BROADER IMPLEMENTATIONS OF PRODUCTION CELLS IN CONSTRUCTION CONSIDERING TIME, SPACE AND INFORMATION LINKAGES

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ABSTRACT

The use of production cell in manufacturing has achieved many benefits, motivating researchers to apply them in the construction environment. The aim of this research is to identify time, space and information linkages considerations in construction production cells applications, seeking opportunities for broader implementations. We adopted a literature review approach focusing on studies in Brazilian construction sector that addressed cells applications. Subsequently, comparative tables of these publications were prepared, analyzing the consideration of time, space and information linkages, as well as identified results. The article pointed out that there is a lack in publications that address the application of production cell in almost all construction flows, except the job site flow, reflecting the tendency of most companies of applying lean concepts first in physical flows. The greatest benefits reported from the applications of production cells were the lead time reduction, cost savings and increase productivity. By analyzing the aspects (group of features that enhance the use of the cell) it was found that "material flow and pull system" and "operators interaction" were the aspects most often considered, but mostly partially. "Flexibility" and "equipment maintenance" were used in very few reported cases. No case reported comprehensive considerations of the three important linkages of time, space and information. Space was the linkage better considered, showing that studied applications tend to be latent physical cells, with lack in time and information linkages. Further studies are proposed in order to investigate the results of more comprehensive applications considering all aspects.

KEY WORDS

Production cell, lean thinking, construction.

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INTRODUCTION

Since the pioneering proposition by Womack and Jones (1996) regarding the five principles of lean thinking, the principle of flow has been highlighted as a cornerstone of this philosophy. To put in place this principle, a tool widely used in manufacturing has been the production cell, which aims to keep the production flow as close to continuous (Liker, 2004).

The benefits brought by cell applications in manufacturing are: reduction of setup time, in-process inventory, lead time and cost; increased product quality, simplified programming, among others (Pattanaick and Sharta, 2009).

The great importance of production cell in manufacturing brings the interest to better understand the concept and to discuss its application in construction environments, aiming similar results. The literature review reported initial applications of production cells in construction, in several cases in partial formats, and arguably limited results.

OBJECTIVES AND METHODOLOGY

The aim of this research is to identify time, space and information linkages in construction production cells applications, seeking opportunities for broader applications. The context of analysis is limited to selected Brazilian construction cases.

The methodological approach used consisted of a literature review (between 2001 and 2010) addressing the implementation of cell production in the construction environment in Brazil. The cases were analyzed taking as references the linkages of time, space and information, as proposed by Hyer and Brown (1999). Enablers for effective cells implementation proposed by theses authors were grouped in aspects such as cell design, material flow and pull system, flexibility, visual management and feedback, operators interaction and equipment maintenance, also considered in the analysis. Main lacks in the consideration of these aspects and linkages were identified, pointing up gaps for future research efforts.

PRODUCTION CELL

According to Rother and Harris (2002), a cell is an arrangement of people, machines and methods in which the activities are close and occur in sequential order, whereby the parts are processed in continuous flow one by one (or in small batches). The U-shape form is common, because it avoids large operator walking distances and allows different combinations of tasks for operators (Lean Enterprise Institute, 2003).

Swank (2003) reports that the cell production is also being applied in the service sector, where teams create flow in small batches and can reduce in-process inventory.

Hyer and Brown (1999) define a production cell as: “Dedicating equipment and materials to a family of parts or products with similar processing requirements by creating a work flow where tasks and those who perform them are closely connected in terms of time, space and information”.

So the authors emphasize two characteristics: (1) the dedication of equipment and material to a family of parts, and (2) the creation of a work flow connected in terms of time, space and information.

In construction, the applications generally focus on the implementation of production cell in a specific set of services, so the first characteristic of dedication of resources is frequently attended. The second characteristic mentioned by the authors, of linkages between people and tasks, generally present gaps even in manufacturing (Hyer and Brown, 1999), and deserves more attention. Hyer and Brown (1999) present enablers that allow the application of production cells comprising the three linkages.

In order to facilitate further analysis, we propose a grouping of Hyer and Brown´s enablers in aspects. The grouped aspects contribute to generalize the analysis for non-manufacturing environments, such as construction and others.

Table 1 presents these proposed aspects and related enablers, as well as their impact in each linkage, adapting the correlation of enablers and linkages proposed by Hyer and Brown (1999).

Table 1: Aspects considered in the implementations of cells and their correlation with linkages; adapted from enablers (HYER and BROWN, 1999).

Enablers	**Aspects**	**Impact on the linkage:**		
		Time	**Space**	**Infor-mation**
• Juxtaposition of sequentially related equipment in cell arranged to accommodate dominant flow • Miniaturization of 'monument' processes • Balanced workstations • Small cell size	Cell design and flow	●	●	●
• Small lot sizes • Small transfer batch quantities • Parts delivered on time • Incoming material conforms to specifications • Effective material handling equipment/processes	Material flow and pull system	●	○	●
• Short set-up times • Cross-training and job rotation • Equipment that can be moved as cell needs change	Flexibility	●		○
• Management control systems that make information quickly available to operators • Presence of feedback loops among cell stations and between cell and customers/supplier • Job designs and other policies that permit operators to take action in response to signals • Job designs and other policies	Visual management and feedback	○		●
• Common operator language • Positive interpersonal relationships between operators • Operators continually share information • Operators skilled at teamwork • Operators have visual access to all cell activities 'line-of-sight' information • Operators have 'whole task' understanding • Low noise environment	Operators interaction	○		●
• Preventive maintenance policies • Operators skilled at preventive maintenance	Equipment Maintenance	●		

Legend: (●) stronger influence (○) medium influence;
Source: adapted and grouped from Hyer and Brown (1999).

In Table 1 one can observe that some aspects affect many linkages, while others have more specific impacts. For example, the aspect "cell design and flow" influence the three linkages: time, space and information. Despite this, only its application would not lead to the complete treatment of these linkages, depending on the application of other aspects. Rother and Harris (2002) emphasize, for example, that just approaching equipment, without creating a one-piece flow (related to the aspect "material flow and pull system"), among other deficiencies, lead to what they name false cell.

RESULTS AND DISCUSSION

APPLICATION OF PRODUCTION CELL IN CONSTRUCTION - BRAZILIAN CASES

Literature review focusing on production cell application in Brazilian construction identified cases related to the job site, as well as to other construction phases. Table 2 presents the papers considered, their focus and related construction flows. We adopted the division proposed by Picchi (2001) that divides the construction project into five main flows: business, job site, design, supply and use and maintenance.

Table 2: Papers related to production cell application in Brazilian construction cases

Authors	Focus	Construction Flow
Bulhões *et al* (2005)	Possibility of implementing continuous flow in construction	Job site
Carneiro *et al* (2009)	Benefits of a successful production strategy	Job site
Carneiro (2007)*	Implementation method of production cells in the construction environment	Job site
Ferraz *et al* (2005)	Model for planning and construction management	Job site
Paixão *et al* (2010)*	Analysis of cost variation over time of production cell in job sites	Job site
Patussi and Heineck (2009)*	Main results of implementing the concepts of cell production in a small job site	Job site
Patussi and Heineck (2006)*	Changes in production occurred after use of the concept of manufacturing cells in small construction companies	Job site
Romano *et al* (2005)*	Flow facilitation in tall buildings construction, through the rationalization of equipment and use of production cells	Job site
Santos *et al* (2002)*	Manufacturing cells concept application in a dry-wall service	Job site
Tavares *et al* (2004)*	Results of production cells application to construction planning and execution	Job site
Ugulino and Lima (2009)*	Improvements in construction processes through the use of mobile production cell in masonry service	Job site
Reis and Picchi (2004)	Waste identification in construction business flow using value stream mapping	Business
Lima *et al* (2010)	Results of value stream mapping applied to architecture executive design in a public agency	Design
Weindorfer (2001)	Productivity improvements in a, Public Works State Department	Design
Barbosa and Lima (2008)	Continuous flow implementation in the production of pre-cast foundation piles	Supply Chain
Salermo (2005)	Lean thinking concepts and tools applied to hospital buildings maintenance	Use and maintenance

The research efforts with asterisk directly address the application of production cells, having as specific objective to implement and/or to analyze the production cells. The others have different main focus, referring indirectly to production cells.

Eleven out of sixteen papers in Table 2 are related to job site flow, while few applications were identified in other construction flows. This reinforces Picchi and Granja (2004) observation that business, design, and use and maintenance flows present few applications of lean thinking tools, compared to job site flow. The application of cells and other lean concepts and tools first in production is also a pathway frequently observed in manufacturing, and reflects lean emphasis on the places were value is added to product that customer pays for and were first results are more tangibles. As Womack and Jones (1996) point out, lean is a business system and not just a production system, so the spreading to other functions and flows beyond production is expected as implementations maturity evolves.

ASPECTS AND LINKAGES CONSIDERED IN DISCUSSED PRODUCTION CELL APPLICATIONS

From the analysis of the cases reported in each study, we identified the aspects addressed in each one, as reported in Table 3. We adopted a classification of the accuracy and completeness of treatment given to each aspect in each paper. For that aim, we analyzed in each study the description of practices or analysis related to enablers associated to the considered aspect. From this analysis, we classified the paper's aspect consideration as partial or comprehensive, following these criteria: if all enablers of the aspect are considered, the classification is comprehensive. For example: Salermo (2005) presented the two enablers (preventive maintenance policies and skilled operators) that are part of the equipment maintenance aspect. We classified as partial consideration the papers with at least one enabler in the respective aspect.

Regarding the use of aspects, one can see that the aspect "material flow and pull system" was considered in all papers, with comprehensive treatment in five of them. One example of improvement on this aspect is the use kanban in mortar production and lay-out planning for materials storage close to application (CARNEIRO et al, 2009). Following, the "operators interaction" aspect was also considered in all studies, but only one comprehensively. Santos et al (2002) presents examples in this aspect, such as workflow and visual controls, close communication as result of multi-skilled team working together. Still widely used were the aspects: "cell design and flow" and "visual management and feedback". Aspects less considered were "flexibility", and "equipment maintenance ".

Job site flow, besides having higher cell cases, presented higher frequency of comprehensive applications. The other flows had only partial applications, except for the use and maintenance flow with one comprehensive application in "equipment maintenance" aspect.

Papers using larger number of aspects classified as comprehensive consideration were: Patussi and Heineck (2009), Santos et al (2002), Carneiro (2007) and Carneiro et al (2009), each one with two comprehensive aspects. One can observe that no research has used all aspects and most existing applications are partial.

For an evaluation of time, space and information linkages consideration, we adopted a criteria for establishing correlation between covered aspects and linkages.

Table 3: Aspects and linkages considered in the discussed papers

Authors	Aspects						Linkages			Construction Flow
	Cell design and flow	Material flow and pull system	Flexibility	Visual management and feedback	Operators interaction	Equipment Maintenance	Time	Space	Information	
Bulhões *et al* (2005)	○	○		○	○		□	◘	□	Job site
Carneiro *et al* (2009)	○	●		●	○		◘	◘	◘	
Carneiro (2007)	○	●		●	○		◘	◘	◘	
Ferraz *et al* (2005)	○	○	○	○	○		◘	◘	◘	
Paixão *et al* (2010)		○			○		□	□	□	
Patussi and Heineck (2009)	●	●	○	○	○		◘	■	◘	
Patussi and Heineck (2006)	○	●	○	○	○		◘	◘	◘	
Romano *et al* (2005)	○	●		○	○		◘	◘	◘	
Santos *et al* (2002)	○	○	●	○	●		◘	◘	◘	
Tavares *et al* (2004)		○			○		□	□	□	
Ugulino and Lima (2009)	○	○		○	○		□	◘	□	
Reis and Picchi (2004)	○	○		○	○		□	◘	□	Business
Barbosa and Lima (2008)	○	○			○		□	◘	□	Supply Chain
Weindorfer (2001)	○	○		○	○		□	◘	□	Design
Lima *et al* (2010)	○	○			○		□	◘	□	
Salermo (2005)	○	○		○	○	●	◘	◘	□	Use and maintenance

Legend of aspects: (●) comprehensive consideration of all enablers of the respective aspect (○) partial consideration of at least one of enabler of the respective aspect; (no symbol): absent
Legend of linkages: **(■)** comprehensive **(◘)** partial **(□)** initial;

The aspect classification of: comprehensive, partial and absent were weighted as 1,0 ; 0,5 and zero respectively and were crossed to Table 1 correlation of aspects and linkage. Table 3 presents the resultant classification: comprehensive, partial and initial.

When analyzing the linkages treatment, we observe that no study covers all three linkages comprehensively. Just one research (Patussi and Heineck, 2009) presented one comprehensive coverage, in space linkage.

Space linkage presents just two cases with initial consideration, while time and information presented respectively 8 and 7 initial classifications. Besides that, in no case space linkage received lower classification than other linkages. One can

conclude that space was the linkage better covered, tending to latent physical cells (time and information deficient), according to Hyer and Brown (1999).
The job site flow applications, besides a better coverage of aspect discussed previously, also presented better classifications in linkages, compared to the other flows.

BENEFITS OF PRODUCTION CELLS APPLICATIONS

Table 4 presents the benefits identified by the authors directly related to the application of production cells. Other benefits mentioned in the research efforts resulting from other tools were not reported in Table 4.

Table 4: Benefits identified by authors resulting from applications of production cell in construction

Authors	Lead time reduction	Reduced Costs	Increased Productivity	Increased financial return received by Employees	Employee satisfaction	Waste Reduction	Skilled employees	Planning simplification	Cleaner and more organized workplace	Increased transparency	Improved ergonomics	Lower employee turnover	Inventory reduction	Increased Quality	Variability Reduction	Others	Number of benefits referred
Bulhões *et al* (2005)	X																1
Carneiro *et al* (2009)	X	X	X	X	X			X		X						X	8
Carneiro (2007)	X	X	X	X	X	X		X		X							8
Ferraz *et al* (2005)								X								X	2
Paixão *et al* (2010)	X	X													X		3
Patussi and Heineck (2009)	X	X	X	X	X	X	X						X	X			9
Patussi and Heineck (2006)	X	X	X	X			X										5
Romano *et al* (2005)	X	X	X	X	X				X			X					7
Santos *et al* (2002)	X						X				X						3
Tavares *et al* (2004)						X		X									2
Ugulino and Lima (2009)	X	X	X	X	X	X			X			X					8
Reis and Picchi (2004)	X																1
Barbosa and Lima (2008)	X															X	2
Weindorfer (2001)			X		X											X	3
Lima *et al* (2010)	X	X														X	3
Salermo (2005)	X						X									X	3
Number of citations	13	8	7	6	6	4	4	4	2	2	2	1	1	1	1	6	

The benefit most often cited in Table 4 was lead time reduction, mentioned in 13 of the 16 studies. The second one was cost reduction, identified in 8 papers, followed by increased productivity mentioned in 7.

Patussi and Heineck (2009) was the only paper that presented consideration of the three aspects, and at least one aspect with comprehensive coverage. This paper was the one that reported the major number of benefits (9).

CONCLUSIONS

The application of the production cell concept in the job site construction flow is very partial yet. In the other construction flows, such as business, design, supply and use and maintenance, the applications are even more limited and partial.

"Material flow and pull system" and "operators interaction" were the aspects most often considered, but mostly partially. "Flexibility" and "equipment maintenance" were used in very few reported cases. Probably this is a consequence of the fact that equipment maintenance in construction is not as critical as for manufacturing. Flexibility is related to multifunctional workers skills, an important issue in construction, demanding future research.

No case reported comprehensive considerations of the three important linkages of time, space and information. Space was the linkage better considered, showing that studied applications tend to be latent physical cells, with lack in time and information linkages.

The major reported benefits from the applications of production cell were lead time and cost reduction and increased productivity.

Designing cells in construction is a recent effort, and the theoretical reference of aspects and linkages is a possible help for practitioners and researchers for that. The analysis of both aspects and linkages pointed out that there is still great room for improvement in the application of production cell concept in construction, motivating further studies for broader cell applications seeking superior results.

In this study we could not identify a real cell implementation in the studied construction cases. Hyer and Brown (1999) argue that "real physical cells contribute in an optimal way to achievement of competitive priorities, such as quality, cost, delivery and flexibility". The authors recognize that this is argument is not confirmed yet, and would demand future research. In the same way, future studies in construction could address that evaluation.

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