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Open BIM based Automation and Robotics for Infrastructure Construction

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Speaker: Rauno Heikkilä

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- Professor, Docent, Dr. Tech, Digitalized Construction and Mining Operations
- Major research interests cover information modelling (BIM in construction, MIM in mining) automation and robotics in the construction of roads, railways, fairways, bridges and buildings as well as in mining
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CIV - Key Research Projects

- **Autonomous Low-Emission Swarm of Infra Construction Machinery**, Total costs 5 MEUR, University of Oulu part 1.5 MEUR, Funding Business Finland and Industry, 2022-2024.
- **Next Generation Mining**, Total costs 11.5 MEUR, University of Oulu part 1.5 MEUR, Funding Business Finland and Industry, 2021-2023.
- **Sustainable Digital Infra Construction**, Total costs 5 MEUR, University of Oulu part 1.8 MEUR, Funding Business Finland and Industry, 2021-2023.
- **Open Infra BIM Ecosystem for Global Markets**, Principal Investigator, Total costs 7 MEUR, University of Oulu part 1.7 MEUR, Funding Business Finland and Industry, 2019-2020.
- **Development of an Adaptive and Automated Control Method for Working Machines and Booms (Smart Booms II)**, Principal Investigator, Coordinator, Total costs 5.3 MEUR, University of Oulu part 1.7 MEUR, Funding Tekes and Industry, 2017-2018.
- **Arctic Development and Education Centre of Autonomous Working Machinery and Vehicles (Ouluzone+)**, Principal Investigator, Coordinator, Total costs 885 kEUR, Funding European Regional Development Fund (ERDF) and Industry, 2016-2019.
- **Global Export Potentials of Open Infrastructure BIM Concept – Case Vietnam (FIBEV)**, Principal Investigator, Total Costs 275 kEUR (University of Oulu), Funding Industry and Tekes, 2015-2017.
- **Built Environment Process Re-engineering (PRE)**, Infra FINBIM Work Packet, Bridge Automation – Development of Building Information Modeling (BIM) and Automation into Construction, Maintenance and Rehabilitation of Infra Products, i.e., Bridges, Roads and Railways, Principal Investigator, Total Costs 400 kEUR, Funding Industry and Tekes, 2010-2013.
Presentation Today

• Introduction to Open Infra Building Information Modeling – the standard and its benefits
• Smart Excavator case - Open BIM based Autonomous Excavator
• Autonomous Machine Swarm – State-of-the-Art, the next research project
• Suggestions for Earth and Lunar Construction Automation Research Collaboration
Open Infra BIM for Construction Automation and Robotics – the Intelligence

Traffic and vehicle control
- Initial data according to initial data model
- Present situation in an information model
- If needed, activation of maintenance works

Maintenance and renovation plan
- Infra design according to initial data model
- New infra information

Transfer of as-built data to maintenance
- Accurate 3-D coordinate system
- Ellipsoid
- Geodetic


Measured as-built data and other observations
- Needed data for machine control systems

Machine control and as-built measurements
- Production planning for infra construction works

Open Infra BIM for Construction Automation and Robotics – the Intelligence

YIV, Information Classification, Inframodel
- Production model
- Design model
- Maintenance model
- As-built model

Accurate 3-D coordinate system
- Ellipsoid
- Geodetic
Open Infra BIM, the Finnish Open Standard for Infra Industry

- The newest version updated based on previous years feedback
- Very widely in practical use in Finland
- Key elements of the concept
  - Accurate modelling guidelines
  - Accurate information classification
  - Open information transfer format (Inframodel)
  - 3-D Machine control systems
  - Open cloud service Infrakit
3-D Machine Control Systems

- Integrates Infra BIM (machine control model) to construction control
- Machine control model is processed from design model
- 3-D positioning for machine (blade) movements, RTK-GNSS or Robotic Total Station
- Movements of different joints and units are real-time calculated (inverse solution)
- Blade deviation from machine control model is real-time calculated and shown (automated guidance)
- Blade deviation is automatically corrected using suitable dynamics (automated control)
Machine Control Model

- Common InfraBIM Requirements YIV2019, Preparation Instructions for as-planned models of earth works (machine control models)
  - Content of machine control model
  - Modelled terrain break lines
  - Naming and coding of terrain break lines and surfaces
  - Continuity of terrain break lines and surfaces
  - Geometric accuracy of terrain break material
  - Regularity of triangulation network
  - Checking of models, model report, naming of as-planned model files, data exchange format
Grashopper - Importing Machine Control Model from an InfraModel File
Grashopper Code for Excavator Control
Commercial Example - Novatron Vision 3D System

- Novatron Oy, a machine control systems provider, a Finnish company located in Tampere, Finland
- Easy and quick installation both to old and new machines
- Novatron provides machine control systems for earthmoving machines: Xsite® control systems and related software solutions and services
- Intelligent 3D solutions enable model-based construction process (Open Infra BIM) and increase the productivity of the earthmoving industry
Commercial example: Remote Control of Working Machinery (Obayashi, Japan)
Remote control system for excavators

Human operator operates the machine remotely

Human robot real-time repeats joystick movements in the excavator's cab

No machine control model implementation yet done

Used through rental services for years in Japan

Commercial Example: Doka Robo, Kanamoto, Japan
Research Example: Remote Control using Drone’s Eye (PWRI, Japan)
Real-Time Site Control – Infrakit Cloud Service
Infracit – Real-Time Open Cloud for Infra Projects
Highway Design and Construction project Vt4 Kirri-Tikkakoski 2021 – a BIM model View in Infrakit Cloud Service (Destia Oy)
Highway Design and Construction project Vt4 Kirri-Tikkakoski 2021 – Infrakit Cross-section showing real-time quality deviations (green points inside tolerances, red points outside tolerances).
The Benefits of Open Infra BIM – Finland Experience

  - In the later third project (2019-2022), the realized reduction in construction time was about eight months in the end of 2021
  - The rapid progress of the work was due to new ways of working in design, construction and quality control
  - The time saving in design was about 20-22 weeks
  - All the machines were equipped with automatic machine control systems
  - Real-time quality control was seen to being preventing potential faults at an early stage during construction

Levels of Automation for Infra Construction Machinery

<table>
<thead>
<tr>
<th>Level</th>
<th>Name</th>
<th>Description of the activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No automation</td>
<td>Human operates machine</td>
</tr>
<tr>
<td>1</td>
<td>Remote control</td>
<td>Human operates remotely machine</td>
</tr>
<tr>
<td>2</td>
<td>Guidance</td>
<td>Operator supported, the operator drives manually machine and blade using computer user-interface to BIM model</td>
</tr>
<tr>
<td>3</td>
<td>Coordinated</td>
<td>Tip control, the operator moves the machine and manages the tool blade manually with the help of inverse kinematics</td>
</tr>
<tr>
<td>4</td>
<td>Partial automation</td>
<td>Controlling, the operator moves the work machine and manages the part of the tool blade manually while the system drives automatically some of the movements</td>
</tr>
<tr>
<td>5</td>
<td>Autonomous</td>
<td>Machine can operate without human driver</td>
</tr>
<tr>
<td>6</td>
<td>Autonomous machine swarm</td>
<td>Autonomous operation of work machines, interactivity and collaboration of working machines</td>
</tr>
</tbody>
</table>
The Smart Excavator (Bobcat E85)
Smart Excavator, Control Methods Available

1) Human Manual
2) Guidance
3) Remote
4) Teach-in
5) Autonomous
Teach-In
Remote
Model based Autonomous Control
Drones on Infra Construction Sites

- Measurement of Digital Terrain Model (DTM)
- Measuring as-built surface
- Safety monitoring
- Capturing video for remote control
- Drone Swarm on construction site
Autonomous Machine Swarm – Example Kajima

Automatic construction machines work autonomously responding to instructions from a tablet device

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Autonomous Low-Emission Swarm of Infra Construction Machinery

- University of Oulu, Joint research project with a group of key industrial players:
  - Novatron, Satel, Destia
  - Noptel, Sisu Truck, Sensible4, GIM Robotics, Nokia, Sandvik
- 5 MEUR, 2022-2024
- The work machine group: Excavator, bulldozer, compaction machine, dump truck
Autonomous Machine Swarm – Ouluzone Test Center (www.ouluzoneplus.com)
Ouluzone – Test Tracks for Autonomous Machinery
Draft Suggestions for Earth and Lunar Research Collaboration

- Open Infra BIM is a standardized open system for model-based design and automated construction of infrastructure projects.
- In principle, the infrastructure needed for the moon can be designed and built with the same proven concept and systems.
- Initially, testing may be performed at suitable test centers on Earth.
- Lunar infrastructure planning can be done on Earth and carried out with autonomous work machines after they have been delivered there.
Thank you for your Attention!

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