Simulation of movements on construction sites.

An explorative study on the influence of 4D-BIM simulation of construction workers movements on construction sites to workhours and labour productivity.
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P5 Presentation

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I Introduction
II Theoretical background
III Implementing Dynamo
IV Simulations
V Behind Dynamo
VI Verification
VII Discussion & Conclusion
Introduction
• BIM
  • Not used to full potential

• Labour productivity
  • Relatively low
To what extent does the modelling of labour and movement of workforce into a 4D building information model have the ability to give insight into and indicate potentials to increase the labour productivity on construction sites.
1) Which definition and aspects of productivity to be used?
2) Which data is needed from all parties to be integrated into a 4D Building Information Model?
3) How to accurately model the data into a 4D Building Information Model with labour and movements of workforce?
4) What are the possibilities of visualising the data into a 4D Building Information Model with labour and movements of workforce?
5) How to model interventions into a 4D Building Information Model with labour and movements of workforce?
6) What is the simulated change in productivity?
7) Can this simulated change in productivity be proved by the physical project?
Theoretical background
• Basis of 4D BIM
  • Relation between 3D and schedule
  • Benefits in
    • Visualisation
    • Multiple stakeholder impact
    • Site logistics
    • Coordinate trades
    • Compare schedules
Choice of Dynamo
• Path analysis
  • Actors
  • Starting point
  • Destination
  • Path
  • Means of transport
  • Activities
• Walk
  • Horizontal working
  • Vertical walking by stairs
  • Vertical walking by elevator
• Wait
• Work
Theoretical background – labour productivity

\[
\text{labour productivity} = \frac{\text{input}}{\text{output}} = \frac{\text{total working time}}{\text{productive time}}
\]
## Theoretical Background

### Unproductive (58.2%)

<table>
<thead>
<tr>
<th>Category</th>
<th>Time (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Muda 1</strong></td>
<td>27.6%</td>
</tr>
<tr>
<td><strong>Muda 2</strong></td>
<td>30.6%</td>
</tr>
</tbody>
</table>

### Productive (41.8%)

- Charging batteries (2.0%)
- Handling/changing hand tools (3.1%)
- Transportation; moving equipment; walking; using vehicles (9.2%)
- Other waste; shovelling snow; removing tarps; stretching cords (7.1%)
- Change of tasks; start-up and clean-up (9.2%)

- Morning coffee break (4.1%)
- Locating tools/ladders (3.1%)
- Locating materials (4.1%)
- Restroom visits (4.1%)
- Waiting for instructions or materials (9.2%)
- Travel from and to lunch (3.1%)
### Theoretical Background

**Labour Productivity**

<table>
<thead>
<tr>
<th>Working time</th>
<th>62,3 - 70,4%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productive (47,0%)</td>
<td></td>
</tr>
<tr>
<td>General instructions (4,2%)</td>
<td></td>
</tr>
<tr>
<td>Others (3,5%)</td>
<td></td>
</tr>
<tr>
<td>Measuring (3,5%)</td>
<td></td>
</tr>
<tr>
<td>Cleaning (3,1%)</td>
<td></td>
</tr>
<tr>
<td>Personal needs (0,6%)</td>
<td></td>
</tr>
<tr>
<td>Rework (0,4%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Walking time</th>
<th>12,3 - 19,7%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transporting (13,7%)</td>
<td></td>
</tr>
<tr>
<td>Traveling (6,0%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Waiting time</th>
<th>17,4 - 17,8%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waiting (9%)</td>
<td></td>
</tr>
<tr>
<td>Idle time (6,8%)</td>
<td></td>
</tr>
<tr>
<td>Resting (2,0%)</td>
<td></td>
</tr>
</tbody>
</table>

---

<table>
<thead>
<tr>
<th>Activities</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charging batteries</td>
<td>2,0%</td>
</tr>
<tr>
<td>Handeling/Changing hand tools</td>
<td>3,1%</td>
</tr>
<tr>
<td>Other waste; shovelling snow; removing tarps; streching cords</td>
<td>7,1%</td>
</tr>
<tr>
<td>Change of tasks; start-up and clean-up</td>
<td>9,2%</td>
</tr>
<tr>
<td>Locating tools/ladders</td>
<td>3,1%</td>
</tr>
<tr>
<td>Locating materials</td>
<td>4,1%</td>
</tr>
<tr>
<td>Transportation; moving equipment; walking; using vehicles</td>
<td>9,2%</td>
</tr>
<tr>
<td>Travel from and to lunch</td>
<td>3,1%</td>
</tr>
<tr>
<td>Morning coffee break</td>
<td>4,1%</td>
</tr>
<tr>
<td>Restroom visits</td>
<td>4,1%</td>
</tr>
<tr>
<td>Waiting for instructions or materials</td>
<td>9,2%</td>
</tr>
</tbody>
</table>

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*Alarcon (1997)*

*El Asmar (2012)*
Implementing Dynamo
implementing dynamo - backbone
implementing dynamo – dynamo workspace
Simulations
• Hotel rooms on all levels
• Working time
• Waiting time
• Walking time
• Typical workday
<table>
<thead>
<tr>
<th>Simulation 0</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation 1</td>
<td>Intervention 1: Extra elevator</td>
</tr>
<tr>
<td>Simulation 2</td>
<td>Intervention 2: Toilets on levels</td>
</tr>
<tr>
<td>Simulation 3</td>
<td>Intervention 3: Elevator to corner</td>
</tr>
<tr>
<td>Simulation 4</td>
<td>Intervention 4: Elevator near work</td>
</tr>
</tbody>
</table>
simulations – visualisation benchmark
## Simulation 0: Benchmark

<table>
<thead>
<tr>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
<th>Level 5</th>
<th>Level 6</th>
<th>Level 7</th>
<th>Level 8</th>
<th>Level 9</th>
<th>Level 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:13:55</td>
<td>0:13:55</td>
<td>0:13:56</td>
<td>0:16:30</td>
<td>0:18:35</td>
<td>0:20:40</td>
<td>0:22:45</td>
<td>0:24:50</td>
<td>0:26:55</td>
</tr>
<tr>
<td>0:06:26</td>
<td>0:06:51</td>
<td>0:07:16</td>
<td>0:15:52</td>
<td>0:17:31</td>
<td>0:19:52</td>
<td>0:22:52</td>
<td>0:24:52</td>
<td>0:26:52</td>
</tr>
<tr>
<td>0:03:03</td>
<td>0:04:23</td>
<td>0:05:43</td>
<td>2:27:48</td>
<td>2:27:48</td>
<td>2:27:48</td>
<td>3:07:00</td>
<td>3:07:00</td>
<td>3:07:00</td>
</tr>
</tbody>
</table>

- **City-Block Time (calculation)** [hh:mm:ss]
- **Vertical Time (elevator)** [hh:mm:ss]
- **Vertical Time (stairs)** [hh:mm:ss]
- **Waiting time (total)** [hh:mm:ss]
- **Working time (total)** [hh:mm:ss]
- **Total time** [hh:mm:ss]

---

**Legend:**
- Blue: City-Block Time (calculation) [hh:mm:ss]
- Dark Green: Vertical Time (elevator) [hh:mm:ss]
- Red: Vertical Time (stairs) [hh:mm:ss]
- Orange: Waiting time (total) [hh:mm:ss]
- Black: Working time (total) [hh:mm:ss]
- Green: Total time [hh:mm:ss]
Simulated productivity Benchmark

<table>
<thead>
<tr>
<th>Level</th>
<th>Total</th>
<th>Crew 1</th>
<th>Crew 2</th>
<th>Crew 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 2</td>
<td>69.99%</td>
<td>57.37%</td>
<td>39.75%</td>
<td>24.64%</td>
</tr>
<tr>
<td>Level 3</td>
<td>69.78%</td>
<td>57.12%</td>
<td>39.50%</td>
<td>24.45%</td>
</tr>
<tr>
<td>Level 4</td>
<td>69.56%</td>
<td>56.87%</td>
<td>39.26%</td>
<td>24.27%</td>
</tr>
<tr>
<td>Level 5</td>
<td>64.75%</td>
<td>51.46%</td>
<td>34.19%</td>
<td>20.48%</td>
</tr>
<tr>
<td>Level 6</td>
<td>64.54%</td>
<td>51.22%</td>
<td>33.98%</td>
<td>20.33%</td>
</tr>
<tr>
<td>Level 7</td>
<td>64.32%</td>
<td>50.98%</td>
<td>33.77%</td>
<td>20.17%</td>
</tr>
<tr>
<td>Level 8</td>
<td>64.10%</td>
<td>50.75%</td>
<td>33.56%</td>
<td>20.02%</td>
</tr>
<tr>
<td>Level 9</td>
<td>63.89%</td>
<td>50.51%</td>
<td>33.35%</td>
<td>19.87%</td>
</tr>
<tr>
<td>Level 10</td>
<td>63.68%</td>
<td>50.28%</td>
<td>33.15%</td>
<td>19.73%</td>
</tr>
</tbody>
</table>
• Crews

<table>
<thead>
<tr>
<th>Total man-hour per room per step for all crews</th>
<th>Total man-hour per room per crew</th>
</tr>
</thead>
<tbody>
<tr>
<td>Studs</td>
<td>Crew 1</td>
</tr>
<tr>
<td>2.5211 man-hour per room</td>
<td>Studs; backer board; doorframes; sheeting one side.</td>
</tr>
<tr>
<td>Insulation</td>
<td>Crew 2</td>
</tr>
<tr>
<td>0.2184 man-hour per room</td>
<td>Insulation; receptacles; holes; sheeting second side.</td>
</tr>
<tr>
<td>Drywall</td>
<td>Crew 3</td>
</tr>
<tr>
<td>1.9079 man-hour per room</td>
<td>Finishing.</td>
</tr>
<tr>
<td>Finishing</td>
<td>0.9331 man-hour per room</td>
</tr>
<tr>
<td>Additional factors</td>
<td>1.0750 man-hour per room</td>
</tr>
<tr>
<td>Total</td>
<td>6.656 man-hour per room</td>
</tr>
<tr>
<td></td>
<td>3.840 man-hour per room</td>
</tr>
<tr>
<td></td>
<td>1.882 man-hour per room</td>
</tr>
<tr>
<td></td>
<td>0.933 man-hour per room</td>
</tr>
</tbody>
</table>
Average times of categories per intervention

- City-Block Time (calculation)
- Vertical Time (elevator)
- Vertical Time (stairs)
- Waiting time (total)
- Working time (total)
- Walking time
- Walking and waiting time
- Total time

Interventions:
- Intervention 1: Extra elevator
- Intervention 2: Toilets on levels
- Intervention 3: Elevator to corner
- Intervention 4: Elevator near work
Intervention 1: Double lift capacity

Intervention 2: Toilets on workfloor

Intervention 3: Placing elevator and stairs more towards main entrance

Intervention 4: Placing elevator near workspaces
Vertical time by stairs

- **Level 4**
  - Intervention 4: Placing elevator near workspaces, 0:03:03
  - Intervention 3: Placing elevator and stairs more towards main entrance, 0:04:23
  - Intervention 2: Toilets on workfloor, 0:05:43
  - Benchmark, 0:05:43

- **Level 3**
  - Intervention 4: Placing elevator near workspaces, 0:02:52
  - Intervention 3: Placing elevator and stairs more towards main entrance, 0:04:23
  - Intervention 2: Toilets on workfloor, 0:04:23
  - Benchmark, 0:04:23

- **Level 2**
  - Intervention 4: Placing elevator near workspaces, 0:01:32
  - Intervention 3: Placing elevator and stairs more towards main entrance, 0:03:03
  - Intervention 2: Toilets on workfloor, 0:03:03
  - Benchmark, 0:03:03

Legend:
- Intervention 4: Placing elevator near workspaces
- Intervention 3: Placing elevator and stairs more towards main entrance
- Intervention 2: Toilets on workfloor
- Benchmark
Vertical time by elevator

Intervention 4: Placing elevator near workspaces
Intervention 3: Placing elevator and stairs more towards main entrance
Intervention 2: Toilets on workfloor
Intervention 1: Double lift capacity
Benchmark
Vertical time by elevator

Level 10
Level 9
Level 8
Level 7
Level 6
Level 5
Level 4
Level 3
Level 2

Intervention 4: Placing elevator near workspaces
Intervention 3: Placing elevator and stairs more towards main entrance
Intervention 2: Toilets on workfloor
Intervention 1: Double lift capacity
Benchmark
<table>
<thead>
<tr>
<th>Level</th>
<th>Intervention 1: Double lift capacity</th>
<th>Intervention 2: Toilets on workfloor</th>
<th>Intervention 3: Placing elevator and stairs more towards main entrance</th>
<th>Intervention 4: Placing elevator near workspaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 10</td>
<td>2:27:48</td>
<td>2:37:30</td>
<td>3:07:00</td>
<td>3:07:00</td>
</tr>
<tr>
<td>Level 9</td>
<td>2:27:48</td>
<td>2:37:30</td>
<td>3:07:00</td>
<td>3:07:00</td>
</tr>
<tr>
<td>Level 8</td>
<td>2:27:48</td>
<td>2:37:30</td>
<td>3:07:00</td>
<td>3:07:00</td>
</tr>
<tr>
<td>Level 7</td>
<td>2:27:48</td>
<td>2:37:30</td>
<td>3:07:00</td>
<td>3:07:00</td>
</tr>
<tr>
<td>Level 6</td>
<td>2:27:48</td>
<td>2:37:30</td>
<td>3:07:00</td>
<td>3:07:00</td>
</tr>
<tr>
<td>Level 5</td>
<td>2:27:48</td>
<td>2:37:30</td>
<td>3:07:00</td>
<td>3:07:00</td>
</tr>
<tr>
<td>Level 4</td>
<td>2:13:48</td>
<td>2:21:54</td>
<td>2:37:30</td>
<td>3:07:00</td>
</tr>
<tr>
<td>Level 3</td>
<td>2:13:48</td>
<td>2:21:54</td>
<td>2:37:30</td>
<td>3:07:00</td>
</tr>
<tr>
<td>Level 2</td>
<td>2:13:48</td>
<td>2:21:54</td>
<td>2:37:30</td>
<td>3:07:00</td>
</tr>
</tbody>
</table>
Total traveling time

- **Intervention 4:** Placing elevator near workspaces
- **Intervention 3:** Placing elevator and stairs more towards main entrance
- **Intervention 2:** Toilets on workfloor
- **Intervention 1:** Double lift capacity
- **Benchmark**
Average productivity per simulation

<table>
<thead>
<tr>
<th>Productivity Benchmark</th>
<th>Productivity Intervention 1</th>
<th>Productivity Intervention 2</th>
<th>Productivity Intervention 3</th>
<th>Productivity Intervention 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average</strong></td>
<td>60.0%</td>
<td>68.44%</td>
<td>69.86%</td>
<td>65.96%</td>
</tr>
<tr>
<td><strong>Crew 1</strong></td>
<td>52.95%</td>
<td>55.60%</td>
<td>57.28%</td>
<td>52.83%</td>
</tr>
<tr>
<td><strong>Crew 2</strong></td>
<td>21.11%</td>
<td>23.35%</td>
<td>23.92%</td>
<td>21.55%</td>
</tr>
<tr>
<td><strong>Crew 3</strong></td>
<td>23.55%</td>
<td>23.35%</td>
<td>23.55%</td>
<td>23.55%</td>
</tr>
<tr>
<td><strong>Alarcon</strong></td>
<td>35.61%</td>
<td>38.05%</td>
<td>39.63%</td>
<td>35.50%</td>
</tr>
<tr>
<td><strong>El Asmar</strong></td>
<td>35.61%</td>
<td>38.05%</td>
<td>39.63%</td>
<td>35.50%</td>
</tr>
</tbody>
</table>
Intervention 4 vs Benchmark

Intervention 3 vs Benchmark

Intervention 2 vs Benchmark

Intervention 1 vs Benchmark

Average difference between interventions and benchmark

Crew 3 (difference)  Crew 2 (difference)  Crew 1 (difference)  Total time (difference)
Behind Dynamo
• Preparing Revit
  • Rooms
  • Site lay-out
  • Working and waiting time
• Typical workday
  • Interview with dry-wall contractor
• Walking speed
  • Horizontal
  • Vertical by stair
• Waiting time
  • Waiting time of elevator
  • Vertical by elevator
• Working time
  • Norms
Verification
• Two sessions
  • BIM-employees of Dura Vermeer
  • Construction team of Dura Vermeer and BIM-consultant
- Problem in decision making
- Introduction of simulations in construction process
- Different building phases
- Dependencies on site and with schedule
- Project size and shape
- Waiting times
- Difference in construction workers
• Traditional projects
• Work productive for entire day
• Discussion
  • Model
    • Typical workday
    • Elevator
    • Waiting time
    • Walking lines
    • Necessity of working time
• Discussion
  • Productivity
    • Ratio between walking, waiting and working
    • Smart construction logistics
    • Different crews
1. Which definition and aspects of productivity to be used?

<table>
<thead>
<tr>
<th>Labour productivity</th>
<th>Input</th>
<th>Total working time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>output</td>
<td>Productive time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Working time</th>
<th>62.3%</th>
<th>70.4%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waiting time</td>
<td>17.8%</td>
<td>17.4%</td>
</tr>
<tr>
<td>Walking time</td>
<td>19.7%</td>
<td>12.3%</td>
</tr>
</tbody>
</table>

2. Which data is needed from all parties to be integrated into a 4D Building Information Model?

- Construction site lay-out
- Walking
- Waiting
- Working
- Typical workday
3. How to accurately model the data into a 4D Building Information Model with labour and movements of workforce?

- Walking
- Waiting
- Working
4. What are the possibilities of visualizing the data into a 4D Building Information Model with labour and movements of workforce?

- Walking lines
- Waiting and Working times
5. How to model interventions into a 4D Building Information Model with labour and movements of workforce?

- Waiting times
- Typical workday
- Site lay-out
6. What is the simulated change in productivity?
7. Can this simulated change in productivity be proved by the physical project?
To what extent does the modelling of labour and movement of workforce into a 4D building information model have the ability to give insight into and indicate potentials to increase the labour productivity on construction sites.

- Quite a big extent
- First step
• Ratio working, walking, waiting
• Multiple actors
• Building shape
• Order of construction
• Refinement of model
  • Visualisation of walking line and waiting times
  • Horizontal walking lines
  • Waiting time elevator