. Buffers help to keep certain dynamics from pushing to the limit the closest currently active constraints in the subsystems. At the project level, buffers can take many forms including: inventory (materials), work-in-process (subassemblies), time (deliberate and unintentional delays), and excess capacity (labor and equipment). At the worker, team and firm levels they may take different forms, since other types of redundancies may exist.

The distinction between flexible competences and buffering practices is a prerequisite to understanding how they impact on aggregate flexibility. First of all, both types of initiatives may originate from deliberate strategies. However, basic and system flexibility types do not come without a cost because structural changes are required to create the competences necessary to respond effectively to variations. Differently, buffering initiatives may seem like easier solutions, but they do not contribute to the overall efficiency. The failure to distinguish the concepts can often lead to misunderstandings. For instance, Corrêa and Gianesi (1994) have mentioned that the more flexible the production system the more difficult it is to maintain consistency in terms of cycle time and quality. Although true, this affirmation does not specify that, in such cases, aggregate flexibility is being more supported by different redundancies than by flexible competences. In other words, it makes no clarification or simply ignores the fact that excessive buffering is the cause of poor performance.

Because of the above reasons, it is a conceptual misunderstanding to describe flexibility as a response to unexpected changes. On the contrary, flexibility is the adaptation of a particular system inside a set of predetermined states. Therefore, this dissertation proposes that systemic efficiency depends on limiting the number and degree of variations the subsystems endure and on making the structural arrangements that originate the flexible competences to match the changes. Exposing the subsystems to a wider set of states than what was originally intended implies allocating to them different types of buffers to absorb different variation types. This, in turn, jeopardizes the performance goals just as much as not placing the buffers would too. Consequently, as mentioned before, flexibility types need to be complemented with control mechanisms in order to keep subsystems within a deliberate set of states.

Regarding the construction sector, it is well-known that the development of tools and practices for production planning and control is the most studied topic (e.g., Ballard and Howell 1997, Alarcón et al. 2005). But there has also been a great concern with the implementation of different types of flexibility within the projects (e.g., Martucci and Fabricio 1998, Ebert and Roman 2006). Additionally, recent studies (e.g., Sakamoto et. Al., 2002; e.g., Nielsen and Thomassen, 2004) have shown the proper sizing and location of buffers to positively impact on project performance. This leads to perceiving that an adequate analysis and representation of organizational robustness in civil construction must encompass the three ways of handling variations, as they are crucial elements to both proactive and reactive management. Hence, a conceptual model is proposed with flexibility as the central element of organizational robustness (Figure 12).

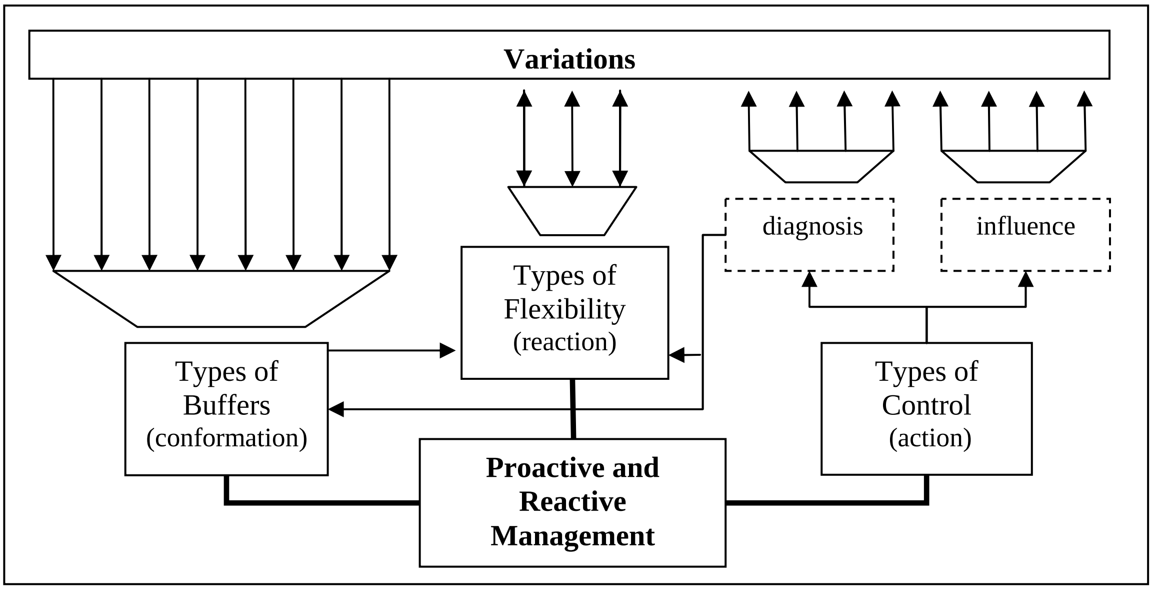

Figure 12 – Variation management as a balance between action, reaction and conformation. Source: Miranda Filho (2008)

5.1.3 - Differentiating Mobile Cells from Manufacturing Cells

In manufacturing, Slack (1987) observed that most managers focused more on flexibility as it applied to the individual resources of manufacture as opposed to the flexibility of the production system as a whole. Oppositely, in the more unstable construction industry, centralized decision-making, poor organizational integration and changes in costumer orders have led the focus to be on aggregate rather than on basic or system flexibility types. However, the flexibility of the project production system as whole (flexible capabilities) has been mostly achieved through buffering initiatives. As a result, the development of system flexibility types that contribute to efficiency and effectiveness, such as the mobile production cells, remains lacking a more comprehensive perspective.

To understand flexible competences, it is important to acknowledge the combined enablers – procedures, policies, resources, design decisions and other factors that make possible the development of flexible production technology and other internal sources of competitive advantage. The critical role of enablers is easily perceived in cell production, which is oftenly described as an application of “group technology” (e.g., Hyer and Brown 1999). Group technology is an alternative method of organization to work structuring based on process specialization. As discussed by Burbidge (1996), the essential step in group technology is to plan a total division into groups and families, in which each group completes all the parts it makes. The author adds that this is followed by changes needed to install the groups and get them running, such as plant layout, changes in operating and payment systems, manning of groups, and training. Evidently, the flexibility of the equipment and bandwidth of worker skills determines the range and sets of parts that can be made by the same group. Hence, there is no universal rule for the number of parts made by a group.

These aspects have also been discussed in detail by Hyer and Brown (1999), who have extended the definition of cell manufacturing beyond issues of structural and infrastructural decisions. According to the authors, the real manufacturing cells are characterized by more than just the dedication of resources to a family of parts which have similar processing requirements. They propose that the discipline of cell production also involves the creation of a work flow where required tasks and those who perform them are closely connected in terms of time, space and information. Although it is not clearly stated, the authors recognize the production cells as integral subsystems requiring proximity between the participating entities. They believe the time, space and information linkages among people and tasks to be the common denominators that distinguish cells from other manufacturing constructs. In their opinion, this broad definitional foundation should allow the cell concept to be applied across industries and sectors.

Indeed, there have been many initiatives in the Brazilian construction sector based on Hyer and Brown (1999)'s definitional elements of real cell production. As shown by Santos et al. (2002) and reinforced by Pattussi and Heineck (2006), there are many advantages to having team members working closer to one another and completing a larger set of closely affiliated subsequent and adjacent tasks before moving to another workplace. Both studies have shown that such a work arrangement improves pull production, anticipation of problems and workflow stability within each subsystem.

However, the ideas proposed by Hyer and Brown (1999) were originated in manufacturing plants, which are well-known for having a considerably more stable work environment than construction projects. Consequently, the initiatives to implement the mobile cell concept in project production have been guided by a disciplinary theory more appropriate for cellular manufacturing, since it is mostly focused on improving the linkages between the workers and tasks belonging to a particular group. This narrow scope of the changes needed for an effective implementation of mobile cells is a constraint for an even greater performance improvement. It is argued here that, instead of just enhancing the interconnections between entities in each subsystem, the dynamic nature of the construction environment and its different hierarchic levels of complexity require the application of initiatives based on all four principles of systemic stability in project production. Thus, an effective cell implementation has to be founded on the same building blocks that generate "higher" level project integrality. This chapter explores this proposition with the objective of showing that the mobile cell concept is more than just a large work package assigned to a group of multi-skilled workers operating closely together.

5.2 - RESEARCH METHODOLOGY

The research protocol consisted of obtaining data from two basic sources: primary sources and secondary sources (e.g., Merrian 1998). The primary data came from in-depth interviews regarding contextual conditions, visits to construction sites, and tours of the production areas. The secondary data came from documents existing in some of the sites and provided by management teams. In accordance with Telem et al. (2006), documentation of primary data was done using simple and reliable equipment - pen and paper - that served the research needs optimally as it was less intimidating to the interviewed or observed persons compared with audio or video documentation. A semi-structured questionnaire presenting a standard set of questions was used to conduct the interviews. This method of gathering information was chosen for being the most appropriate when the logic of a situation is not clear (e.g., Easterby-Smith et al. 1991). The method's suitability for an exploratory study was confirmed as relevant aspects and consistent patterns appeared when the interviewees spoke about the cells they have implemented and the outcomes that have resulted from the changes they made.

The data collection process lasted a period of four weeks and was conducted in 5 building firms that compete against one another. The firms were very open to sharing experiences. But to further encourage their participation, these participants were promised a copy of a summary of the study and its conclusions. During the field research, a total of 8 constructions sites were visited, some more than once, and 10 site managers were interviewed. Site managers comprised those project managers who may control individual or multiple construction projects at any given time. The location of most interviews was the construction site. It was picked for being the place where the project managers felt the most comfortable in speaking openly. In addition, 5 senior managers, one from each firm, were interviewed. The senior management group consisted of company owners and chief operating officers who work mainly outside the construction sites.

The cases were intentionally selected for being considered theoretically useful due to their differences in strategic choices and production practices. Thus, among other questions, the interviewees were asked to comment and rate different types of control, flexibility and buffers with respect to their relevance in the projects: 1 (low); 2-3 (below average); 4 (average); 5-6 (above average); and 7 (high). Although the use of Likert scale "opinion-type" questions does not provide strong quantitative evidence, this 1-to-7 rating scale was useful in identifying trends and even causal connections between system design decisions. The considered types and their nomenclature were extracted from the literature review (e.g., Slack 1987, Corrêa and Slack 1994, Sakamoto et al. 2002, Nielsen and Thomassen 2004):

- Control: coordination, monitoring, forecasting, subcontracting and partnering;
- Flexibility: flexible labour (multi-skilled workers);
- Buffers: inventory, capacity, work-in-process and time.

5.3 - RESULTS

5.3.1 - Case Descriptions

The five firms are both developers and builders, being mainly involved in multi-storey residential and office building projects. The firms perform their activities in the city of Fortaleza, in the Brazilian northeast, where they pretty much compete in the same niche market. For these firms, quality and delivery performance are qualifying criteria (Voss, 1995), which must be met if they are to be in the market. The order winning performance criterion among all competitive priorities is product flexibility as defined by Slack (1987). Hence, the firms can be considered to belong in the same strategic group (e.g., Christiansen et al. 2003), since they follow a similar strategic orientation and share the same geographic area.

The study of firms from one construction type presenting the same market characteristics was important to leave out many uncontrollable variables and highlight as much as possible differences in production system design and their effect on control and buffer types. Moreover, because the aim of the research is to explore aspects of a new project production paradigm, the selection of a group of groundbreaking construction firms that execute challenging, large buildings (rather than infrastructures, for example) constituted a crucial key to the success of the study. For these reasons, the construction industry in the city of Fortaleza (Brazil) was chosen because of its richness, its complexity of needs, as well as an unusual level of openness to scholarly inquiry. But most important of all, it is well recognized that the construction firms in Fortaleza are amongst the most advanced in adopting lean construction principles and practices. As a matter of fact, the five firms are members of the INOVACON Building Technology Programme, which is sponsored by the group of participating building firms and CNPq, the Brazilian National Agency for Research and Development. The Programme aims at informing or transferring state of the art technology from various fields of the architecture engineering and construction industry to the participating firms, including innovative production principles and practices.

As expected, despite a number of similarities between the firms, there were also some remarkable differences, especially in strategic choices concerning team skills (specialized or multi-skilled) and levels of subcontracting (make or buy) and partnering (strategic collaboration or substitution). Furthermore, at the time of the interviews, the firms not only differed in their strategic choices in production strategy, but were also in distinct stages of implementing the "best practices" acquired from the INOVACON Programme. Strategic choices and production practices in firms A and B were considerably different than those in firms D and E (Table 1). The intermediate case was represented by firm C, which had implemented a fair amount of "best practices" but maintained a structure based on specialized teams and subcontractor substitution.

Table 1 - Comparison between strategic choices and practices in the five building firms

Firms	Respondents	Practices	Team Skills	Subcontracting	Partnering
A	1 senior and 2 site managers	JIT, LPS	Specialized	Low	High
B	1 senior and 1 site manager	JIT, LPS, LOB	Specialized	Medium	High
C	1 senior and 2 site managers	JIT, LPS, LOB, Andon, Kanban, 5S	Specialized	Medium	Medium
D	1 senior and 2 site managers	JIT, LPS, LOB, Andon, Kanban, 5S, FRS	Multi-skilled	Low	High
E	1 senior and 3 site managers	JIT, LPS, LOB, Andon, Kanban, FRS, Poka-Yoke	Multi-skilled	Low	High

Four years is the length of time generally necessary for a company to be able to asses the results of introducing a new strategy (e.g., Acur et al. 2003). So even though firms A and B had fallen behind, they were following fast the steps of D and E, which had been undertaking these changes for more than three years. By emphasizing the implementation of the same bundles of practices, they hoped to achieve the same level of operational performance. As mentioned by

Christiansen et al. (2003), having a strategic group membership gives the company a better understanding on which bundles of practices to implement. This is quite handy due to resource constraints and time pressure. Workload and production rate balancing with Line of Balance (LOB), production shielding with Last Planner System (LPS), site scheduling based on Just-in-Time (JIT) principles, Kanban signalling, fool proof (Poka-Yoke) devices, and different types of Andons were some of the practices in use or being implemented. A number of studies report with further details these and other developments made within companies belonging to the INOVACON Programme (e.g., Heineck et al. 2002, 2002a, Kemmer et al. 2006, 2007).

Most respondents in firms C, D and E described the implementation of the practices as an ongoing action programme to develop process focus and pull production. Consistent with the observations made by Laugen et al. (2005), the interviewees mentioned that the firms came to realize that bundles of "best practices" underpinning pull production supported each other and had to be implemented in order to achieve a significant positive effect on performance. This is a clear indication that they perceive, perhaps intuitively, the different hierarchic levels of complexity in the construction environment and the need to implement at the level of operations a set of initiatives based on the interrelated principles of systemic stability.

5.3.2 - Summary of Findings

5.3.2.1 - Description of practices

The five firms adopt similar higher level strategies to limit the frequency and magnitude of changes the production system undergoes during the project life cycle. For instance, senior management has reduced external drivers of complexity by focusing the business orientation on certain customer segments and specific geographic area. The reduction of product proliferation limits the degree of product uniqueness and the corresponding level of organizational complexity. Additionally, project management applies different control strategies to influence variation types and thereby reduce the amount of buffers supporting aggregate flexibility types. This can be observed in the decisions to buy from local suppliers, prepare a model apartment for clients, open a showroom for finishing materials, and maintain unfinished apartments, just to mention a few.

In their line of work, the project managers expect clients to demand changes that can cause perturbations in the construction processes and force some revisions in the production system design. Therefore, with respect to the hybrid architecture of the product, the firms allow buyers to choose from different basic variants, which they can further enhance with numerous accessories. The exterior (layout and dimensions) as well as part of the interior design are fixed and offered as an integral unit. But other portions of the apartment's interior space are not. The interior is organized on a modular basis and allowed to become unique, especially on the level of the accessories. As discussed by Voordijk et al. (2006), the firms are aware that the extent to which strategies for postponement of decisions and late customization can be realized depends very much on the modularity of interfaces between components. Still, the interviewees consider it desirable when the clients and their technical advisers make early decisions and preferably regarding just the finishing materials like lighting accessories, tiles, and sanitary facilities. The concern with time-based competitiveness and optimal conditions for the construction process has led the management teams to implement the event control-related strategies described above and their architects and specialist designers to make designs with limited variation.

But the focus of the present chapter is the production system design changes that enable the work teams to manage tasks and control variations at the level of operations. As discussed throughout most of chapter 2, despite the influence coming from external drivers, it is important to recognize the internal drivers that largely contribute to the heterogeneity of participants and to the difficulty of interlinking them. In other words, internal adjustments can be made to reduce the degree of organizational complexity and enhance interactions within the system. Improvements in these aspects help to eliminate intermediate barriers to the flows, including layers of authority relationships in the chain of command, and empower the work teams to make decisions and counter the non linearities that harm performance. Thus, the main strategic choices in production strategy and “best practices” implemented in firms D and E are broadly described next, illustrating how they are linked to the principles of systemic stability in project production. During the study it became clear that the two firms were just as much concerned with eliminating internal causes of variations and imperfections as they were with avoiding changes on the buyer’s side.

The firms devised many small-scale innovations that were soon copied and improved by other firms participating in the INOVACON Programme. These are mostly low cost managerial and technical procedures engendered by site personnel to improve competitiveness either in terms of costs, time, or quality. Regarding the site layout, initiatives to increase the transparency of production status and fast recognition of problems can be seen all around, improving the flow of materials, resources and, most of all, information. The first thing the visitors notice when coming to one of the construction sites is a fence made with a grid of small iron bars surrounding the whole site (Figure 13). The transparent site fence totally exposes the working area to buyers, potential clients and other passbyers in the outside. Moreover, there are gates around the fence, allowing materials to be simultaneously unloaded by different directions.

Figure 13 – Transparent fence (left) and gate (right) surrounding a construction site in Fortaleza. Source: Miranda Filho (2008)

Wooden tunnels with open sides connect the external part of the sites with the site offices and other interior parts of the building under construction (Figure 14). They allow visitors and workers to safely access different construction work places while viewing the surroundings. In accordance with the 5S approach, the construction sites are planned ahead to have fixed storage areas and pathways for materials and personnel. These initiatives not only help to keep a tidy and ordered work environment, but also improve the transparency and flows within the sites.

Having fences, pathways, site offices and labour rest areas, sanitary facilities and eating rooms painted in white also contributes to a general appearance of tidiness.

Figure 14 – Fixed storage area (left) and pathway (right) seen from an open wooden tunnel at a construction site in Fortaleza. Source: Miranda Filho (2008)

Various support mechanisms, including visual aids, are used to enhance the proximity between entities and tasks in terms of time, space and information. For instance, bricks and other construction materials are unloaded to special docks along the site fence, which are at the same height as the lorry platform (Figure 15). From there, the materials are moved to previously defined storage areas and later to the cargo lift following marked pathways that represent the shortest possible transportation distance between the three points. Pathways, storage areas and other site locations are signalled by marks on the floor or identification tags and cannot be used for different purposes. Additionally, video cameras are used to make visible the invisible critical spots in the construction sites. For instance, the worker in charge of operating the cargo lift from the ground floor controls the safety of all the loading and unloading operations in each story through a video camera installed in the cargo lift.

Figure 15 – Unloading dock (left) and signalled storage area (right) at a construction site in Fortaleza. Source: Miranda Filho (2008)

In the early stages of construction, the site offices are placed in a way that allows the management teams to visualize and control the work done in the proportion of land occupied by the tower block. Internal divisions are avoided in the offices and glass windows and doors are used to allow an easy visualization from the inside to the outside and vice versa (Figure 16). The workstations in the offices are not only spatially close, but also the computers are networked together. These cautions are maintained throughout the construction stage, even though the position of the office may change a couple of times.

Figure 16 – Site office with glass windows and doors (left) and with no internal divisions (right) at a construction site in Fortaleza. Source: Miranda Filho (2008)

Enablers to improve the linkages between entities in terms of time, space and information are also directly applied to the interrelations between work teams. To begin with, work specialists and support personnel are easily distinguished from a distance by the different colours of their helmets. In more advanced stages, work teams and other key personnel on site also use walkie-talkie radios to quickly exchange information about problematic events or to find out each others whereabouts. Furthermore, different Andon systems have been devised to improve communications between specialist, management and support teams within construction sites. These visual aids use color codes to show the status of ongoing operations in the different floors and thereby help in preventing possible disturbances in workplaces. If the allocated work team, work space, materials, and project details are all set to start production at each morning, the team leader in that storey or apartment presses the Andon green button, which turns on a correspondingly green light in the panel installed at the site management office (Figure 17). The green light immediately signalizes to the project management team that production has been properly shielded from variations and that the work package is being performed as planned in that particular workplace. Whenever team leaders anticipate problems within a few hours ahead, the yellow button is pressed and the correspondingly yellow lights are turned on at the site office. The yellow lights warn the management team of the possibility of occurring work stoppages in those working places. Managerial actions start right away in order to solve the problems and thereby ensure a steady production pace. Accordingly, the situation should never be allowed to evolve to a point where the red button is pressed. A red light calls for explanations and registration of causes, since it is the result of cumulative failures in work preparation, anticipation of problems, and supportive actions to avoid stoppages.

A key aspect of the Andon system implemented is that the work force perceives a new balance of power on site. As observed by Kemmer et al. 2006, the work teams facing problems put orders to those in charge of finding a solution to avoid stoppages on site. This is taken so seriously that when the red button is pressed, the red light in the Andon panel is activated along with an electric signalling that makes a buzzing sound in the site management office. The buzzer only stops when the team leader up in that storey presses the green Andon button. The idea is that the management personnel should immediately stop their more bureaucratic activities to promptly find a solution to the current problem. Of course, the yellow and red lights can be avoided if the proper support is provided early during the work preparation. But the logic remains the same at all times. That is, the traditional command hierarchy shifts into a structure aimed to support and prioritize the activities that are truly the most valued by the final client. These aspects of the Andon system reveal that the underlying assumptions in firms D and E are quite different from those in traditional construction firms.

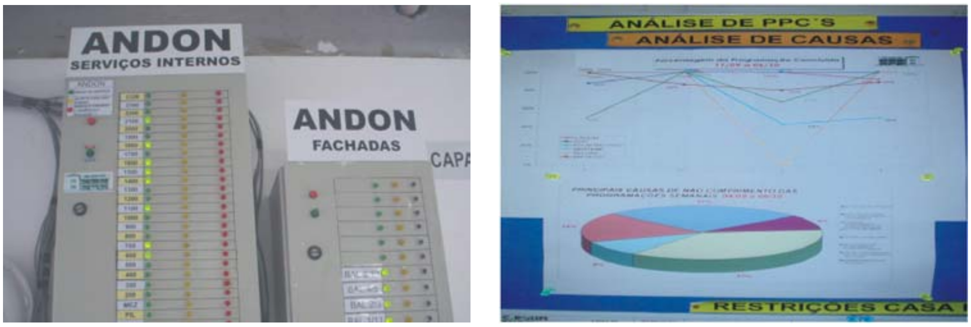

Figure 17 – Andon control panel (left) and graphical statistics of the reasons for non-completion of weekly work plans (right) at a construction site in Fortaleza. Source: Miranda Filho (2008)

Efforts to improve the linkages between workers and tasks within each team are also quite evident. For instance, drawings and other work content specifications are made available at the workplaces. Additionally, in more advanced stages, illumination sockets are available in the rooms and lamps can be provided to increase visibility when work is in progress. These are two examples of initiatives that create a work-flow where tasks and those who perform them are closely connected.

The Andon and other operational-level initiatives discussed so far are clearly fundamented on the principle of *direct interconnections*, since they strengthen the linkages between work teams in terms of time, space and information. By enhancing the lateral relations in that particular level of system complexity, these initiatives help the teams to keep variations under control and to thereby improve the quality of physical and information flows in the network. Compared to cellular manufacturing, construction layouts are much more dynamic. Physical barriers are created everyday as the product takes shape, making the workstations move around based on the start and finish of activities. Thus, the experience of firms D and E illustrates the effective implementation of cell production in construction sites as requiring enablers that make time, space and information linkages possible inside the teams as well as between the teams.

The enhanced lateral relations between the teams support the implementation of initiatives based on the principle of *influence over upstream factors*. For instance, at the end of each work day the team leaders deliver mortar production orders to the mixing installation situated at the ground floor. Coloured cards (also known as Kanban cards) specifying the mixture of sand and cement quantities, the workplace of destination and the name of the leader of the client work team are placed on a Heijunka box fixed at the mixing area (Figure 18). Each card represents a demand order for one mortar batch, which is equivalent to the quantity of mortar transported in gauged wheelbarrows. The team leaders place these cards according to the time intervals (hours and fractions of hours) in which the work teams wish the mortar batches to be delivered to their workplaces. This practice allows team leaders to go beyond their workscope and reduce inflow variations by avoiding uni-lateral decision-making and actions of the mixing team.

However, lateral relations imply that influence is exercised in both sides. Early in the beginning of each work day, if demand orders of mortar mixes are too much concentrated in a particular time interval, the mixer operator balances demand orders by distributing evenly the cards of different teams across sequential time intervals. This helps to stabilize workflow in the network by ensuring that all teams are supplied and kept busy. The reduction of the number of batches to be delivered in a particular time interval also contributes to minimizing conflicts over the cargo lift utilization. Vertical transportation of materials to discharging areas can become a constraint to workflow stability if actions are not taken to improve the cargo lift utilization. Having the mixing team balance demand orders in the Heijunka box is just one such action. Additionally, floor and mortar batch identification gadgets are placed on the wheelbarrows to reduce mistakes in material delivery and usage. These visual control mechanisms keep the cargo lift from being occupied with unproductive activities.

Figure 18 – Heijunka box for mortar production orders (left) and identification gadgets on a wheelbarrow (right) at a construction site in Fortaleza. Source: Miranda Filho (2008)

Having representatives from work teams get involved in short and medium term planning is another way of letting them influence factors upstream. This is being achieved with the Last Planner System (LPS), which is a short-interval planning method that addresses the problem of improving work flow reliability in construction projects. The method provides a disciplined approach to short-interval planning and specifically focuses on reducing variations in the flow of work at the team level. Thus, weekly planning and coordination meetings are attended by all major team leaders and subcontractor foremen. During the meetings, the decision-making process to decide what work can be done, and how much can be done is very much based on the inquiry approach. Differently from advocacy approach, the inquiry approach tries to develop a collective understanding of the problem and evaluation of options to choose from, resulting in a collective ownership of the decision (e.g., Meijer 2003). Consequently, stakeholder collaboration and commitment to weekly work plans is improved, since decision-making does not follow the traditional top-down approach.

In accordance with Figure 11 of the previous chapter, the influence over upstream factors achieved through the weekly meetings can be simultaneously depicted by the double-tipped horizontal arrows of enhanced lateral relations between teams and the upward pointing arrows of influence coming from lower subsystems. The success of the Last Planner System can be partially explained by the fact that, at least for a short period of time during the week, entities representing distinct hierarchic levels of complexity come together bringing their different understandings of large and small-scale systemic properties. Therefore, by being more than just short-interval planning, this “best practice” has contributed to making the projects of the firms realize cost savings, fewer inventories, and less project completion time.

In the weekly meetings, an updated 6 to 8 week work flow is created from the master schedule. Once activities are placed onto this look-ahead schedule, the participants begin identifying and eliminating all the constraints that may keep the activities from being successfully executed when the time comes (Figure 19). During the following weeks, requirements for sound execution are analysed and fulfilled, including material, equipment and labor needs; detailed work specifications; and prerequisite work assignments. The goal is to “shield” work teams from poor quality work assignments by removing constraints and allocating resources to the activity prior to its inclusion in the weekly plan. Thus, weekly plans are extracted from the look-ahead window, but encompassing only those work activities that are ready to be started (all constraints removed). The use of look-ahead planning, Kanban systems and higher level strategies for the purpose of influencing factors upstream corroborates the previously discussed notion that a firm and its subsystems are flexible in adapting to variation part because they are proactive in controlling it.

Figure 19 – Master schedule using the Line-of-Balance (LOB) technique (left) and constraint removal control list (right) at a construction site in Fortaleza. Source: Miranda Filho (2008)

Interestingly, despite the recommendations from some academics, the firms avoid having a significant “workable backlog” of activities in their projects at any given time. The only exception is to have a pre-approved backup plan in the case of a team assignment being delayed. The reason lies in the fact that cash flow is a sensitive matter to these firms. The production pace requires great control and should not be too fast because either the firms or the clients are self-financing the building construction.

The implementation of a formal look-ahead planning process in combination with a learning process is a remarkable characteristic of the Last Planner System in the projects belonging to firms D an E. Oppositely, in firms A, B and C the look-ahead planning was more informal and the emphasis of the implementation was more on the weekly work plans. Interviewees in firms D and E reported that they had considerably improved their Percent Plan Complete (PPC) measurements over the years and that during that time the reasons for non-completion of tasks gradually shifted from internal to external causes. In other words, they had reached a significantly higher and more stable PPC across multiple sequential projects. This suggested that the improvement of weekly work plans could not be satisfactorily explained just by the experience gained throughout a particular project or the more complete implementation of the Last Planner System. On the contrary, this clearly indicated that higher planning reliability and planning compliance resulted from a number of management and system design changes conducted to create a more integral project production model.

There were, amongst the changes, a set of initiatives supporting *continuity through time*. By ensuring more stable factors, these initiatives have played an important role in the success of the new production model. During the interviews, it became clear that continuity is manifested in many forms and different time-scales, benefiting both planning and learning processes. Regarding the project organization, firms E and D have realized that production stability can also be improved by having along different project stages the same group of people enhance downstream predictability for themselves and for others. In other words, production is best shielded when the participation of stakeholder groups representing different hierarchic levels of complexity is maximized, allowing early involvement and increasing organizational proximity. The interviewees felt that promoting a broader participation amplified the benefits of many practices, including the look-ahead planning process.

For instance, the firms are aware that the opportunities identified for improving the work content and constraints cannot be fully applied in an ongoing project due to broader project management issues, such as contracts and material delivery dates. The reduction of cycle times or batch sizes from the full implementation of the proposed improvements would imply in rescheduling many different project flows. This is a major problem for a large-scale product development conducted under stressful conditions. Therefore, the lessons learned in a particular project have a much greater possibility of being fully applied in the next project, since they will be inlayed in plans from the beginning.

The firms partially surpass this problem by conducting First Run Studies (FRS) in several construction activities separately sometime before their actual start date. As discussed by Saffaro et al. (2006), this experimentation technique is used to establish a work standard and thereby increase plan reliability. The work standard includes the definition of: work objectives; work methods employed; team size; work pace; and work paths. A First Run Study allows the identification of constraints and the early incorporation of improvements, leading to a better adjustment between product and work content. However, the success of First Run Studies requires their insertion in the look-ahead planning so as to ensure that most designs and materials have been delivered by the time the experiments begin. Moreover, it requires an early selection of subcontractors and even partnerships with some material suppliers. But still, the interviewees recognized that these conditions are not always met because of design changes during the construction phase and sometimes substitution or late selection of subcontractors.

The failure to generate, at all times, the proper conditions for successful First Run Studies has been one of the reasons firms D and E maintain a low level of subcontracting and try to keep long term relationships with most subcontractors. The firms changed their fundamental assumptions and now consider each building as a prototype for project participants to learn to work together and improve their methods for the next similar projects. During a particular project life cycle, lessons learned from errors generated in the building design or production planning process are incorporated to be used in the next project. Moreover, the productivity gains from improvements in repetitive construction activities are monitored to update learning curves. This database supports the planning of future projects with a fair amount of reliability, since it reflects the actual methods to be employed and their current performance levels. But most important of all, the firms believe that continuity makes it possible for work teams to perform well by just receiving basic directives, even when the establishment of detailed work standards is not possible. For this, the firms recognize the importance of maintaining as much as possible the project organization through time in order to develop know-how while sharing values and culture. In closing, continuity through time is seen as a basis for continuous improvement, planning reliability and delegation of responsibility.

Allocating larger work packages to multi-skilled work teams at the operational level is another example of an initiative that supports continuity, but in a smaller time-scale. For instance, at the time of the field research, the masonry work package in firm D had been increased to comprise a total of 15 transformation activities with similar processing requirements. The *delivery of complete subsystems* is a constant objective, even though processes suffer from higher uncertainty in the final stages of construction. Put differently, the large work packages are maintained even when uncertainty in individual client needs forces a reduction of the batch-size (the number of storeys, apartments or rooms handed-over from the previous trade to the next trade).

The changes in batch-size are very much a consequence of the establishment of a so called costumer order decoupling point (e.g., Meijer 1998), beyond which production is only performed for a known costumer order. Before this inventory point, the working places are defined as each storey. The repetitive construction activities conducted until then are part of a less integral process in which the work packages of different teams are more loosely coupled in terms of time and space. Not only that, each multi-skilled team delivers various functional requirements in a single output, which has a more standardized interface with the output of the subsequent team.

After the costumer decoupling point, project managers may decide to leave parts of the apartments unfinished if they have not been sold and begin work packages in the critical path only in the latest possible start-date. However, process integrality is considerably increased beyond this point because the batch size is reduced to become each individual apartment. This has a significant effect on the way buffers accumulate in the system. Furthermore, for those apartments that have been sold, the batch sizes can be made even smaller depending on the degree of late changes requested by clients in the finishing jobs. In the very last stages of construction, daily production orders regarding the work to be done in each room are issued and distributed among the work teams. Still, none of this alters the goal of having each team be responsible for performing a larger number of activities in every workplace. The loss of benefits from spatiotemporal continuity due to the reduction in the number or size of units handed-over is alleviated by the greater number of activities performed in each unit.

5.3.2.2 - Comparison between production models

The above mentioned practices and strategic choices in production strategy create the general work conditions at the construction sites. These infrastructural decisions improve the quality of the interactions in the work environment and thereby directly support the implementation of mobile production cells. The impact of the practices and strategic choices on overall performance was assessed by comparing the relative importance managers from the five firms give to different types of control, flexibility and buffers in their projects:

- *Inventory*: Just-in-Time material delivery is used for low cost and locally supplied construction materials. However, the distance or low delivery reliability of some suppliers makes necessary a certain level of inventory for some materials. Hence, inventory was given a **below average** relevance in most answers from all five firms. Besides Just-in-Time, some interviewees mentioned the smaller inventory as a consequence of the caution in avoiding buffers of workable assignments;

- *Capacity*: in general, managers considered avoiding added capacity as a way of lowering costs. However, the three firms with specialized teams gave it a **below average** relevance because additional capacity is sometimes necessary for minimizing delays. On the other hand, the answers in both firms using multi-skilled teams gave **low** relevance to this type of buffer. Firms D and E are much reluctant in accepting workers that are not familiar with organizational procedures and culture. These firms prefer to increase work hours or move multi-skilled workers between functions to absorb demand fluctuations;

- *Work-in-Process*: the interviewees described it as being mainly a consequence of the batch size. This internal inventory along the production line has a **below average** relevance for firms A, B and C because of higher hand-overs between specialist teams. There is a concern that the reduction of batch-size will allow disruptions to disturb subsequent trades. Firms D and E are less concerned about interdependency problems and consider this type of inventory to have **low** relevance inside work packages performed by multi-skilled teams. Small transfer batches are possible due to lower rework and setup times in these activities;

- *Time*: a reduction in batch-size means that rooms will spend less time standing idle waiting to be worked on. This allows the total building time to be reduced using different planning techniques. Firms D and E use a pull technique to develop a schedule with minimum buffers inside work packages performed by multi-skilled teams. Any time left after working from a target completion date backwards is used to build the project buffer. Most answers in both firms considered this buffer as being of **average** relevance. With no reference to decide what assigned tasks should have unpadded durations, firms A, B and C unfairly distribute time buffers along tasks and tend to consider them as being of **above average** relevance for project performance.

- *Flexible Labour*: Many respondents mentioned that reductions in batch size and building time may turn the project manager into an informational bottleneck unless they are met with the proper conditions. Firms D and E coped with the problem by investing on structural and infrastructural resources to create autonomous multi-skilled teams in charge of performing work packages. The work package's payment is previously negotiated because each presents a different set of activities and a distinct level of difficulty. In both firms there was a tendency to rate this flexible competence as being of **high** relevance. Managers in firms A, B and C classified the use of this type of basic flexibility as of **low** and **below average** relevance in their projects, despite the fact that most recognized its development to be highly desirable;

- *Coordination*: managers in all five firms agreed on the importance of coordination. But there were striking differences in opinions regarding the management of work between internal clients. In firms D and E, the answers suggested that employing mobile cells reduced both the intensity and frequency of managerial interventions. It was mentioned that multi-skilled workers generated fewer hand-overs while material flow control practices like Kanban supported autonomy and decentralization in problem solving. Most managers rated this type of control with an **average** relevance, since they felt a reduction in worker job control. As expected, the answers in firm C tended to give coordination an **above average** relevance while those from firms A and B tended to consider coordination as of **high** relevance;

- *Monitoring*: at the construction site, monitoring is mainly done through inter personal contacts, performance measurement and visual controls. The amount of monitored variables is perceived to vary during the construction phase. Surprisingly, its relevance was evaluated as of **above average** by most managers in all five firms. However, the interviews revealed that this happens for different reasons. Management in firms D and E is concerned with better supporting the work of mobile cells. Therefore, the creation of a data base from self performed and subcontracted activities is seen as a way of avoiding unnecessary buffers and improving plans in current and future projects. Except for firm C, firms with specialist teams considered monitoring to be part of an effort to micro manage quality and interdependency problems. In their case, the objective of monitoring is to support managerial interventions;
- *Forecasting*: it requires the development of procedures and an investment on structural resources to monitor, organize and store data. It is seen as a strategic decision to support other strategies. According to the answers, it has **high** relevance for firms D, E and C and **average** relevance for firms A and B. Interviewees in firms A and B recognized forecasting as useful, but mentioned the lack of organizational culture and appropriate structural and infra structural decisions to make the best of it. Differently, firms D and E need a more accurate forecast on the amount of resources and production rhythm because of small transfer batches and time buffers in their plans. Since First Run Studies are sometimes not possible due to project stress, forecasting is done by adjusting productivity data from learning curves of previous projects to the dimensions and characteristics of the next similar project. However, forecasting shows deficiencies when applied to non-repetitive activities or activities that suffer changes in the original scope of work;
- *Subcontracting*: a firm's control of all the value string can be reduced by outsourcing non-strategic activities to more competent specialists. By distributing technical and financial risks to subcontractors, the general contractor may concentrate on core competencies and tactical level issues. However, the interviews showed subcontracting primarily used with the purpose of cost reduction and not necessarily because of high technical competence requirements. Therefore, unlike what is theoretically intended, subcontracting was perceived to not generate the expected benefits. In fact, managers complained about often having to monitor and intervene on some subcontracted activities. The lack of commitment with project goals and attempts to optimize workload were cited among the main causes of problems. Thus, subcontracting had a **low** relevance in both firms with multi skilled teams and in one firm with specialized teams. These builder-developer firms prefer to focus on training, committing and motivating their own staff;
- *Partnering*: managers argue that long-term alliances with subcontractors and suppliers are improbable due to characteristics of the building sector. Therefore, a certain level of substitution is likely to occur from project to project. Nevertheless, the firms seek as much as possible to establish strategic partnering with project participants in order to obtain collaboration during and after project execution. Continuous improvement is also fostered as lessons learned in one project are more likely to be implemented in future projects. But

just as important is the perception that long term relationships allow operational procedures and performance standards to be known ahead, making forecasting of outcomes in plans more accurate. With the exception of firm C, all other firms gave partnering a **high** relevance for project performance.

Although data collection did not include representative sets of quantitative data from all five firms, the comparative analysis above shows the two firms with multi-skilled teams as the ones having the best alignment between strategic, tactical and operational choices. This is noticed by their capability to maintain smaller buffers without making the construction process highly volatile. Firms D and E understand that, when competing through production, the competitive capability is derived from internal competences, such as the ones obtained with the mobile cells, and from the capabilities of the outsourced operations. Therefore, both firms seem to share the common goal of increasing simplicity and integrality within their projects. They are primarily doing this by limiting the heterogeneity (amount and variety) of project participants in the construction sites. Thus, strategic choices in production strategy involved a combination of low level of subcontracting and high levels of partnering and labour multiskilling.

In fact, the strategic choices in firms D and E reveal the need for greater changes in the work environment when it comes to implementing the cell organization of operatives in construction sites. The comparison between the five firms shows that the degree of leanness achieved seems to be related to implementation "width" and "depth". In this field research, width can be understood as the amount of practices from the lean construction toolbox that have been effectively implemented at the level of operations. On the other hand, depth refers to higher level strategic changes undertaken in order to make the best use of the practices. Although there is clearly a strong complementarity between the practices, some may only bring the best results under certain circumstances. This study has confirmed that this is partially due to major strategic choices. This is clearly the case of firm C if compared to firms D and E. It just could not benefit from the same results by only relying on lean construction practices. The reason lies in the fact that production practices are mostly fundamented on the principles of direct interconnections and influence over upstream factors. Complementarily, strategic choices can support a division of work founded on the principles of continuity through time and delivery of complete subsystems. A combination of initiatives based on the four principles of systemic stability is needed to generate integrality at the level of operations, otherwise the results will not be satisfactory. These observations corroborate the affirmation that there may not be such thing as a "best practice", unless there is a clear understanding of the underlying strategies, principles and assumptions that make it so highly effective in some firms. A true best practice, such as the mobile cells, does not arise from a stand-alone practice, but rather from well aligned internal adjustments that create a new production model.

Accordingly, another aspect that stands out is the importance of changes in management style and decision-making. Without these, the combination of strategic choices and practices that generate mobile cells will not be fully effective in improving the degree of leanness. Just as an example, the field research showed that the total benefits achieved with this type of system flexibility are also dependent on the proactive decisions regarding the use of buffers in tactical level plans and on the different types of control that support those decisions (Figure 20). If the competences of mobile cells are taken into consideration, planners can increase the overall project efficiency by appropriately sizing and placing buffers where they are truly needed. This awareness during project planning leads to gains that compensate the production system's cost of becoming flexible. For instance, Firm D has reported that one of its projects achieved a budget reduction equivalent to the cost of two and a half apartment units after it used a more “mature” version of its project production model.

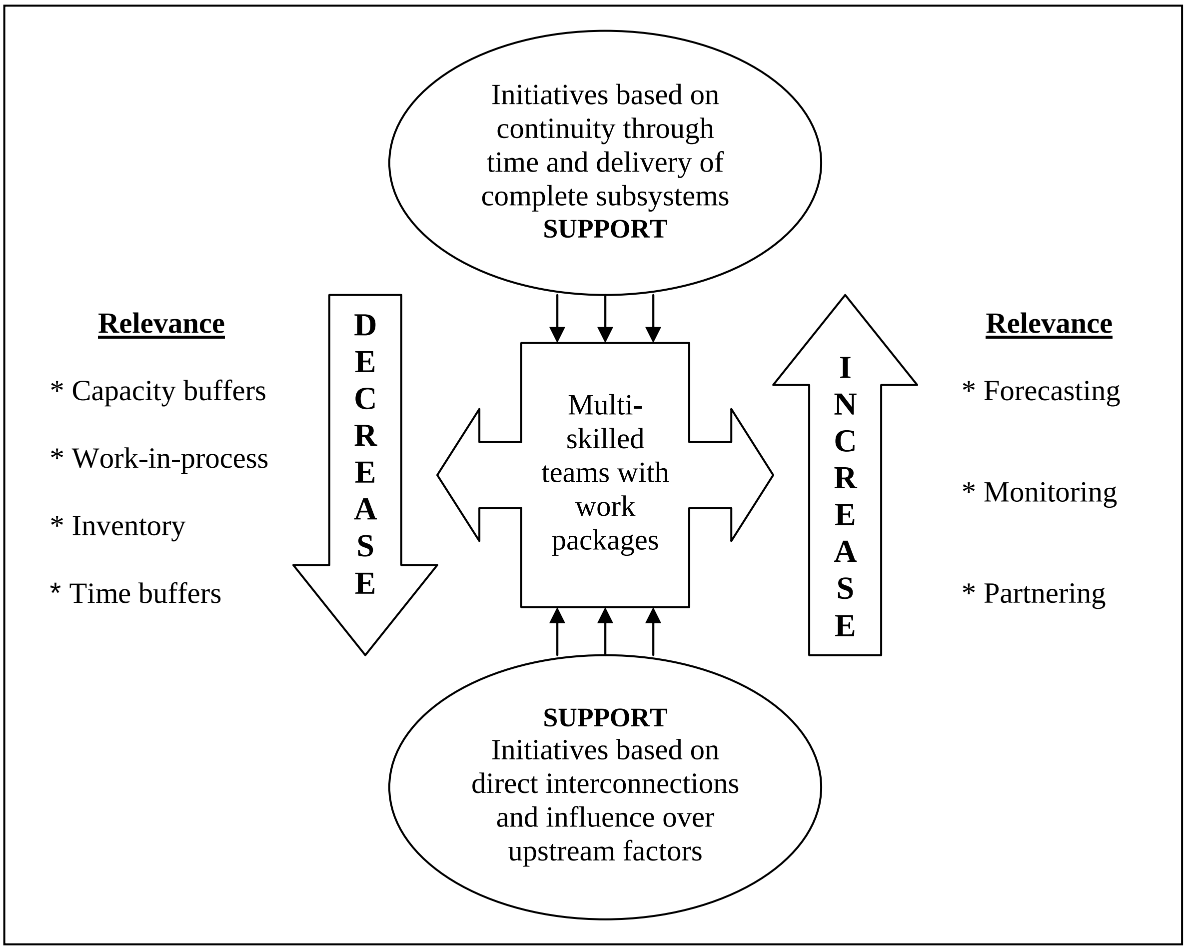

Figure 20 - Trends in the relevance of different types of buffers and controls after implementing mobile cells. Source: Miranda Filho (2008)

A final observation is that quality, delivery speed, and delivery reliability are the “first-order effects” of mobile cell implementation in firms D and E. These improvements are a direct result of the increased inflow stability and reduction of rework and setup times within work packages conducted by mobile production cells. However, quality and delivery performance are qualifying criteria for the five firms in the study. Interestingly, product flexibility, which is the order winning performance criterion, is just a “second-order effect” of mobile cell implementation. Although time-based competitiveness has been improved with the mobile cells, product flexibility remains being mostly supported by project buffers.

5.4 - CONCLUSIONS

This exploratory study has compared different strategic choices and operations practices in a more qualitative manner. The main thrust was to empirically examine the requirements for creating a system flexibility type at the level of operations and how it affects control and buffer types in the project production system. It is important to mention that the case findings discussed above were validated by explicitly asking the respondents to provide feedback and comments on the interview reports prepared. During the follow-up meetings on the results of the study, managers agreed with the observations made and approved the conclusions presented.

At present, there are plenty of studies showing the positive impacts and minor tradeoffs caused by lean practices in civil construction. However, as lean construction broadens its scope and evolves into being more than just a pull production programme, the content of production strategies and general contexts of best performers need to be explored. Regarding the former, the findings presented in this chapter confirm that the formalization of a production strategy can only be close-to-complete if the important competitive criteria, structural and infrastructural decisions, theoretical principles and underlying assumptions are made explicit.

Owing to the fact that many production practices are easily imitable, this study provides evidence that true “best practices”, such as the mobile cells, arise from adjustments between strategic choices, production practices and management style. The findings suggest that lean practices enhance the interconnections between site personnel and tasks, while at the same time permitting influence over upstream factors. In addition, strategic choices that favour continuity through time and delivery of complete subsystems are needed to increase the gains. Thus, the common rationale seems to be the creation of a less complex and more stable organization characterized by having participants that are less heterogeneous, closely connected to one another, and responsible for carrying out a larger number of activities in the construction process.

The application of initiatives based on the four principles of systemic stability at the level of operations removes structural constraints that impede a work team’s ability to reduce the number of events causing dynamics and non-linearities within the dynamics. The research results indicate that real mobile cells arise as more of these initiatives are applied to construction processes. The outcome of such arrangements is a system flexibility type designed to reduce trade-offs and to thereby help in an optimal way to the achievement of competitive criteria.

Accordingly, in order to assess the effects of a production system design that supports the mobile cell concept, a conceptual model has been proposed with control, flexibility and buffers forming the three pillars of organizational robustness. As proposed in the model, the findings indicate that flexibility is indeed the central element around which control and buffers are developed. Although buffers should be sized and positioned according to the situation, there is somewhat of a confusing guidance on how to actually do it. Nevertheless, this study shows that multi-skilled work teams supported by enablers of vertical and lateral relations possess reliable and timely information for control purposes and therefore do not need self-contained tasks and slack resources within their work packages. Thus, flexible competences within the production system must guide buffer management. In closing, these observations corroborate the previously mentioned importance of paying more attention to infrastructural decisions when developing project production models because of their top-down effect over structural decisions regarding the definition and allocation of buffers.

CHAPTER 6 – ENABLERS AND IMPACTS OF CELL PRODUCTION: Similarities between a Builder-Developer Firm and a Subcontractor Firm

The understanding of why mobile production cells may work better in some organizational settings than in others requires the adoption of a more comprehensive perspective. Any effort to successfully reduce non-linearities within a complex organizational system cannot afford to ignore the organization's smallest complex element. Thus, organizational strategies and policies for workforce management, qualification and motivation need to be addressed for an effective cell operation.

In the context of workforce autonomy, it is important to recognize that, even though altruism can exist, the majority of people think about themselves first before taking into account the welfare of others. It is useless to try to change this. The human species is essentially selfish and needs to frequently receive stimuli in order to act in favour of a cause that transcends individual interests. In the same way, the people in any organization are primarily moved by their own personal objectives, such as career progression and monthly payments. The only way to make an employee also pursue organizational goals is to motivate him through a set of extra benefits. Therefore, ignoring the existence of personal needs and the importance of motivational factors not only leads to failures when attempting to introduce "best practices", but also when trying to establish solid theoretical foundations or build long lasting organizations.

However, from where they stand, project managers tend to strictly focus on variables in the work environment. By doing so, they are likely to overlook why workers behave differently when exposed to similar challenges under the same motivational factors. The fact is that labor force commitment is a matter that calls for a better understanding on worker motivation and personality types considered proper to the new production paradigm. The interest in this subject comes from the notion that effective cell operation in construction projects may require more than operations practices programmes and discussions of adequate cultural and leadership characteristics.

Given the significance of labor resources in the construction industry, this chapter summarizes an empirical qualitative study aimed to understand differences in personal motives and how such differences are being balanced and tailored to work teams supported by lean practices. The discussion is based on lessons learned from two case studies where autonomous teams were implemented to react to the vicissitudes of work in a construction projects context. The findings show the close relationship between worker motivation and strategic choices in production strategy. This has allowed the identification of two important conditions that need to be attained by firms interested in developing mobile cells.

6.1 - THEORETICAL BACKGROUND

Lean principles and practices are commonly described as being aimed at the removal of buffers and non value adding activities for the purpose of shortening workflow interruptions and cycle times. Their implementation is known for causing production to operate with a balanced, synchronized material flow, which improves performance by increasing productive work hours and production rate. Under certain circumstances, such increase in the proportion of work time actually spent performing transformation tasks may seem to worsen job stress. However, as

Conti et al. (2006) put it, lean production is not inherently stressful and worker well-being is not deterministic.

Whether or not lean practices are viewed as stressful is most likely to depend on each individual's motivation to make the best use of them. If the right motives are in place, lean practices may even be seen as facilitators to both individual and organizational goals. In this case, lean production will be considered to have stress reduction characteristics as it diminishes flow problems and provides support for the achievement of overall goals. Because of the different perceptions, it is important that the implementation of lean techniques and principles be made regarding aspects of human motivation.

Although motivation is usually raised as a general concept, a motive should be understood to result from the interaction between an underlying need and environmental factors. In fact, the negative or positive stimuli created by organizational policies and management practices have been the subject of different studies in production management (e.g., Buch and Sander 2005, Zuo and Zillante 2005, Bititci et al. 2006). But the understanding of why each individual behaves differently under the same external press and the role of production strategies in this matter still remains a challenge to organizations. Part of the answer is likely to be found in the realm of personal needs, which is rarely addressed by academics in industrial management. The literature in the field usually focuses on relationships between work-related variables without reference to employee's lives outside of the workplace.

Owing to the increasing interest on workforce autonomy in construction, this chapter further develops on the subject of worker motivation and explores strategic choices made by companies that have conducted the change process towards cellular construction. By analysing the interrelationship between motivation and production strategy, the exploratory research conducted aimed to expand the knowledge on the new production paradigm. Thus, the findings presented are based on a literature review on motivation and on two case-stories: one from a firm that specializes in high rise buildings and one from a geotechnical engineering firm. It is suggested that firms must become increasingly aware of the need to match employees with certain personal characteristics that suit best the new roles of middle managers and work teams. It is also argued that to fully profit from mobile cells, organizations must increase the use of permanent teams so that the different individual characteristics be gradually accommodated and used in the most effective manner.

6.1.1 - Motivation

6.1.1.1 - External motivational factors in tall structures

The traditional view on motivation in construction firms like in many other business organizations can be explained by the Taylor model and Maslow's Hierarchy of Human Needs. As mentioned by Buch and Sander (2005), its origin can be traced to the technological development of the construction sector, which increased the division of the working functions. This contributed to the employment of middle managers in the linking role of planning and controlling tasks and thereby to the elimination of the workers' independent thinking. Gradually, an organizational paradigm was established where managers were seen as valuable while workers as disposable.

The motivational factors used by traditional hierarchical organizations to stimulate the staff reflect this top-bottom order of importance and command approach of the Taylor model.

For instance, top managers in general do not perceive earnings and promotions as motivational factors, since they are usually well remunerated, qualified professionals. What drives them is the exercise of power, influence and prestige over other employees. Companies may create a stimulus by offering opportunities to extend their knowledge in conferences and courses. For employees holding the position of middle managers the earnings, bonus schemes and training to improve skills are important, but satisfaction comes more from recognition and possible promotions. As part of the permanent staff, employees at this level share the desire for more autonomy and feel rewarded whenever they are delegated with responsibility. But the greatest challenge lies in the motivation of work teams at the level of operations. Workers at this level generally present poor education, few abilities, high turnover and low productivity. They are mainly focused in assuring security both in terms of revenues and employment. So simply offering performance related pay may not make up for the anguish of being dismissed whenever the production volume is down or when a project formally ends (Caldas 2000).

What stands out is that people are not motivated to work by money alone but by a combination of factors. According to Chiavenato (1999), in Abraham Maslow's theory humans seek to meet basic needs and only then aim at satisfying successively higher needs that occupy a set hierarchy: physiological, safety, belonging, esteem, and self-actualization. The higher needs only come into focus once all the needs that are lower down are mainly satisfied. As discussed above, in hierarchical structures people in each level seek exactly what the organization hasn't offered them at that particular level (Figure 21). This clearly shows that employees possess different needs that can hardly be fulfilled by the organization, especially when it follows an organizational model that segregates different levels by an order of importance and provides their needs according to this logic.

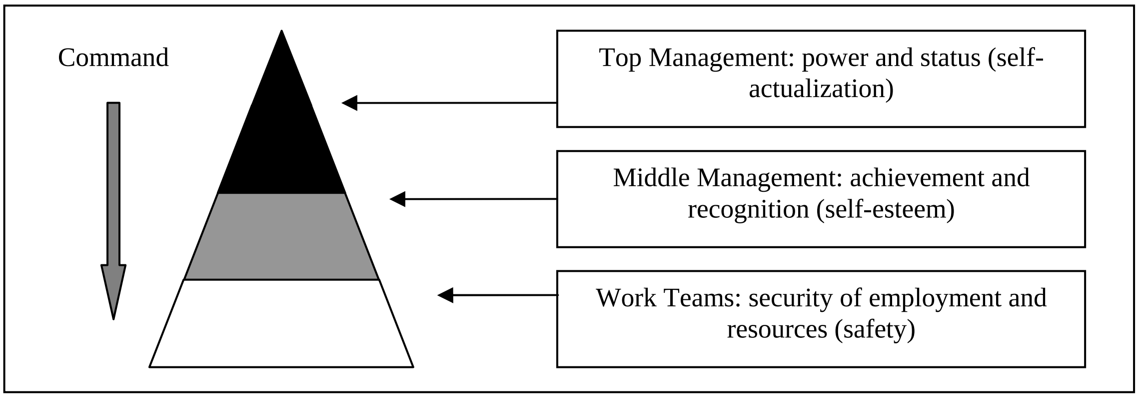

Figure 21 - Hierarchy of needs in traditional organizations. Source: based on Chiavenato (1999)

6.1.1.2 - External motivational factors in flat structures

Traditionally, the motivational factors adopted in hierarchical organizations make middle management the level in charge of pulling production. But centralization is only suitable for organizations facing stable, homogeneous environments. Van Der Merwer (2002) argues that organizations facing a shifting heterogeneous environment will find the flat structure more effective as it applies fewer horizontal layers of management and fewer distinct policies along them. Among other aspects, such structure intends to create similar motivational factors to both middle managers and work teams and to bring them closer in terms of responsibility and commitment to organizational goals. This proximity is a pre-requisite for delegation of responsibility, which provides to employees in different levels the authority to pull production and to respond to problems in a dynamic environment.

In the actual stage of technological development, the construction industry is very dependent on the behaviour of individuals. Therefore, an organizational change towards mobile cell implementation must also aim at improving the human aspect. Thus, management choices in designing and operating project production systems require caution as they impact heavily on motivation, stress levels and project culture (e.g., Zuo and Zillante 2005, Bititci et al. 2006, Conti et al. 2006). The synergy between the two sets of choices and each individual's expectations to satisfy personal needs is what generates the potential for motivation.

To this regard, production system design involves a wide set of policies that help shape the organizational structure and environmental factors for motivation. Although strategic choices and production practices, such as multi-skilling and Kanban respectively, can enhance autonomy in construction processes, researchers like Buch and Sander (2005) contend that such decisions will not be enough without the introduction of performance-related pay and team building initiatives. Collectively, these internal adjustments not only help in team building, but also improve interdependencies and create intangible competences. Consequently, they support a low level of job control, which characterizes a typical lean plant. The focus of managerial control is partially transferred to the outputs of the teams, since a considerable portion of the work under a tight schedule is managed by groups of motivated, skilled individuals. As mentioned by Conti et al. (2006), this actually improves both product and work-life quality.

In addition, the operation of project production systems must adapt under the penalty of suppressing the motivational efforts. This involves changing the management style towards management of people and their needs. Since leadership and human motivation are two ever crossing subjects, managers and other site leaders must fulfil a number of roles including those of coordinator, facilitator, motivator and politician. Such roles reveal the importance of motivation under any circumstance to achieve successful project delivery. In accordance, Dainty et al. (2003) found that contracting organizations consider building, developing and maintaining the project team to be the most demanding and important task of project managers. Howell et al. (2004) describe it as shaping circumstances for team members to deepen their relatedness by cultivating commitment-making and producing coherence of intentions. In summary, because conflicts are likely to occur during project production, project success is strongly dependable on the leaders' effectiveness in managing team social-dynamics.

6.1.1.3 - Personal needs

There are personal aspects that need to be addressed since they affect motivation. Defying underlying assumptions in each individual's conceptual system is one, which is most critical during periods of strategic changes (e.g., Werther Jr. 2003). Not meeting individual underlying needs is another, since motivation is no longer understood to arise exclusively from externally applied forces. However, project and process managers are poorly trained and equipped to address these and other issues that cause behaviours. As mentioned by Dainty et al. (2003), there have been attempts to determine the factors that lead to project success, but it remains unclear as to the precise individual characteristics and intra-team processes that lead to effective project performance.

Nevertheless, the good leaders are those perceptive to what makes people in the group going: status, knowledge, ambition, security, etc. Such knowledge of individual needs and characteristics helps to better manage people as it highlights potential strengths and weaknesses. This gives managers the confidence of knowing what can be expected from employees in highly unstable processes where the controlling style has given way to autonomous teams.

Usually, an individual has different levels of conscience regarding each of his/her own personal characteristics: competencies, knowledge, social role, self image, personality and needs. In general, an individual is capable of describing many personal characteristics during an interview, but McClelland (1984) asserts that the needs constitute the biggest challenge for being a characteristic lying in the subconscious. However, besides the Picture Story Exercise (PSE) used by psychologists, traces of personality and implicit needs that influence the behaviour can be identified by asking the people who directly work with the individual. This type of recognition highlights the importance of developing flat organizational structures and the leaders' so-called perceptive capability. According to David McClelland's Motivation Theory there are three basic motivational needs:

- Power: is the need to influence and control other's behaviour. The individual seeks to increase his hierarchic position and strength;
- Achievement: is the drive to accomplish or excel goals. The individual appreciates challenging environments and recognition;
- Affiliation: is the desire to maintain close relationships with others. The individual obtains much satisfaction from interpersonal and teamwork activities.

The need for power and achievement correspond with Maslow's higher-level needs, that of sell-actualisation and self-esteem. But the difference in McClelland's theory is that each individual is dominated by one of the three needs independently of environmental factors or which position he/she occupies in the organization. Although the needs can be learned to a certain extent, adult learning research states that they are acquired and fixated during childhood years. Once formed, the dominant need is hard to change unless the individual undergoes a traumatic experience. Thus, understanding different personality types helps to predict behaviours and appreciate differences. For instance, a construction worker dominated by power tends to have a more coach and teacher-like behaviour towards other team mates. On the other hand, a worker dominated by achievement tends to be very demanding on those who work with him because he is very demanding on himself. This type of worker is usually a high achiever that commonly receives financial rewards for the superior performance. In some cases, misjudgements could lead to labelling the first type of worker as oppressive or lazy and the second as selfish or ambitious.

The same understanding should be applied to managers. Leaders tend to be more effective if their personalities are adjusted to deal with the present problem. In an organization, a leader with the need for achievement is more indicated to push deep changes while a leader with the need for affiliation is very good for mediating conflicts. Obviously the leader may no longer be the most adequate person for the job when the situation changes. For instance, a leader with the need for achievement may consider stimulating a period of organizational change and loose interest afterwards during a period of stability. But there are also leaders with the capability of adapting to circumstances. Similar to organizations that adapt to changes in the external environment, these individuals are also somewhat successful in developing other needs throughout their career. Evidence of such learning even inside the same function is provided by Cox et al. (2003), who found that construction managers become aware of more performance issues other than just cost and on-time completion as they gain experience through the years. The individual learns to combine the dominant need with another to deal with specific situations.

6.1.1.4 - Motives for autonomous teams

The Situational Leadership method from Hersey and Blanchard (1986) holds that managers must use different leadership styles depending on the workers' "maturity" for the task. Maturity is based on how ready (competence) and willing (motivation) the worker is to perform the required task. Therefore, an individual or group may be mature for some tasks and immature for others. According to the method, there are four leadership styles that match the four combinations of high/low readiness and willingness. Delegating is among the four leadership styles and should only be applied to highly mature employees who are both competent and motivated.

Although low job control and high worker maturity are essential aspects to workforce autonomy, lean practices applied to cell operation mainly support the readiness dimension of task maturity. Therefore, other aspects of production models considered to be best-in-class, such as the Toyota Production System, need to be unveiled to fully understand the workforce's willingness to perform tasks. Among other things, it is likely that the use of permanent teams not only allows the development of skills and shared values through time, but also the arrangement of workers with different task maturities in a way that suits best organizational goals and, to a certain extent, individual needs. This shows that structural and infrastructural decisions need to be made carefully because a true "best practice" arises from ensuring adherence to the requisites and evolving needs of both internal and external clients.

For this, organizations must see workers as internal clients and should try as best as possible to identify and satisfy their needs. Like any other client, a worker also "pulls" value from the organization and will only be compelled to take on the assignment if he feels that it strongly meets his expectations. Thus, the satisfaction of workers' technical and humane expectations is a pre-requisite to turning them into quality workers. Only then they will be ready and willing to help the firm meet the final costumer's expectations. As observed by Möller (1997), quality personnel are the foundation of all other quality types in a Quality System.

6.2 - LESSONS LEARNED FROM PRACTICE

In order to develop a basis for effective delegation of responsibility in construction processes, an empirical qualitative study was carried out to draw lessons from the experience gained by firms working with autonomous teams. The study was a continuation of the exploratory field research described in the previous chapter. It involved visits to construction sites and open-ended interviews with managers from two civil construction firms: a firm that specializes in high rise buildings and a geotechnical engineering firm. Exploring the experiences of two very different firms allowed highlighting the similarities in developing workforce autonomy. But more than identifying similarities between strategic choices and motivational factors, the objective was to verify the existence of a common perception of the personalities and needs considered to be appropriate to the new production paradigm. This was done through the collection of examples of what is considered to be good and bad behaviour in the two work environments.

6.2.1 - Case 1: Experience from a Builder-Developer Firm

To maintain the anonymity of research participants, the construction firm in this study received the pseudonym of “firm D” in the previous chapter. The firm is a contractor for private investors and occasionally both a developer and builder of multi-storey residential building projects. At the time of this study it had an annual construction volume of 50,000 square meters and was simultaneously undertaking six luxury high rise residential building projects in the city of Fortaleza (Brazil). Product quality, delivery and flexibility are considered to be the three important performance criteria in its niche market.

As mentioned in the previous chapter, firm D opted to self perform many activities in the projects’ critical paths and to maintain partnerships with subcontractors in order to reduce problems that might affect internal subsystems and project goals. As specificity grows, firms can subcontract less. Additionally, the firm had been implementing a lean construction programme for over three years. According to the interviewees, the introduction of performance-based financial incentives and supplementary training activities together with bundles of production practices, such as Kanban, Last Planner System and First Run Studies, were the main reasons for the improvements in quality and productivity rates.

However, more humane practices are also adopted and just as likely to respond for the positive impacts. For instance, instead of only placing warning signs at the construction sites, the management team also places colourful educational posters in the main rest areas and in passages used by the workers. Teamwork seminars, musical contests with lyrics about lean construction, and soccer tournaments are used as social-networking tools. Distribution of performance certificates, celebration of birthdays, and night school programmes are also some of the initiatives sponsored by the firm to increase the welfare of workers and to thereby reduce absenteeism and staff turnover.

All these initiatives comprise external motivational factors and are the most obvious characteristics of the production system when visiting the construction sites. But what stood out during the interviews were the less obvious managerial practices concerning labor motivation, which are used to develop quality personnel. For instance, the firm believes that a small group of people has a much better chance of solving individual differences. So in each team a leader naturally arises, usually being an experienced worker with the healthy desire for power as well as the will to exercise it. Such worker becomes the team’s spokesperson for re-negotiating the payment of work packages whenever changes occur in the original scope of work. These leaders are also effective in standing up for the team’s interests and getting things done from internal suppliers.

The firm perceived that the production system design and the performance-based financial incentives improved the workers’ cooperative and proactive behaviour within the teams, but also propitiated a certain level of competition between teams. Such dispute for individual benefits led the firm to consider adding collective production goals and bonus schemes in the hope of creating intra-team collaboration. However, managers feel that friction will continue to occur since the system has been fundamentally designed to stimulate achievement and recognition at the level of operations. Moreover, there are many uncontrollable forces outside the managerial sphere that can impact on the achievement of production goals. Therefore, proactive management towards the organization of production is complemented by reactive management regarding the accommodation of conflicts. It was mentioned that as the project stress increases and control over dynamics decreases, the higher is the manager's need for affiliation in order to maintain a friendly work environment and to gain commitment for successful project delivery.

Friction also occurs inside the teams and requires attention to avoid dissatisfaction. In the beginning the firm faced problems by creating "heterogeneous" teams of workers who performed activities with different productivity rates and quality standards. Complaints from high achievers about having to carry out the work of others were common and attempts to outline the profile of workers soon followed. Data collecting procedures and the foreman's observations were critical to evaluate and build teams according to each worker's profile. The problem is now considered surpassed and the firm has become less task-focused and more people-oriented. The change originated a policy to allocate only the right people to participate in the team and the right team to perform the task.

6.2.2 - Case 2: Experience from a Subcontractor Firm

The firm is headquartered in the city of Fortaleza (Brazil) and offers a wide range of services in geotechnical engineering. At the time of the field research, it had been working for more than thirty years as a subcontractor in construction projects in all northeast Brazil, an area three times larger than France. Over the years the firm has invested time and money developing technical expertise and acquiring equipments to increase the efficiency of its transformation activities.

Moreover, flow improvements are a major concern, especially in services that use the most expensive machinery, present low cycle time and have a great local market demand. One example is pile construction using all terrain track mounted hydraulic drill rigs. Single Minute Exchange of Dies (SMED) and Work Sampling are some of the techniques the firm has used to analyze, reduce and standardize changeovers during pile construction (e.g., Miranda Filho et al. 2005). For the firm, time-based competitiveness is important because the activities performed in most projects have a small duration. Therefore, the firm has been figuring out ways to reduce setup time not only during the project, but also when moving equipments and teams from one project to the next. Since each project is seen as a small batch to be delivered, these initiatives are considered important to promote the flexibility of the production system as a whole.

But there are other ways in which the firm has improved aggregate flexibility. Very often the clients wrongly conceive the firm as a product supplier instead of a service supplier in an integral supply chain. Consequently, clients adopt transactional oriented procurement models and tend to pull services urgently from the firm without proactively exchanging information. In the past, the firm used several buffer types for protection against such client orders, but the increasing competition in the marketplace has forced it to devise different control strategies to support aggregate flexibility. For instance, the firm has decided to retain some less profitable services in-house in order to increase predictability to its other service lines. One example is subsoil investigation. The firm would prefer to give up this line of business, but it allows knowing ahead what private investors or public organizations are up to. These and other upstream services provide knowledge of the market and help the control needs of “core” services downstream. In this case, a control strategy has been established to warn the system before events happen and to thereby support actions that reduce the intensity of perturbations afterwards. Still, it is only possible because the firm maintains a buffer of skills. This is a firm level strategy to *influence factors upstream*, but with some additional advantages of *delivering complete subsystems*.

Initiatives at the project level to improve aggregate flexibility also abound. For instance, if the client decides to hire two geotechnical engineering firms to perform the foundations of a large construction project, the contracts are structured to allow the first firm to finish its share of the job to start working on the portion allotted to the other firm. This starts a competition that creates a win-win situation for the general contractor and subcontractors. It gives the firm that has its teams temporarily occupied in other projects the flexibility to arrive a bit later and still get the job. But most important of all, it awards the subcontractor that comes in first or presents the highest productivity rate with the benefits of *spatiotemporal continuity*.

There have also been initiatives at the team level to improve aggregate flexibility. For example, the root pile execution process used to be performed by nine workers distributed in two teams. While four workers were exclusively involved with the drilling subprocess, the rest was responsible for the cement grouting subprocess. But time-based competition led the firm to analyze changeovers for pile drilling and to take actions to improve teamwork and automate activities. As a result, the two teams were combined and the total number of operatives was reduced to seven workers. In accordance with the principle of *delivery of complete subsystems*, the “new” team of seven workers became fully responsible for each constructed pile. Support mechanisms, such as the grout pump, were also implemented to further improve the *direct interconnections* between tasks and those who perform them. Additionally, the workers eliminated from all the pile construction teams were combined to form new teams that are equipped and assigned to perform rotary drilling, percussion drilling and tiebacks in different construction projects. Summarizing, aggregate flexibility was also increased with the implementation of operational improvements that allowed the creation of more teams with the same workforce.

However, the interviewees agreed that the firm’s most important flexible competence comes from labor multi-skilling. As a subcontractor the firm is much concerned with mix flexibility and delivery flexibility. According to the interviewees, both types of flexible production capabilities are strongly supported by labour flexibility. Therefore, the firm has long used an on-the-job-training programme in which the workers are trained to perform different types of services. The objective is to absorb demand fluctuations with an “inventory” of skills and competences in each worker rather than adding workforce capacity to the firm. Different from the previous case-story, the flexibility to deal with uncertainty in the marketplace is the “first-order effect” of the application of the mobile production cell concept in the geotechnical engineering firm.

The firm’s strategy requires permanent teams to be effective because of the need to retain skills and competences that take a long time to be built. Hence, during the field research, the firm maintained 9 teams that could be combined and dismantled according to the type of flexibility required. Individually, each team may be composed of 3 to 7 workers, depending on the type of service. As expected, the interviewees mentioned that the firm’s flexible capabilities are more constrained by the availability of expensive equipments and machinery than by the workers' skills.

The teams are assigned to perform services in building projects and civil infrastructure projects in both urban and remote sites. In terms of remoteness, the most extreme situation happens when the majority of project participants are initially not located adjacent to the project site and all design, construction and facility management actors are located far away (e.g., Kestle and London 2002). It is a very common situation when geotechnical engineering processes are conducted in civil infrastructure projects like dams, pipelines, energy towers and transmission towers. Even when located inside urban areas, as are often the cases of residential building projects, the construction sites' facilities belong to the contractor. Moreover, these facilities are usually not prepared when the subsoil investigation or foundation work begins. The main consequences are lack of supervision, logistic difficulties and poor communication with the teams.

This peculiarity of geotechnical engineering causes dissatisfaction among workers and is considered harmful to the firm's production strategy. One interviewee put it this way: "We try our best to treat them well because they spend too much time on the road and often perform their jobs in extremely harsh conditions." Thus, more than performance-based financial incentives and other reward systems, the firm has improved policies that engender well being and alleviate the dissatisfaction of being frequently away from home. However, the interviewees consistently affirmed that carefully selecting the right people to participate and lead the teams is just as important as creating motivational factors.

Unlike the previous case study, these are truly autonomous teams that require proficient, high achievement team leaders because of the expensive machinery and the frequent absence of a foreman or any other supervisor at the project sites. Thus, each team has a worker carefully selected by middle management to be the permanent leader. These individuals are said to lead by example, to involve subordinates in setting targets and to drive them towards the project goals. Moreover, the interviewees mentioned the caution to avoid indicating workers with a high affiliation need to the position of team leader. Such individuals tend to be more lawful to their team mates than to the firm. Experience has shown that their subordinates take advantage of this. Consequently, the selection of a team leader is something that the firm takes very seriously. Managers argued that failing to choose the right person for the job of leader implies that the firm will either loose by having to dismiss an employee who was once a good operative or by maintaining an inadequate team leader. In closing, managers are aware of the need to use employees with certain technical skills and personal characteristics that best match the type of job being performed.

Additionally, different from what is commonly proposed in manufacturing literature, the interviewees describe these autonomous teams as reacting negatively to the rotation of team members and even to the temporary movement of multi-skilled workers between crews to fill short-term vacancies. Although the exchange of workers has to be done occasionally in order to support the firm's flexibility capabilities and to provide on-the-job-training, it often requires managers to exercise a certain amount of power and coercion to happen. It was mentioned that clan culture is part of the cause of the rejection of workers, even though they are technically proficient at performing the operations. The managers observed that collaboration and information sharing diminishes when team members do not have continuing affiliation. This happens despite the fact that their workstations are spatially linked during foundation construction. But it was also said several times during the interviews that the opposition to rotating people to and from other cells also arises as a consequence of achievers preferring to work with other high achievers and not feeling motivated to perform services that pay less. The interviewees consider the management of such behaviour a challenge to any project-based firm.

6.3 - REQUIREMENTS FOR THE NEW PRODUCTION PARADIGM

The experience gained in the two workplaces shows that the use of autonomous teams requires certain conditions to be beneficial for construction projects. Besides the individual initiatives tailored to the particularities of each case, two major conditions and their implications have been outlined: the need for teams to be built from within and the need to allocate the right people for the job. The importance of attending the two conditions is most likely to be true for any type of business organization that strongly depends on the human structural resource.

The first condition requires continuity in the organization. As mentioned by Conti et al. (2006), in current benchmark companies such as Toyota, the updated philosophy states that Just-in-Time should not be applied to the people. Thus, several humane practices need to be employed to reduce job stress and labour turnover. Similar to subcontracting decisions regarding make or buy, a firm must carefully decide whether it is going to develop quality labour from within or if it is going to "buy" supposedly mature workers elsewhere for its activities. The decision to develop internally requires strategic choices and structural changes to maintain and invest on people in the firm. On the other hand, "buying" experienced skilled workers may seem cheaper, but there is no guarantee that they will be as motivated and effective in the new work environment.

Furthermore, knowing that the lean philosophy has been somewhat successfully "translated" to the construction industry through a considerable amount of academic investigation and practitioner creativity, suggests that perhaps the same can be done with ideas from other successful production models. As proposed by Wallace (2004), maybe it is time for construction academics and practitioners to look at Volvo's strategies and techniques developed to reduce high labour turnover and absenteeism and verify their complementarity with those of lean construction. The analysis of the two case studies suggests that both sets of techniques may not be at odds and could very well converge towards a single best practice model. Worker motivation for delegation appears to be the linking element between Toyota's lean philosophy and Volvo's human-centred approach.

The second condition requires motivation to be no longer seen as generated only by external factors. In the new organizational paradigm, the construction firms are moving motivational factors that were once exclusive to middle managers to the work teams at the level of operations. By providing the work teams with basic needs, such as security of employment and resources, the firms clear the path for workers to pursue higher needs such as achievement, recognition, power and respect by others. This has been the primordial step to bringing employees closer in their commitment to organizational goals and to turning delegation of responsibility into reality. But an organizational culture strongly oriented towards achievement will only be effective if people with the right needs are in place.

Regarding cell operation in construction projects, experience from practice indicates that competent individuals with the need for achievement are those that closely match the level of maturity required for regular operatives in autonomous teams. Indeed, there are "natural habitats" for people with different needs and the high efficiency provided by lean practices creates the appropriate environment for high achievers. However, effective team-based work in a more competitive environment requires fostering from individuals with a certain level of affiliation need. Team leaders must develop it to manage conflicts and dissatisfaction. They should also avoid causing dissatisfaction by imposing their own standards to teammates who are likewise high achievers. In addition, an individual with a higher need for power rather than for affiliation will make the best leader of a high performance team. In accordance with the Jidoka pillar of the Toyota Production System, it takes authority to stop the production line when something goes amiss in an environment where high achievers drive themselves hard towards the goals.

These aspects show that even though motivational factors applied to different hierarchic levels are less distinct in flat structures, personal needs in autonomous teams can still be represented in a hierarchic manner. However, unlike Maslow's hierarchy, the needs are cumulatively developed and are shaped by training programmes and one's life experiences (Figure 22). A worker's career mobility will depend on how successful he/she is in developing new skills and in learning to combine the dominant need with other needs so as to become effective in different job functions.

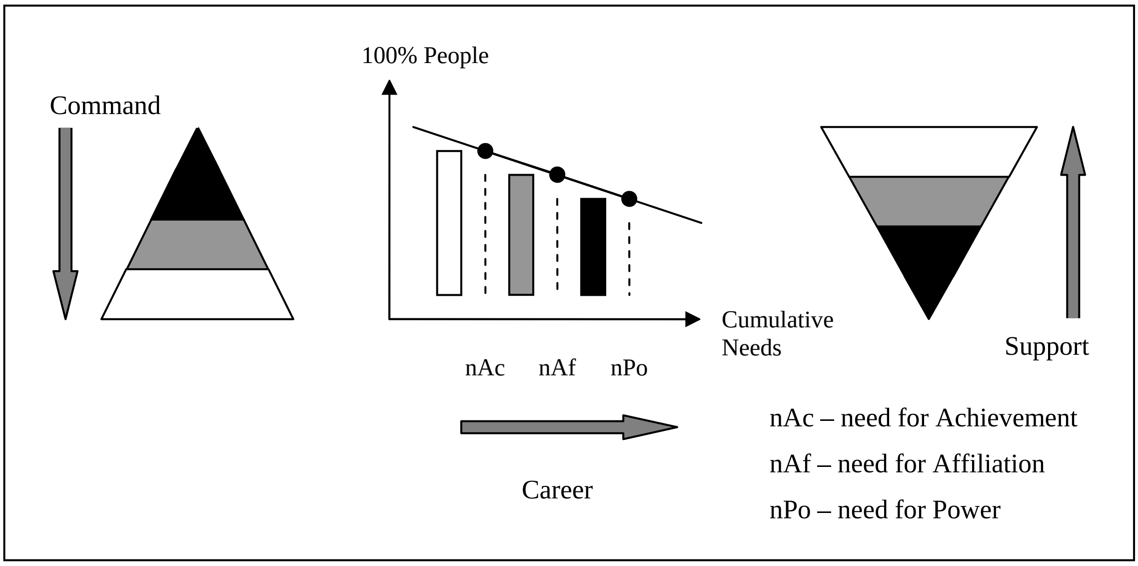

Figure 22 - Hierarchies of command, cumulative needs and support for effective cell operation in construction projects. Source: Miranda Filho (2008)

6.4 - CONCLUSIONS

This dissertation has presented and discussed issues relating to complexity at the project level. However, a further understanding of the organization's smallest complex element is also needed for the effectiveness of the new production paradigm. Recognizing this gap, this chapter has explored the strategic choices of two very different firms to provide a better knowledge of why lean practices supporting workforce autonomy are more fruitful to some individuals and organizational environments than to others. Based on the findings of the two case studies, an individual's willingness to "pull" work instead of having it "pushed" to him will depend on how motivated he is to perform the assignment. Personal characteristics, such as underlying needs and competences, combined with motivational factors generate the worker's maturity to perform a task. This individual complexity must be addressed for effective teambuilding and delegation of responsibility.

The findings also indicate that teambuilding is more successfully developed in organizations that seek to maintain their staff. Knowing what a worker is likely to do or how he is likely to respond to different situations allows managers to position the right people in the right place. This contributes both to individual motivation and to the reduction of non linear interactions between participants, making the work environment less uncertain and improving plan reliability. In other words, proactive decisions ensuring the continuity of organizational factors can enhance predictability at the operational level. This is particularly important to reduce internal variations that would otherwise have to be dealt with by the production system's flexible competences and buffers. Likewise, it relieves leaders from the role of buffering qualitative variables within dynamics that could harm team spirit, cohesion and trust.

In summary, workflow stability in production can be partially credited to mature workers built within a more permanent organization. Yet, more than a challenge, meeting these two conditions represents a paradigm shift for a project-based industry in which the majority of firms use staff turnover and high levels of subcontracting as strategies to obtain different flexibility capabilities. The incapability of adopting policies in favour of the two conditions will most likely become a structural barrier to the full implementation of the mobile cell concept in different organizational settings.

CHAPTER 7 – FINAL CONCLUSIONS

This dissertation contributes in several ways to knowledge in the field of production system design and operation in construction projects. First, it provides a new insight into the effective implementation of mobile production cells in the construction environment by discussing aspects of organizational integrality in project production. Second, it proposes a broad description of the content of production strategy so as to understand the tangible and intangible attributes that influence the emergence of a true "best practice", such as the mobile production cells. Third, it characterizes the mobile cell concept as the outcome of initiatives founded on the same set of principles underlying integrality and simplicity in other representative subsystems of a complex organization. Finally, it compares the workings of different project production models to highlight the relationship between this type of system flexibility, buffering and control practices. An explanation of these contributions follows.

7.1 - CONTRIBUTIONS TO KNOWLEDGE

At present, definitions of what is truly meant by the term "production cell" vary among academics and practitioners in both manufacturing and construction. In order to bring further clarifications to both sectors, the research focused on the more complex and dynamic environment of construction projects. By doing so, the dissertation offers not only a better description of the "mobile production cell" concept, but also a more comprehensive perspective of the conditions necessary for effective cell operation in general. The ideas were drawn from insights gained while conducting exploratory library and field research to address the broad research questions, *"What are the changes that allow the emergence of real mobile cells?"*, *"How does this true best practice relate to other successful renewal initiatives in project production?"* and *"How does this system flexibility type contribute to the performance of the project production system as whole?"*. The answers to these three questions provide a solid understanding of the production system design features that allow a work team to qualify as a real mobile production cell.

Regarding the first question, *"What are the changes that allow the emergence of real mobile cells?"*, it is important to note that construction peculiarities causing the physical part of the production system to be redesigned for every new project and even many times during a project life cycle have deviated and restricted managerial attentions to structural decisions and tradeoffs between competitive priorities. The great concern with the match between resources and tasks to accomplish project goals has made production system design an issue mostly approached from a project management perspective and not really from an organizational one. Consequently, the other less obvious aspects of production system design that last longer and even stretch well beyond project boundaries have been frequently neglected by traditional construction management literature.

To address these aspects, this dissertation suggests a broader view on the content of production strategy. It is proposed that the workings of a best-in-class production model can only be fairly understood if the infrastructural decisions, theoretical foundation and underlying assumptions are also investigated. This interpretation was important during the field observations and interviews because it created awareness of the need to explore the "soft" factors that strongly impacted the emergence of the production models and their competences.

The case studies confirmed that, besides external influences, the organizational contexts were shaped by structural and infrastructural decisions founded on explicitly expressed principles and tacit conceptualizations. However, as it turned out, the mobile production cells and other flexible production competences in each context mainly emerged from infrastructural decisions concerning the relationship with subcontractors, production planning and control, workforce management, and quality control. Also evident was the paradigm shift beneath the surface represented by the strategic choices and production practices.

Underlying all strategic actions and changes were the explicit or tacit assumptions held by managers, a number of which defy traditional construction management paradigms. The analysis of the production models revealed as the most fundamental the belief that the general contractor must perform the role of base organization, seeing as "internal projects" the temporary processes performed by internal and external specialist teams. This assumption corroborated the research hypothesis, *"The renewal initiatives are shifting the large-scale product developments back to the fundamental ideas of project production"*, and appears to be the "mother" of all other assumptions supporting the discipline necessary for organizational integrality and effective cell operation. By recognizing that project managers should not be seen as process leaders because of their macroscopic perspective of things, the firms in the case studies have revaluated traditional paradigms about system design and operation so as to delegate responsibility to those who are actually closer to the operations. As discussed in detail in the previous chapters, a number of initiatives supporting integrality and simplicity have been implemented to provide to the work teams in charge of the "internal projects" the best conditions for autonomy and to ensure that their contributions are driven by the base organization's overall objectives.

Addressing the second research question, *"How does this true best practice relate to other successful renewal initiatives in project production?"*, the exploratory library and field research revealed that the infrastructural decisions fostering workforce autonomy at the level of operations share the same rationale with those improving interactions in the higher levels of project organizations. The common logic appears to be the creation of a less complex and more stable organization characterized by having participants that are less heterogeneous, closely connected to one another, and responsible for carrying out a larger number of activities in the construction process. This rationale is applied to different scale subsystems in the organizations and is well in accordance with the research hypothesis, *"The search for integrality and simplicity, in contrast to complexity, is what intuitively guides the successful renewal initiatives in project production"*.

The research strongly indicates that shaping the production system according to this rationale requires the implementation of initiatives founded on a relatively small number of principles. During the research, consistent patterns were uncovered allowing the way of thinking about integrality in project production to evolve to the point where its discipline could be summarized in four principles: (1) continuity through time, (2) influence over upstream factors, (3) direct interconnections, and (4) delivery of complete subsystems. Despite the numerous strategies and practices causing structural changes to the organizational pattern, it became clear that only the initiatives aligned with these principles can actually support integrality and simplicity. The case studies on mobile cell implementation demonstrated that strategic choices and practices intuitively founded on the principles enhance systemic stability by either reducing the number of potential sources of unwanted dynamics or minimizing the non-linearities within dynamics. They confirmed what the observations and literature discussions on design-build and partnering approaches had already indicated. The case studies also confirmed that the delivery of complete subsystems is indeed the most supportive principle, since it allows different stakeholders to participate in a larger number of production steps and thereby increases the benefits of the other three principles.

Best practice implementation or development in different contexts is a topic that has long intrigued academics in both manufacturing and construction. Based on the above theoretical foundation, the analysis of the case studies provided insight into the reasons why a "best practice" programme will not by itself guarantee improved performance when implemented alone. Two complementary reasons have been discerned. First, the cases showed that initiatives to improve the production system design are rarely founded on more than one of the principles above. For instance, lean practices enhance the interconnections between site personnel and tasks. Some may even facilitate influence over upstream factors. But strategic choices that favour continuity through time and delivery of complete subsystems are needed to complement and increase the gains. Therefore, a single initiative may not be enough to provide to a particular subsystem the stability needed to achieve management goals or be improved. Second, the notion that systems possess different hierarchic levels of complexity helps to explain the perception that some initiatives, such as the design-build model, are more effective in improving integrality and simplicity only inside specific levels. The findings supported the research hypothesis, *"A "true" best practice can only emerge from a substantial number of internal adjustments"*.

In accordance, the case studies illustrated that real mobile cells become evident as more initiatives based on the four principles of systemic stability are applied to construction processes. The observation that mobile cell enablers are founded on these principles helped to further answer the first research question. But most important of all, this insight was particularly promising to characterize the mobile cell construct through a proper underlying theory and to confirm the hypothesis, *"A better understanding of integrality building blocks and enablers gives project organizations an idea of what is needed to implement mobile cells and to make them work best"*. Thus, the research findings not only contribute to building a theoretical foundation of integrality in project production, but also to filling a perceived void in the implementation of mobile cells in construction projects.

With respect to the second research question, a final comment is that every business organization must develop strategies to deal with the two main sources of uncertainty: market instability and labour instability. As shown in this dissertation, the integral processes and integral supply chains created under the "umbrella" provided by the general contractor support the emergence of capabilities to handle both issues. Regarding labour instability, it is important to note that people at all levels need a sense of predictability about the future and want to feel empowered and motivated. Therefore, despite the diverse mix of influences from the external context, the new production paradigm is all about trying to achieve higher performance by adjusting the production system design as best as possible to a natural human behaviour. Workflow stability improves as a result of the increased integrality, particularly because it improves predictability and empowers stakeholders at all levels to help in keeping the production system operating optimally against the closest active constraints. However, the challenge of implementing initiatives that support higher organizational, electronic, geographic and cultural proximity all the way down to the level of work teams is what makes the mobile production cells the final outcome of an integral project production system.

As for the research question, *"How does this system flexibility type contribute to the performance of the project production system as whole?"*, the findings demonstrated that in more controlled environments, such as the projects belonging to firms that specialize in high rise buildings, the mobile production cells are especially significant to the enhancement of response flexibility (e.g., Slack 1987), which is the ease with which the production system moves from one state to another in terms of cost, time, or both. In these project production systems, there are different control types limiting the variations that the subsystems have to endure. For these firms, the creation of stability begins with the strategic decision to concentrate on certain customer segments and is continually reinforced towards the level of operations, where lean construction practices are applied to further increase the control over variation types. The resulting inflow stability, lower setup times and lower rework rates within work packages performed by cells add up to time compression, which directly supports response flexibility.

In a more unstable and complex business environment, such as the one encountered by the geotechnical engineering firm, the mobile production cells have the additional task of supporting range flexibility, which is the range of states the production system can adopt. The field research showed that delivery reliability, delivery speed, and process quality continue being the "first-order effects" of cell implementation, even in foundation engineering processes. However, the improved time-based competitiveness from the implementation of real mobile cells generates only part of the flexible production capabilities required for such an uncertain line of business. As previously discussed, the firm has devised other strategies to enhance aggregate flexibility, including investments on basic flexibility types. One example is the high degree of multiskilling in the workforce. The wide range of products has led this subcontracting firm to widen the range of states which the resources are capable of achieving. Still, in addition to the flexible production competences generated from basic and system flexibility types, the firm also uses different types of buffers to complete the aggregate flexibility necessary for its production system to adapt to wider and sometimes unexpected states.

The comparative analysis of experiences in the geotechnical engineering firm and in firms that specialize in high rise buildings revealed that the production system's exposure to a greater or smaller number of possible scenarios does not change the "first-order effects" of cell implementation. The field examples showed that the initiatives promoting this system flexibility type make it so that it primarily improves the production system's time-based competitiveness and response flexibility. In fact, the range of states achieved (or the number of parts processed) to support range flexibility is an attribute more directly supported by some of the resources constituting the cell, such as the flexibility of the equipments or bandwidth of worker skills. Therefore, this dissertation shows that the system design features enabling the emergence of mobile cells are mostly about the development of a system flexibility type that allows the production system to move quickly, smoothly and cheaply from one state to another. These findings are relevant because time is an important competitive criterion in project production. They serve to confirm the research hypothesis, *"The mobile production cell is a competitive weapon for time-based competition"*.

7.2 - FUTURE RESEARCH

A comprehensive theoretical foundation is essential when it comes to renewing or aligning strategies, practices and tools inside organizations. However, despite the unquestionable contributions brought by some of the existing theoretical frameworks, it is necessary to move forward and add to the ongoing academic efforts aimed at building an even more ample theoretical basis to cover situations encountered in project production systems. As part of such effort, to our knowledge, this dissertation is the first to have articulated a theoretical framework of integrality in project production and to thereby characterize the mobile cell construct through a proper underlying theory.

The case studies on cell implementation helped to put greater confidence in the theory by confirming the existence of consistent patterns behind all successful renewal initiatives applied to the delivery of capital projects. They confirmed the perception that research on this "best practice" would be incomplete without an exploration of the new production paradigm around it. But they also contributed to raise awareness that the mobile cell is just one of many possible production competences emerging from integral project production models. Thus, several recommendations for future research are provided next with the objective of giving continuity to the work initiated in this dissertation:

- Conduct field studies in other organizational settings where autonomous, multi-skilled teams have been implemented. Because of the various tangible and intangible attributes influencing the emergence of real mobile cells, true tests of what works and what does not work can only be undertaken via case studies. Thus, extensive observations in different field settings are required to further support the ideas set forth here. Additionally, a closer look at distinct organizational circumstances can reveal other enabling factors that may be useful to cell implementation in construction projects;

- Analyse the possibility of decomposing each of the four principles of systemic stability into smaller sets of sub-principles. The four principles are not rigid rules and are still very broad in nature. Decomposing them would definitely help in specifying, adding or improving ideas. Most important of all, it would help to translate principles into actions and to thereby further operationalize integrality in project production;

- Propose perceptual and objective measures to assess attributes considered important in the new project production paradigm. Among other applications, these can be used to improve the requirements during the selection process of a design-build contractor. Besides low bid, construction experience and financial stability, the pre-qualified design-build contractors have to be analysed on the basis of criteria reflecting how well they articulate with the networks under their command;

- Explore theoretical frameworks in the behavioural sciences to further understand the discipline and drivers of organizational integrality. The notion that people at all levels need a sense of predictability and share the desire for more autonomy strongly calls for new insights that allow rethinking and improving workforce management strategies in dynamic and uncertain environments;

- Verify through numerous field studies the existence of patterns in the performance and development of other flexibility types. Research is needed to identify the "first-order effects" of particular flexibility types and the enablers that typically have the biggest impact on them. This can considerably facilitate the understanding of the implications of individual or combined construction strategies on project performance.

7.3 – FINAL CONSIDERATIONS

Because of the cruciality of time-based competitiveness to project production, it is important to stress that the implementation of the mobile production cell concept has implications for project scheduling. Through the case studies, it became clear that variations in activity duration are considerably lower in work packages performed by autonomous, multi-skilled teams. The reason is that the delivery of a complete subsystem alongside initiatives founded on the other principles of systemic stability contributes to the reduction of many potential sources of variation, thus improving the sound execution of activities. Not only the workflow becomes less uncertain, but also activities can begin as soon as their predecessors are finished. The result is the achievement of shorter cycle times inside those work packages. Consequently, project planners expect each work package to finish at its earliest finish time, counting from the actual start date.

The case studies showed that this assumption remains even as plans are changed throughout the project. For example, project management may decide to handle external uncertainty after the costumer order decoupling point by reducing the batch size or by delaying the beginning of a work package to its latest allowable start date. Either way, the work package's estimated overall duration is still considered optimistically because internal sources of variation in activity duration have been diminished. In other words, time buffers inside work packages performed by cells are viewed as of little necessity.

Practitioners in the field are likely to find this information to be particularly useful for supporting work structuring through pull scheduling (e.g., Ballard and Howell 2003a), which is a tactical level planning process aimed to produce a schedule with the least amount of padded durations. The process is based on working from a target completion date backwards and is done with the participation of representatives from the work teams so as to allow planning across work scopes. Theoretically, the estimates provided by the various teams should be realistic and have no contingencies. The idea is that any time or cost left over should be aggregated and "owned" by the project to subsequently form the project buffer or to be distributed to the most uncertain and fragile activities. However, in practice this is when the drawbacks begin to emerge.

Strategic alliance agreements, design-build and other higher-level initiatives that create closer ties and support early involvement of specialty contractors in project planning are not enough to avoid disagreements when project participants gather to negotiate who can apply duration cuts to activities and who should receive contingencies. Decision making becomes tricky in these steps because the recommendations in most project-scheduling techniques are quite vague. The only certainty is that the duration cut is not applicable to all activities. And even when it is, different cutting ratios must be used for different tasks because of their distinct challenges. But the bottom line is that representatives from the work teams feel uncomfortable to cut on duration and cost estimates if they do not perceive the project management team as being capable of providing the proper working conditions for an even workflow at the construction site. Lack of trust leads project participants to overestimate activity durations or resource capacities in order to compensate the duration cuts.

In the new project production paradigm, the provision of better working conditions means adopting strategic choices and production practices that foster predictability and empowerment all the way down to the frontline workers. As discussed throughout this dissertation, the combination of such initiatives at the level of operations is what originates the mobile production cells. Still, many work teams are unable to become mobile cells because the project management team may direct those initiatives towards a select group of specialty contractors. Therefore, it is essential to take into consideration the competences of the “real” mobile cells during project planning. Put differently, tasks conducted by teams working as mobile production cells must be planned in a different manner than those conducted by teams that are not. This distinction helps to increase contractor satisfaction.

Taking into account the competences of this system flexibility type in the production system contributes to reducing several drawbacks of the existing project-scheduling techniques. For instance, if duration cuts are necessary, the activities within work packages performed by cells are natural candidates due to their greater stability. Whenever possible, the time removed from these activities can be used to form the project buffer. Complementarily, because of the high workload and optimal design of mobile cells, feeding buffers and inventories need to be deployed in front of their work packages in the critical chain.

The confidence that mobile cells can sustain a good performance with little, if any, provision of time buffers was a remarkable aspect of the case studies. The representation of the activities that constitute a work package as a single block in the Line of Balance diagram displayed the underlying assumption that the rate of production for a work package performed by a cell is uniform. Moreover, the shift from the numerous detailed activities in traditional Critical Path Method scheduling to the more compact work packages in Line of Balance control was a testimony that the initiatives implemented were successfully allowing project management teams to delegate micro management to autonomous teams at the level of operations.

But as relevant as time-based competitiveness may be, the improvement of the system’s flexible production capabilities is also important for project-based-firms. This is another external dimension of competition supported by the implementation of mobile cells. Just as an example, the possibility of removing redundancies from individual trades without risking underperformance and use them to form the project buffer is evidence of a flexible production competence supporting the whole system’s adaptation to external uncertainty. This illustrates that the creation of “real” mobile cells through initiatives based on all four principles of systemic stability contributes in an optimal way to the achievement of competitive priorities such as quality, cost, delivery, and flexibility. In the case studies, the experience with this type of system flexibility has shown that the production system continues to be robust, but more efficient and effective at the same time. Furthermore, the idea that buffers “belonging” to some participants can be safely taken from their operations to be used for the benefit of the entire project organization is the clearest demonstration of the inner workings of an integral production system.

The degree to which improvements in time-based competitiveness and flexibility are simultaneously achieved will depend on the amount of initiatives supporting integrality throughout the organization’s multiple levels of complexity. Therefore, both types of improvements are essential for bringing about awareness on the need for integrality in project production and understanding of the concept of mobile production cell in the construction industry. In closing, by opening the discussion of what it takes to effectively create workforce autonomy in construction projects, this dissertation will hopefully stimulate researchers and practitioners to examine the ideas set forth here and to develop principles and methods to guide future efforts directed towards the creation of integral project production models.

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