rate. The use in construction started recently, with some works on its application in the development of the production system design, more specifically, the Phase Scheduling (Frandson et al. 2013; Linnik et al. 2013).

Frandson et al. (2013) define Takt time as the "unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand rate)". The main aim of the TTP is to design the production system for continuous workflow, keeping the trades in a balanced pace of work (that match the demand rate) through a sequence of zones (Frandson et al. 2013).

The zones are "physical and clearly defined locations" to avoid ambiguity about location boundaries, the same as in the Line of Balance (Frandson et al. 2015). In a production plan devised using the TTP method, the trades must complete their work in the assigned zone in an amount of time set by the takt time (Frandson et al. 2015).

To develop a production plan using TTP, it is necessary to define zones and takt time, the trades sequence and duration, and balance their workflow (Frandson et al. 2013). All these steps are devised with the participation of trades and general contractor in an iterative fashion, and decision are made collaboratively by communicating and exploring production systems alternatives (Frandson et al. 2015).

2.6 Discussion about Location-based Planning Tools for Construction

When comparing the three methods for construction planning, all have a number of similarities: they aim for continuous workflow and for setting a unique production rate for activities in order to reduce the WIP. However, as visual tools, they have different graphical representation of construction activities (see Figure 2).

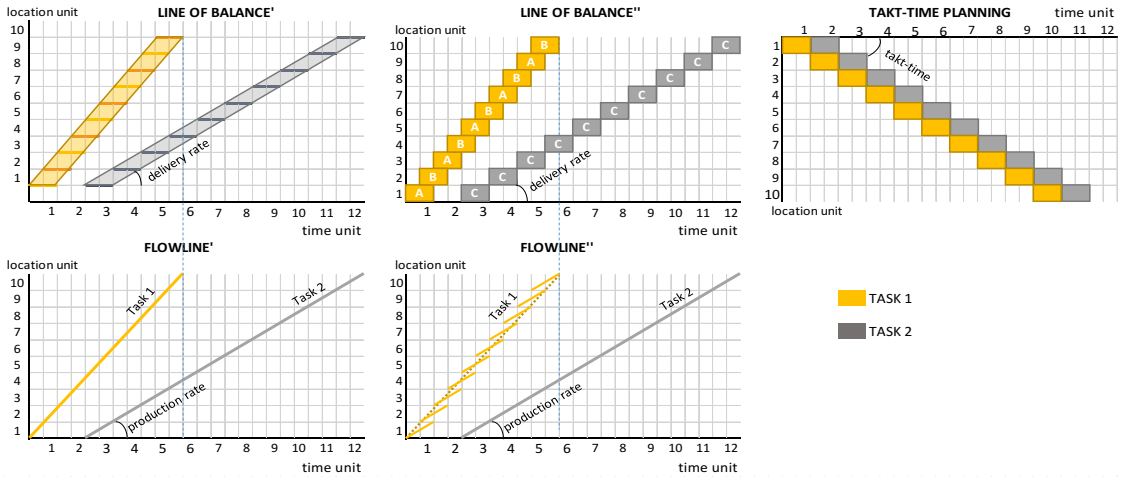

Figure 2: Different construction planning techniques based on location.

In the LOB method, workflow is visualized by dual parallel lines that represent an activity. The crews' workflow became clear in the current LOB, by using boxes with the name of the crew. In turn the flowline represents an activity by a single line starting in the beginning of first day and finishing at the end of the last day.

In relation to the lines/boxes slope, Su and Lucko (2015) point out that the line of balance presents the delivery rate, whilst the flowline shows the production rate. The difference between them are: the delivery rate starts counting after the first unit completion, whilst the production rate starts counting from the beginning of activity execution (Su and Lucko 2015). In TTP, the boxes slope represents the takt-time, or customer demand rate, or phase demand rate when applied in the phase scheduling.

Buffers are used in different ways: the LOB uses time buffers between critical activities,

as well as the flowline. Further, the TTP incorporates buffers in the crew's production capacity (i.e., the activity cycle time is shorter than the takt time) (Frandson et al. 2015). Although Frandson et al. (2015) expose that LOB uses buffers only between activities, Valente et al. (2014) used buffers inside the crew's production capacity, yet, not balancing the workers operational time. A comparison is presented in Table 1.

Table 1: Comparison among the lean tools for construction planning.

	Line of Balance	Flowline	Takt-time Planning
Crews' workflow visualization	Formerly: No Currently: Yes	Depends on the level of plan detail	Partial (crews can work in two locations at the same time, or executing work backlog)
Task visualization	Formerly: two parallel lines; Currently: boxes	One line	Boxes
Task duration per location	Location quantities divided by standard crew's productivity	Location quantities divided by standard crew's productivity	Equal to takt-time or shorter
Tasks representation	Formerly: Start and finish dates of first and last units; Currently: start and finish dates by unit	Start date of the first unit and finish date of the last unit	Start and finish dates per unit
Use of buffers	Buffers inside the work package duration; Buffers between critical activities	Buffers between activities	Buffers inside the work package duration: difference between takt-time and cycle time
Pace achievement (balancing the lines)	Adding or reducing the number of crews to execute an activity; Changing the crews' composition and amount of service inside the work package	Changing the crews' composition	Changing the crews' composition and amount of services inside the work package; Distributing the workload among crew's members; workable backlogs
Slope of line represents	Delivery pace	Production pace	Takt-time: available production time divided by demand
Level of detail of plan	Flexible	Flexible	High
Collaboration	Varies according to the level of plan	Varies according to the level of plan	Highly necessary

Project uncertainties also influence the way these methods are implemented. In low complexity projects, or in projects with known partnerships, the uncertainty is lower and the interdependencies are known. In this scenario, buffers between activities can be reduced, and TTP can be applied. However, in scenarios where the project has high uncertainty, it is recommended to protect the production from cascading delays, that could be avoided by allocating buffers between activities, such as the LOB and Flowline do it.

3 Conclusions

In this paper, the authors compared the lean construction activities to design a production system, and the mainly location-based tools to represent the work structured. It became clear that the WS is the design of construction processes which can be used by both PSD and PS. The level of detail of the WS varies according to the information availability whether the moment of decision making.

Comparing the three location-based methods, it was found that the line of balance and flowline are very similar tools, and both evolved in construction, becoming flexible to be applied in any level of uncertainty of work structuring. Both protect the production system against variability and delays through the allocation of buffers between activities. Both methods try to achieve the same production rate, however, without forcing it, as the Takt-time planning does. The latter is the most recent method applied in construction and it requires more work backlog in order to avoid the crews' idleness or demobilisation. Crews must work in the same pace or shorter than the takt-time. No buffers are allocated between activities, which increases the risk of cascading delays in projects with high level of uncertainty. It has been used in phase scheduling, and collaborative participation of contractors to develop it is necessary.

A final summary of these comparisons is presented in Figure 3, where the location-based tools are positioned according to their potential use in production system managerial activities. Differences among the tools were identified for lean construction practitioners to be able to choose the most suitable one according to the project context. The results will be used in an ongoing research about integrating the design and construction planning and control system in projects with overlap between these stages.

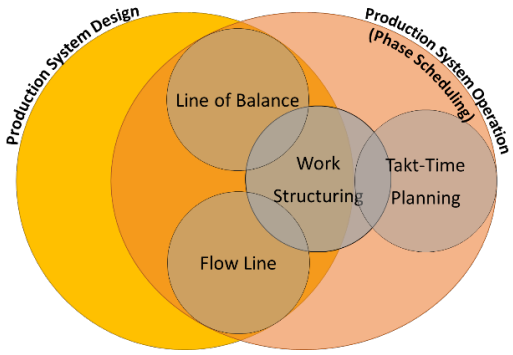

Figure 3: Position of lean tools in relation to planning activities in lean construction management.

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