

APPLYING THE CONCEPT OF MOBILE CELL MANUFACTURING ON THE DRYWALL PROCESS

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ABSTRACT

This paper presents the results of an exploratory study investigating the application of the “mobile cell manufacturing” concept within the construction environment. The investigation was carried out using a case study research method and focused on the drywall process. The initial phase of the project involved a diagnosis of drywall practices in a medium sized company. That diagnosis pointed out a number of problems such as equipment improvisation, poor workflow planning and the absence of adequate drywall design plans. In order to tackle these problems simultaneously we experiment with the idea of “cell manufacturing” in one case study. Using Hyer and Brown (1999)’s list of cell manufacturing enablers we conclude that our cell got to the stage of a “latent physical cell” because it was characterised by spatial proximity, but with deficiencies in time and information linkages. The study indicates that the concept of “mobile cells” is feasible in construction and deserves further research and dissemination in industry as it enables (and requires) a simultaneous integration of all lean construction ideas within a single environment. Future studies on this topic need to start right from the beginning of the construction project in order to prepare the site for the new production dynamics required by “mobile cells”.

KEYWORDS:

Drywall, mobile cell, cell manufacturing, innovation

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INTRODUCTION

Previous research carried out by the principal author assessed the current state of some core production management principles in construction sites of Brazil and the UK. That study demonstrated empirical evidence matching five flow principles and correspondent heuristic implementation approaches. Similarly, the same empirical evidence also unveiled a serious level of deficiency on the integration of “literal replications” with other complementary practices. The best performers were those sites that presented a small but well connected set of practices matching the theory. The study concluded that the agenda of construction research should include the need for systemic integration of the various lean heuristic implementation approaches in construction practice (Santos 1999). Cell manufacturing (CM) encapsulates most lean production practices within a single environment, thus we understand that it can be used as a focus for lean implementation initiatives worldwide.

Hyer and Brown (1999) define a cell as a “discrete production environment that dedicates equipment and materials to a family of parts or products with similar processing requirements”. It does this by creating a work flow where tasks and those who perform them are closely connected in terms of time, space and information. Steudell and Desruelle (1992:264) understand cells (or work-cells) as a group of closely linked, dissimilar workstations (automatic or manual) dedicated to performing a sequence of production on families of similar parts or products

Cell manufacturing is regarded as one of the foremost operations management approaches that have contributed to significantly improve production productivity worldwide (Rasaratnam and Ko 1997). It is an alternative method of organising production to those based on process specialisation, which is the traditional method still in use by most batch and jobbing factories in the world (Burbidge 1996). It offers the potential to move from an inflexible, repetitive mass production approach to a more flexible small-lot production. In the manufacturing sector, with the advanced technologies of robotics, automated guided vehicles (AGVs), automated storage/retrieval system (AS/RS) and computer-aided design (CAD), cell manufacturing offers the advantages of production line efficiency as well as the flexibility and technical competence of job shop production (Yang and Deane 1994). Thus, cell manufacturing has been viewed as a bridge from conventional manufacturing to Computer Integrated Manufacturing (CIM) (Yang and Deane 1994).

In the majority of studies on cell manufacturing, cells are assumed to be fixed or their locations to be known a priori the commencement of operations (Rasaratnam and Ko 1997). That is not the case in most construction processes and operations, in which workstations generally move around a fixed ‘product’. Indeed, the objects of construction are wholes assembled from ‘parts’ (fixed position manufacturing). During the assembly process, the parts themselves become too large and heavy to move through workstations. Thus, the workstations have to move through the emerging wholes, adding pieces as they move (Ballard and Howell, 1998). Thus, we set to study the application of “mobile cells”, in other words, cells that retain all characteristics of a “real cell” whilst having to move around the product.

This study was developed based on British Gypsum (BPB) drywall technology. Currently this company is the leading producer of plasterboard in Europe, Canada and South Africa and

has substantial European investments in the manufacture of complementary building materials and paperboard products. BPB product range covers boards, plaster, gypsum blocks, jointing & finishing, metal profiles, accessories & fixings, ceilings, flooring, insulation, decorative products, tools, paperboard and paper sacks. In Brazil BPB product range include boards, jointing & finishing and metal profiles accessories & fixings. It imports all other drywall components from its UK and other subsidiaries. The introduction of these products to the South American market has been achieved via BPB Placo do Brazil, a BPB subsidiary and one of the sponsors of the research project described in this paper.

CELL IMPLEMENTATION ISSUES AND BENEFITS

Implementation of CM involves an integrative discipline that goes beyond just a physical configuration (Hyer and Brown 1999). It must be viewed as multi-criteria decision making problem, including all strategic considerations (Yang and Deane 1994). At the operational level the essential step in implementing CM is to plan a total division of products and processes into groups and families, in which each group completes all the parts it makes. A part or product family is defined by similar processing requirements. Thus, a family must possess a sufficient level of process commonality to allow operations to follow a similar sequence through the cell and to minimise the need to spend time on set-up changes between family variations. The savings from cells depend on finding groups that complete all the parts they make (Yang and Deane 1994; Burbidge 1996; Sarker and Li 1997; Hyer and Brown 1999).

Physical proximity is essential to achieve the status of a “real” cell. Hence, family-dedicated equipment must be co-located and arranged within the cell such that it reflects the dominant flow pattern of cell parts. Operators must be close enough to each other to allow them to easily transfer materials, but perhaps more importantly, to see each other, converse, work as a team, and resolve problems quickly (Hyer and Brown 1999).

Reported benefits of cells include cost reduction, lower production flow time, increased machine utilisation, reduced inventory level, better quality control, fast response to product change, reduced set-up time, reduced throughput time, reduced work-in-progress, simplified process and operation’s flow and improved human relations (Yang and Deane 1994; Rasaratnam and Ko 1997). Steudell and Desruelle (1992:302) argue that cell manufacturing makes tracking work-in-progress simple and virtually unnecessary. Furthermore, process transparency increases when we move people, tasks and machines closer together, as there is increased potential for continuous, natural communication within the production team (Formoso and Santos 2002). Information sharing will be an outgrowth of this phenomenon and operators are more likely to be aware of inventory status, bottlenecks, part shortages and other key performance factors if they are near each other (Hyer and Brown 1999).

RESEARCH METHOD

The concept of “mobile cell manufacturing” was applied on the drywall construction process. The investigation demanded the development of the study in “real world” conditions to reflect an actual situation faced by practitioners in everyday life. Real world conditions imply

little or no control over the events surrounding the observed practices (Robson 1993; Yin 1994).

The first phase of the research was a diagnosis of current drywall practices in a medium sized construction company in Curitiba, Brazil. The analysis of practices within this case study took four weeks and used a standardised observation protocol. This protocol included open-ended interviews, photographs, application of a checklist on “best drywall practices”, video-recording and quantitative indicators. The second phase was the implementation of the mobile cell itself on a construction site and, due to time constraints, this entire phase took around six months. It involved a number of activities such as training sessions for the workforce (two months), planning and development of new workstation set-ups (two months) and the actual cell implementation (two months).

Analysis was carried out using an approach similar to the pattern-matching method described in Santos, Powell and Hinks (2001). In this approach, when similar results happen and for predictable reasons, the evidence produced is seen to involve the same phenomena described in the theory and, therefore, it is called “literal replication”. In contrast, when the case study produces contrasting results, but also for predictable reasons, it is called “theoretical replication”. For each “literal replication” there must be an equally plausible rival example showing a “theoretical replication” (Yin 1994). This pattern-matching analysis used Hyer and Brown (1999) definitional elements that characterise a real cell, as described below:

- *Definitional element 1*: the dedication of equipment to a family of parts or products which have similar processing requirements;
- *Definitional element 2*: the creation of a work flow where required tasks and those who perform them are closely connected in terms of time, space and information.

DIAGNOSIS OF CURRENT DRYWALL PRACTICES

The first phase of this research showed that site practices followed in general the process stages shown in * MERGEFORMAT Figure 1. The diagnostic showed that the production batches for each stage were exaggerated and quite often resulted in large amount of work-in-progress. For instance, in one occasion the research team observed the operators installing rafters in all twenty two stores of the investigated building. Only installed all rafters they initiated the next drywall stage, which was “installing studs”. As a consequence of this practice any design change implied large amount of rework. Indeed, application of the work sampling technique showed that more than 6% of the time was dedicated to rework operations.

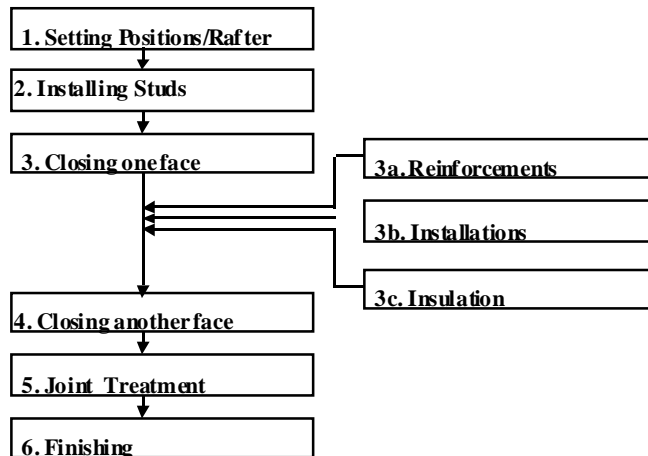


Figure 1 - Drywall Process Stages

The shadowed polygon in Figure 2 illustrates the contrast between BPB recommended practice and the actual practice in the construction site (It is not in the scope of the present paper to discuss if BPB recommendations can be considered as best practice. However, we evaluate practices recommended by other producers such as Knauf (Germany) and Lafarge (France) and the analysis showed a reduced amount of differences among them). According to interviews with the subcontractors this construction site represented a typical situation which could be found in other construction companies, regardless the source of technology. It is important to point out that the workteam at this site presented, in average, five years experience working on the drywall process and, adding to that, they had attended training sessions on BPB drywall technology.

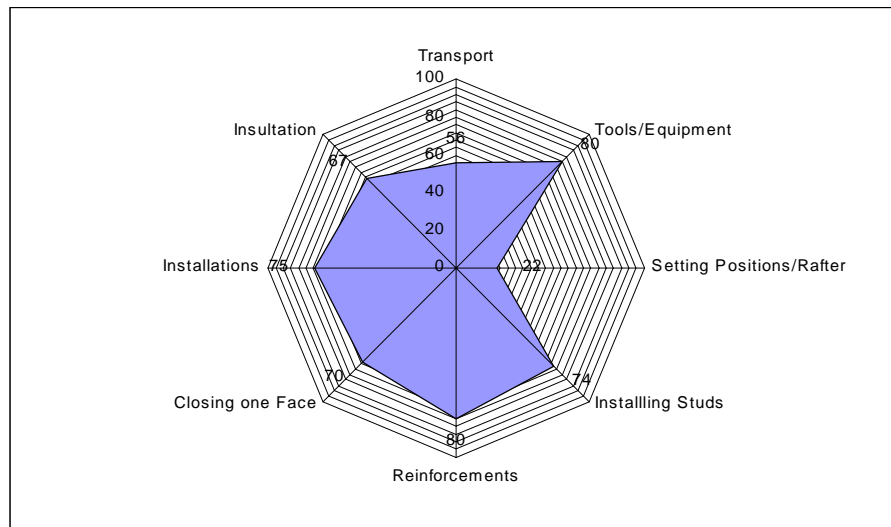


Figure 2 – Assessment of Drywall Practices in a Brazilian Construction Site

The following sections highlight some of the main aspects for each of the variables analysed in this particular case study.

TRANSPORT

The observations showed that only 50% of best practices considered as “applicable” were present on this site. It was not possible to see a systematic layout planning which defined storage locations or delineated transport pathways. A clear sign of the lack of attention to workflow was the recurring enclosure of workstations in small spaces. This practice created significant difficulties in communication between drywall workstations and resulted in longer transportation routes. In a way, these drywall operatives assembled components as they would assemble bricklaying. Furthermore, site operators used inadequate equipment to transport plasterboards.

TOOLS

The research shows that 80% of the tools listed on the “best practice” check-list and considered as “applicable” were present in this construction site. In other words, only 80% of the tools they needed to properly do their work were present on site. The time for workstation set-up was excessively high and it was virtually impossible to transport all equipment with only one transport operation. Indeed, the work-sampling data showed that 39% of the total time was used in auxiliary operations. Also, most workstations presented ergonomic problems that range from wide spinal movements to great instability on improvised scaffoldings. The improvisation of tools was widespread and affected the end result of the drywall operations.

SETTING UP POSITIONS/RAFTERS

The application of the best practice checklist showed that only 22% of “applicable” practices for this group of items were present on this construction site. The researchers perceived a clear lack of application of the “transparency principle” (Santos and Formoso, 2002). For example, the supplier recommended a clear visual control indicating the position of windows and doors, but this practice was not observed during this study. Increase of transparency means to increase the ability of a production process to communicate with people. The way in which information is organised for accessibility is the distinguishing feature of transparency. In conventional communication, information is transmitted in a “push” mode and the user has little or no control over the amount and type of information transmitted or received. In contrast, in the new paradigm nothing is transmitted: an information field is created which can be “pulled” by any person at any time (Greif 1989; Santos 1998). The substantial time wasted by drywall operatives searching for positions and setting-up measures demonstrate the need of practices applying these ideas in the drywall process.

INSTALLING STUDS

The application of the checklist showed that 74% of the practices related to “installing studs” recommended by BPB and considered as to be “applicable” were present on this site. Most difficulties were due to non-standard design details and the long distances to reach electrical

sources. Indeed, the observations showed that the construction workers spend considerable amount of time producing studs for 120° corners. Also, whilst BPB recommends the use of specially adapted scissors to cut metallic studs, the subcontractor on this site used an angle grinder.

INSTALLING INTERNAL REINFORCEMENTS

The research identified on site only 80% of “applicable” practices for this group of items. However, there were considerable difficulties to verify the presence of these items since there were no drawings or clear specifications indicating the actual need and location for reinforcements. The internal reinforcements were usually installed in three different levels with positions marked using a tool developed by the subcontractor.

FIXING THE PLASTERBOARDS

The researchers observed only 70% of supplier’s recommended practices for installation of plasterboard, e.g. drywall operatives did not mark the boards before cutting. Although they placed the plasterboard before the electrical and other systems, as recommended by BPB, research demonstrated divergent views on what should be the correct assembling order. Indeed, in another construction site analysed by the research team the subcontractor placed the plasterboard only after the electrical and hydraulic system, despite of an increase in the number of operations.

BPB recommends a precise location of electric and hydraulic components through the slab since drywall technology does not tolerate the same level of deviations found in bricklaying. The diameter of tubes in the installations has to be compatible with the thickness of the drywall in order to avoid complete closure of drywall sections and, therefore, compromising sound and fire insulation. Research has demonstrated numerous examples of blatant disregard for factory recommendations. For example, BPB recommends joints should not be in line if more than one plasterboard layer. However, the researchers did not observe the practice of testing all systems before placing the second drywall face. It is apparent that the lack of such tests can result in higher costs during the later stages of the construction process of even after delivering the product to the end customer. There is also a risk of generating pathologies in the plasterboards in the case of appearing leakage.

INSULATION

The assessment of this item shows that the construction site presented two of the three items recommended by BPB. The missing item in most drywalls was the use of a tape at the interface between the stud and ceiling/floors in order to improve insulation. The lack of drywall drawings was also burden for researchers to investigate the correctness in the application of drywall technology in this site.

IMPLEMENTING A MOBILE CELL

Implementation started after a meeting with a company director which was involved in the project since the diagnostic study presented previously. As a result the company provided two stores of a tall building for the research team to demonstrate their ideas of mobile cell

implementation. The company also offered support for developing any necessary tool (s) to enable workstation mobility.

Subsequently the research team carried out twelve training sessions on key aspects of cell manufacturing involving people from all hierarchical levels in the construction site. These training sessions were developed within the university and covered topics such as ergonomics, layout planning and process transparency. One fundamental topic that underlined the content of all sessions was the need to reduce batch size and work-in-progress and the dynamics of cell manufacturing, particularly the impact of these changes on the task distribution among workers.

Cell implementation required that all drywall process stages had to be completed before the team could move to another workplace. In order to achieve that, at some point, the workers had to help their colleagues to complete their tasks. This would allow activities to be 'balanced' in the workstation and improve overall efficiency. This 'helping out' between workers implied a minimum level of multi-skilling, quite a complex (not to mention sensitive) undertaking given that traditionally these workers receive their payments based on their individual productivity alone. Figure 3 shows the comparison between the workflow in an apartment of a store prior and before the cell implementation, the arrows show the workstation and the numbers indicates the construction process stages performed in each workstation, following the workflow illustrated in Figure 1.

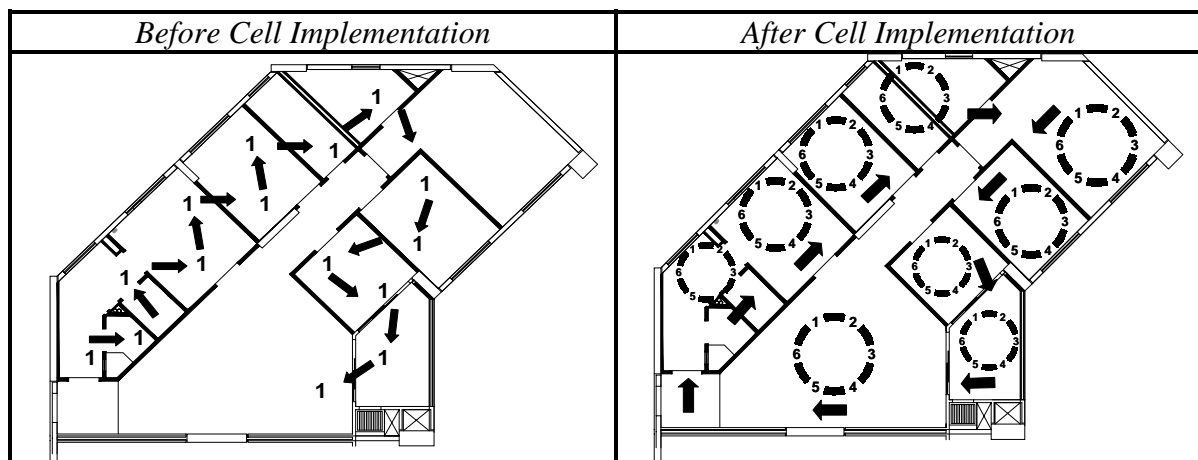


Figure 3 - Workflow Prior and Before Cell Implementation

A partnership was established with UFPR's Mechanical Engineering Department (DEMEC/UFPR) to design a mobile workstation in order to implement the mobile cell approach. This design took in consideration all ergonomic issues and the need for a self-sufficient workstation. The idea was that workers should find all materials and information they need in a single-point and, also, to be able to move most production resources simultaneously and quickly. This mobile workstation was a key factor for implementing the concept of mobile cells on site. Figure 4 illustrates the original design (left) and the material and tool's cart which were the main part of the workstation. Note that some of the equipment traditionally used by drywall workers remained on site.

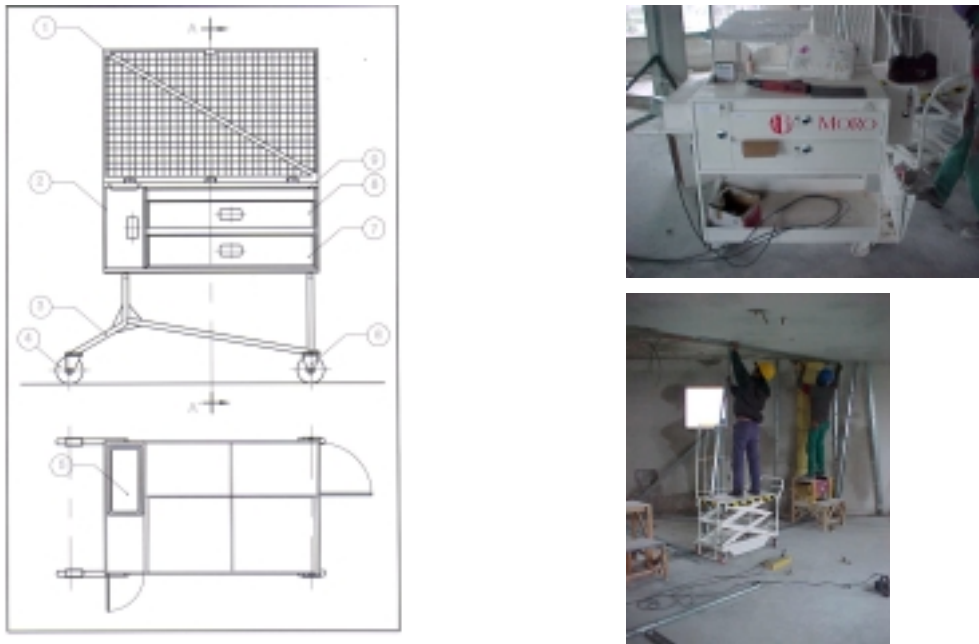


Figure 4 - Example of tools developed in order to enable mobile workstations

The experiment lasted approximately two months and the assessment involved comparisons in terms of costs and productivity with the traditional drywall practice. This paper presents solely the theoretical generalisations in terms of “enablers” that were identified, taking the work of Hyer and Brown (1999) as the baseline for analysis. Table 1 presents the situation of our case study in relation to these factors and present some short comments on each of them. We implemented Last Planner right from the beginning of the work along with Activity Based Costing. These tools were quite helpful to stabilise and monitor drywall performance as well as enable detection of factors that were having negative effect on the workflow and final cost. The training sessions have covered the dynamics of these tools and all workers took an active role in their implementation.

Implementing the Cell Manufacturing concept had a significant impact in all problems pointed during the diagnose phase. Within the drywall cell there was lesser improvisation on transport and storage locations since now the drywall team was responsible for layout and workflow planning. Previously this was the foreman responsibility and there was little commitment of the workforce to implement his plans. Additionally, the improvements in ergonomics increased the motivation of workers and their perception on the benefits that cell manufacturing brought to their every day operations.

Table 1 – Check-List on “Enablers of Real Cells” (based on Hyer and Brown, 1999)

<i>ok</i>	Enablers	Comments
	1. Small lot sizes:	<i>Dividing production in small independent work packages was a key factor to improve workflow in this case study</i>
	2. Small transfer batch quantities	<i>The original site planning did not allow us to evaluate transfer batches since downstream processes were not present on site.</i>
	3. Parts delivered on time:	<i>In our case the main supplier did not get fully involved in the cell implementation and that was a great burden to achieve a “real cell”.</i>
	4. Incoming material conforms to specifications	<i>There were no drywall drawings and specifications!</i>
	5. Effective material handling equipment & process:	<i>It is even more critical when the worker is a subcontractor. In this case the subcontractors had most of the tools recommended by the drywall supplier;</i>
	6. Short set-up times	<i>see example of mobile workstation</i>
	7. Balanced workstations	<i>One must focus on the optimisation of the workflow and not on the production capacity of a particular machine or operator. In our case study the subcontractor supervisor insisted on assigning tasks outside of the cell environment to electrical and piping operators as a way to keep them busy.</i>
	8. Small cell size:	<i>Our cell had 5 workers and usually their operations were limited to a 10 m radius</i>
	9. Cross training and job rotation:	<i>It is probably the hardest part because it involves changes in the way people’s productivity is assessed. We achieved only slight job-rotation on small tasks.</i>
	10. Juxtaposition of sequentially related equipment:	<i>see mobile workstation</i>
	11. Miniaturisation of “monument” processes:	<i>Integrating various equipment in one is a useful alternative for enabling higher mobility. We did not attempt that but, in certain way, the mobile material/tool cart has enabled the reduction of the workstation size and, therefore, increasing setup speed.</i>
	12. Equipment that can be moved as cell needs change:	<i>see mobile workstation</i>
	13. Preventive maintenance policies	<i>The company had a policy of employing a separate team for maintenance, which is against TPM practices found in other sectors.</i>
	14. Operators skilled at preventive maintenance	<i>We did not get to the stage of implementing preventive maintenance but we perceived as necessary to achieve full results.</i>
	15. Common operator’s language:	<i>In our case they were all Brazilians.</i>
	16. Positive interpersonal relationships between operators:	<i>They were working together for about five years, which make our work much easier.</i>
	17. Operators continually share information:	<i>Their proximity within the cell enables this continuous exchange of ideas.</i>
	18. Operators skilled at teamwork	<i>This aspect need some improvement in our case study since there was some hierarchical barriers among workers.</i>
	19. Operators have visual access to all cell activities	<i>A careful workflow and visual control devices were key to implement this practice</i>
	20. Operators have “whole-task” understanding	<i>The training sessions plus the activities on site reduced their segmented view of the drywall process.</i>
	21. Management control systems that make information quickly available to operators:.	<i>Activity Based Costing helped the subcontractor to realise the actual costs of its operations. Last planner helped him to develop realistic plans.</i>
	22. Presence of feedback loops among cell stations and between cell and customers suppliers:	<i>The near absence of supplier and client involvement on the construction site did not allow this loop to happen.</i>
	23. Job designs and other policies that permit operators to take action in response to signals	<i>Labourers and drywall operators had little opportunity to contribute and participate in the cell implementation or take initiative on cell problems</i>
	24. Job designs and other policies that hold operators jointly accountable for results	<i>The payment system remained the same throughout the exploratory study and that did not allow the team to be jointly accountable for results.</i>
	25. Low noise environment	<i>The workflow has improved and its problems were quickly identified/corrected.</i>

Cycle time was reduced with the reduction on set-up time and improvements in the communication among the drywall team. In order to promote better communication they now have a walk-talk attached to the workstation. Furthermore, people working in different process stages were now working closer to each other and that was key factor to promote faster correction of errors.

Process charts developed for this study showed that, although cell manufacturing has a profound impact on process cycle time, the process sequence and the content of most operations showed in Figure 1, remain more or less the same. The poor level of drywall practices identified on site and presented in the previous section had a direct impact on the effectiveness of this cell manufacturing experiment. It become evident that rising the worker's competence on drywall practices and enabling them to have access to basic drywall production infrastructure is a necessary condition to successfully implement a "mobile cell" in construction.

CONCLUSION

Comparing the results of this case study with the classification proposed by Hyer and Brown, (1999) we understand that our cell got to the stage of a "latent physical cell". Indeed, it was characterised by spatial proximity, but with deficiencies in time and/or information linkages. There was practically no feedback loop with internal customers or with drywall suppliers and the balance and the practice of assigning tasks for electrical and piping operators outside of the cell environment did not induced efforts to balance workflow in time and space. Earlier decisions in the design (ex: level of process interdependency) and planning stage (ex: production batch size) had severe negative impact on the implementation of our mobile cell. Thus, future studies on this topic need to start right from the beginning of the project in order to prepare the field for this new production dynamics. Finally, our study indicated that mobile cell is feasible in construction and deserves further research and dissemination in industry. Mobile cells can definitely enable the integration of all lean construction ideas within a single environment and, thus, offer significant opportunities to academics and practitioners throughout the construction industry in the quest for waste reduction.

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BIBLIOGRAPHY

Burbidge, J. L. (1996) "*The first step in planning group technology*". International Journal of Production Economics, 43, pp. 261-266, 1996.

Formoso, C. T. and Santos, A. (2002) "An exploratory study of process transparency in construction sites" Journal of Construction Research, World Scientific Publishing Company, Vol. 3, No. 1, pp. 35/54.

- Greif, Michel. (1989) *“The Visual Factory: building participation through shared information”* Translation of L’usine s’affiche. Productivity Press.
- Hyer, N. L. and Brown, K. A. (1999) *“The discipline of reall cells”* Journal of Operations Management, Elsevier, 17, pp. 557-574.
- Lemer, Andrew C. *“Construction research for the 21st century”* Building Research and Information, E. & F.N. Spon, Volume 20, Number 1, 1992.
- Logendran, R. and Ko, C. S. (1997) *“Manufacturing Cell Formation in the Presence of Flexible Cell Locations and Material Transporters”* Computers Industrial Engineering. Vol. 33, No. 3-4, pp. 545-548.
- Rebentisch, E. S. and Ferreti, M. (1995) *“A knowledge asset-based view of technology transfer in international joint ventures”* Journal of Engineering Technology Management, 12, 1-25.
- Robson, C. (1993) *“Real world research : a resource for social scientists and practitioner”* Oxford: Blackwell.
- Santos, A. dos; Powell, J. and Hinks, J. (2001) *“Using Pattern-Matching for the International Benchmarking of production Practices”* Benchmarking An International Journal, MCB University Press.
- Santos, A. dos; Powell, J. A.; Sharp, J. and Formoso, C. T. (1998) *“The principle of transparency applied in the construction industry”* In: Sixth Conference on Lean Construction, Guarujá, Brazil.
- Santos, A., dos (1999). *“Application of flow principles in the production management of construction sites”* PhD Thesis. School of Construction and Property Management, University of Salford, England. 463 p. + app.
- Sarker, B. R. and Li, K. (1997) *“Simultaneous route selection and cell formation: a mixed-integer programming time-cost model”* Integrated Manufacturing Systems, MCB University Press, 8/6, pp. 374-377.
- Yang, J. and Deane, R. H. (1994) *“Strategic implications of manufacturing cell formation design”* Integrated Manufacturing Systems. MCB University Press, Vol. 5, No. 4/5, pp. 87-96.
- Yin, R. K. (1994) *“Case study research: design and methods”* Second edition. Applied Social Research Methods Series, Volume 5, Sage Publications.