CONCEPTUAL FOUNDATIONS FOR A NEW LEAN BIM-BASED PRODUCTION SYSTEM IN CONSTRUCTION

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Production Systems in Construction

What is a production system in construction?

“A framework of **methods** and **tools** to manage **construction processes** according to the three target variables **quality**, **time** and **costs**.”  
(Borrmann et al, 2018)
Motivation

Productivity has been particularly poor in the construction industry

Output per hour worked (Q1 1997 = 100)

- Construction of buildings
- Whole economy

© FT

Source: Financial times
Lean Construction

The Optimist

THE GLASS IS HALF FULL.
Lean Construction
Lean Construction

Everything that is **not needed** is waste

BIM can help to define what **is needed**
Building Information Modeling (BIM)

**CAD DRAWING**
- Technical image

**CAD 3D**
- Virtual image

**BIM Object**
- Name: Lego
- Type: Block
- Cost: 0.02 €
- N.: 123_AK_34_9K
- Date: 16-04-2016
- Validation: Yes
- Material: Plastic

**ENTITY IfcDoor**
SUPERTYPE OF (IfcDoorStandardCase)
SUBTYPE OF (IfcBuildingElement);
  OverallHeight: OPTIONAL IfcPositiveLengthMeasure;
  OverallWidth: OPTIONAL IfcPositiveLengthMeasure;
END_ENTITY;
**Goal:** Shifting production system design efforts towards the digital prototype

- Integration of **BiM** and **Lean** on data processing level
- Storing Last Planner System (LPS) process information in the IFC file format
- Conceptualizing a new lean BIM-based production system:
Goal: Shifting production system design efforts towards the digital prototype

- Integration of BiM and Lean on data processing level
- Storing Last Planner System (LPS) process information in the IFC file format
- Conceptualizing a new lean BIM-based production system:
Research question & hypothesis

How to use BIM to standardize lean production systems in construction execution?

Borrmann et al. (2018); Ratajczak et al. (2018)

- Poor productivity
- One-of-a-kind character
- Difficult to standardize production systems

Binninger et al. (2018); Kenley (2005); Koskela (2000)

- BIM is getting more and more important
- Lean Construction is a good idea to stabilize workflows

Rossini et al. (2017); Won and Lee (2016)

- BIM & Lean have positive synergies

Dave et al. (2013); Khan and Tzortzopoulos (2014); Sacks et al. (2010b; a)

- How to use BIM to standardize lean production systems in construction execution?

Making LPS routines BIM-based through linkage on data processing level
Research Methodology

**Secondary analysis**
- Systematic literature review

**Problem statement**
- Lack of standardized production systems

**Suggesting solution**
- BIM-LPS integration on data processing level

**Developing solution**
- Theoretical integration model
- Methodology for application in practice
- Requirement analysis for implementation
- Software prototyping

**Evaluation**
- Pilot construction sites
Preliminary literature findings - Shortcomings

Frameworks of co-applications (Guerriero et al. (2017); Scheer et al. (2014))

1. Adding aspects of Scrum
2. Adding aspects of (digital) Kanban
3. Adding aspects of Earned Value Management

Partial implementation of LPS steps (Bhatla and Leite (2012); Gerber et al. (2010))

1. Clear roles (Dave et al. 2015)
2. Visualisation, Pull-System, Digitize! (Mossman 2015; Rybkowski 2010)
3. Cost control (Novinsky et al. 2018; Zhang et al. 2018)
The **BeaM!** process from LPS perspective
Concrete Slab
Shell workers
1st Floor
200 m³
4 weeks
25,000

Digital Process Kanban (DPK)
DPK – Network View
6 week look-ahead-window
Designing Operations

**Concrete Slab**
- **Trade:** Shell workers
- **Location:** 1st Floor
- **Quantity:** 200 m³
- **Duration:** 4 weeks
- **BCWS [€]:** 25,000
Creating Digital Operation Kanban (DOK)

<table>
<thead>
<tr>
<th>Concrete Slab</th>
<th>Total BCWS [€]</th>
<th>Total Process Duration [d]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25,000</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Activity</th>
<th># Workers</th>
<th>Quantities</th>
<th>Share of BCWS [%]</th>
<th>Operation Duration [d]</th>
<th>Constraints</th>
<th>Create DOK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Formwork</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Service Installation</td>
<td></td>
<td>+ 30 m²</td>
<td>+ 10</td>
<td>+ 5</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Reinforcement Placement</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Concrete Pouring</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Formwork Removal</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

BeaM!
Digital Operation Kanban (DOK)

BeaM!

5 days
2 workers
Floor 1
30 m²
DOK – Network View

Warning when Critical Path duration of DOK exceeds DPK duration

DO = Depends On
FB = Followed By

Duration (Critical Path, DOK) = 19 days
DPK + DOK – Gantt View

Master Schedule
Phase Planning
Lookahead Planning
Commitment Planning
Monitoring & Learning

Process-ID: 01
Process-ID: 02
Process-ID: 03
Process-ID: 04
Process-ID: 05
Process-ID: 06
Process-ID: 07
Process-ID: 08

Today
In 1 week
1 week
look-ahead-window
Construction Formwork
Service Installation
Reinforcement preparation
Reinforcement placement
Concrete Pour
Formw. Rem.

DOK – Gantt View

Master Schedule
Phase Planning
Lookahead Planning
Commitment Planning
Monitoring & Learning
**DOK – Gantt View**

**OPERATION-ID: 01.02**

- **SERVICE INSTALLATION**
  - **CONTRANTS**
  - **Committed as planned?**

**Phase Planning**
- Construction Formwork
- Service Installation
- Reinforcement preparation
- Reinforcement placement
- Concr. Pour.
- Formw. Rem.

**Master Schedule**
- Process Start
- Process Finish
- W1
- W2
- W3
- W4

**Constraint**
- W1
- W2
- W3
- W4
DOK – Gantt View
<table>
<thead>
<tr>
<th></th>
<th>MO</th>
<th>TU</th>
<th>WE</th>
<th>TH</th>
<th>FR</th>
</tr>
</thead>
<tbody>
<tr>
<td>SERVICE INSTALLATION</td>
<td>REINFORCEMENT PREP.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SERVICE INSTALLATION – W2 - MO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># Workers</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantities</td>
<td>5 m²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spent hours</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

**Weekly Work Plan (WWP)**
Construction Formwork
Service Installation
Reinforcement preparation

W1
W2
W3
W4

Process Start

Process Finish

SERVICE INSTALLATION

Done as committed? Yes No

Reason for Non-Completion

WWP Monitoring

Master Schedule
Phased Planning
Lookahead Planning
Commitment Planning
Monitoring & Learning
KPIs

- LPS metrics (PPC, TMR, TA)
- EVM metrics (EV, AC, PV)
KPIs

- LPS metrics (PPC, TMR, TA)
- EVM metrics (EV, AC, PV)
- Kanban metrics (CT, LT)
KPIs

- LPS metrics (PPC, TMR, TA)
- EVM metrics (EV, AC, PV)
- Kanban metrics (CT, LT)
Preliminary Results

- Database schema
Preliminary Results

- **Database schema**
- **Integration model**

<table>
<thead>
<tr>
<th>Step</th>
<th>Phase scheduling steps 1-6 by Ballard (2000b)</th>
<th>Digital Kanban-Board functionality</th>
<th>BIM: IFC manipulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Have master schedule as starting point and identify milestones</td>
<td>Select BIM-Objects in IFC Viewer and press &quot;create Milestone&quot; button</td>
<td>Instantiate IfcTask object and set boolean IsMilestone to true</td>
</tr>
<tr>
<td>1</td>
<td>&quot;Define the work to be included in the phase; e.g., foundations, building skin, etc.&quot;</td>
<td>Select BIM objects in IFC Viewer and press &quot;create Digital Process Kanban Button&quot; OR create corresponding Digital Process Kanban on mobile device and send it to BIM-Board and then link to BIM objects</td>
<td>Kanban trigger instantiation of IfcTask objects which are linked to selected BIM objects (IfcElements) through IfcRelAssignsToProduct objects</td>
</tr>
<tr>
<td>2</td>
<td>&quot;Determine the completion date for the phase, plus any major interim releases from prior phases or to subsequent phases.&quot;</td>
<td>Click on respective milestone and set finish date</td>
<td>Set attribute LateFinish of Type IfcDateTime in entity IfcTaskTime and relate to milestone IfcTask objects in step 0</td>
</tr>
<tr>
<td>3</td>
<td>&quot;Using team scheduling and stickies on a wall, develop the network of activities required to complete the phase, working backwards from the completion date, and incorporating any interim milestones.&quot;</td>
<td>Arrangement of Kanban via touch control on BIM-Board defines dependencies</td>
<td>Manipulate the IsSuccessorFrom and IsPredecessorOf attributes of IfcTask objects defined in step 1</td>
</tr>
<tr>
<td>4</td>
<td>&quot;Apply durations to each activity, with no contingency or float in the duration estimates&quot;</td>
<td>Click on respective Kanban and set duration</td>
<td>Assign duration through type IfcDuration and relate to IfcTask objects defined in step 1</td>
</tr>
<tr>
<td>5</td>
<td>&quot;Reexamine logic to try to shorten the duration.&quot;</td>
<td>Collaborative re-arrangement of Kanban via touch control on BIM-Board</td>
<td>Update of dependencies in IfcTask objects defined in step 1 according to re-arrangement</td>
</tr>
<tr>
<td>6</td>
<td>&quot;Determine the earliest practical start date for the phase&quot;</td>
<td>Click on first Digital Process Kanban of the phase and set start date</td>
<td>Set attribute EarlyStart of Type IfcDateTime in entity IfcTaskTime and relate to first arranged IfcTask object in step 5</td>
</tr>
</tbody>
</table>
Preliminary Results

- Database schema
- Integration model
- IT architecture
Next Steps

- Concluding requirement analysis for implementation
- Prototypical software implementation
- Definition of use case scenarios
- Piloting
- Evaluation according DSR
- Answering research question
THANK YOU FOR YOUR ATTENTION
References


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