Autonomous SWARM at PWRI 21.4.2023

Finnish-German BIM Workshop, Berlin 5.9.2023

Improving the Productivity of Infrastructure Construction by Open Infra BIM based Automation

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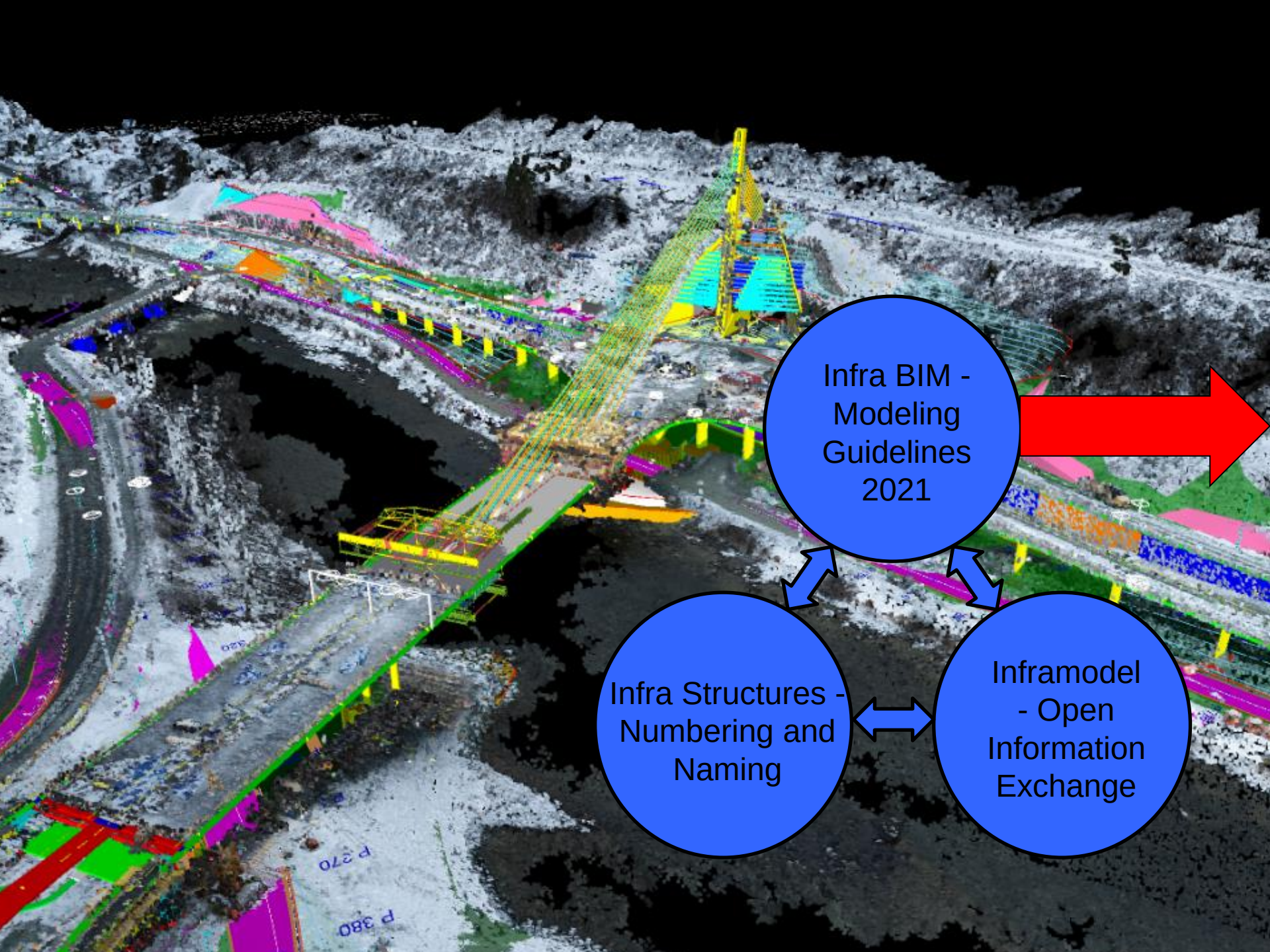
- Professor, Dr. Tech, Civil Engineering Research Unit
- Head of Digitalized Construction and Mining Research Team
- Major research interests cover information modelling (BIM in Construction, Mining Information Modelling in Mining), automation and robotics in the Construction of Roads, Railways, Fairways, Bridges and Buildings as well as in Mining

Introduction

- Productivity of infrastructure construction = Output/Input of the operational process
- General possibilities to improve productivity are:
  - Maximize output from the design and construction process
  - Minimize Input to the design and construction process
- To mazimize the output we have to
  - Use better technologies such as Open Infra BIM & Automation
  - Develop new innovative solutions for products & services
  - …
- To minimize the input, we have to
  - Improve the working efficiency, shorten execution time,..
  - Decrease mistakes and errors,…
  - Decrease waste such us waiting times for materials, information and decisions, rework, incorrent processing,…

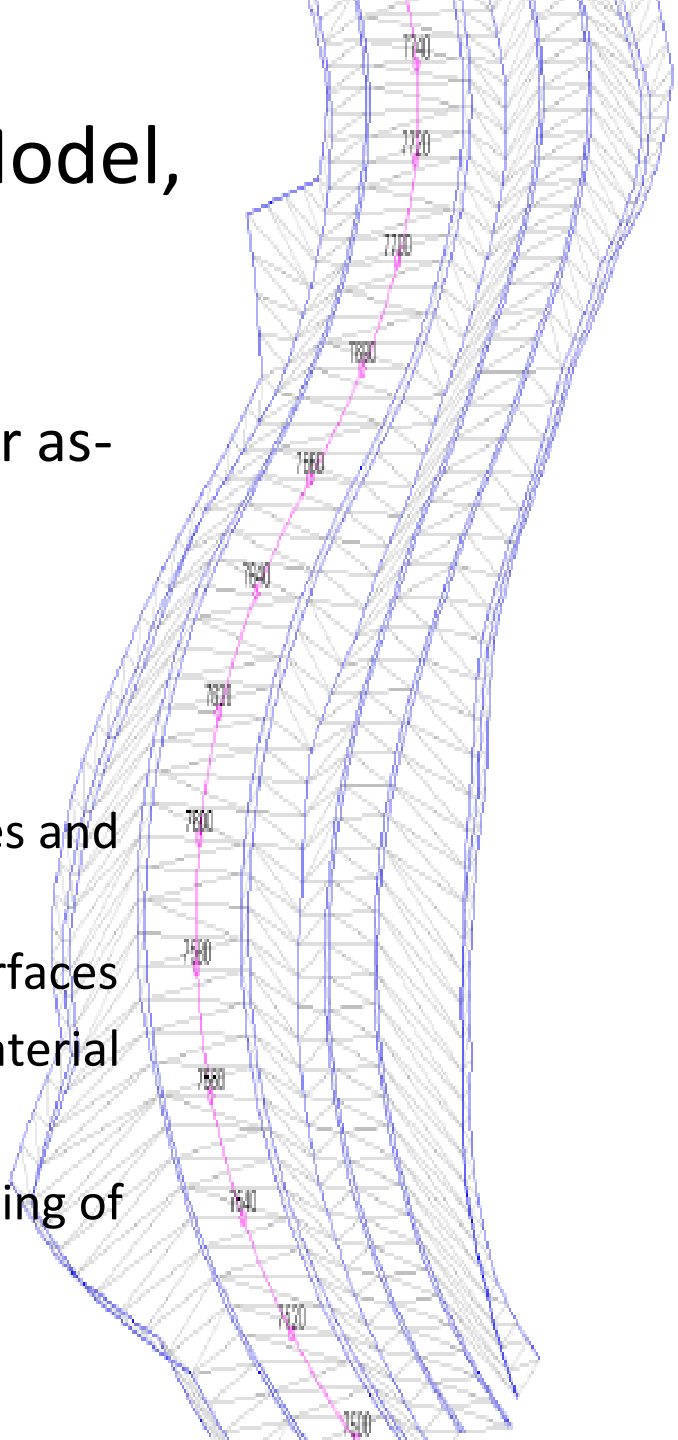
Features of Infra Construction Sites

- Long sites, typically 10-100 km, or over 1000 km (E39, Norway, 2015-2035)
- Tens or hundreds of working machines and vehicles
- Works of soil bed cutting, rock cutting and blasting, construction of structural layers, asphalt spreading, compaction,…
- Lots of material movements
- Continuous interaction with traffic
- Very costly, typically tens or hundreds of MEUR/project (motor way 3-5 MEUR/km), duration 2-3 years
- Relatively very high accuracy of construction needed


Infra BIM - Modeling Guidelines 2021
Infra Structures - Numbering and Naming
Inframodel - Open Information Exchange

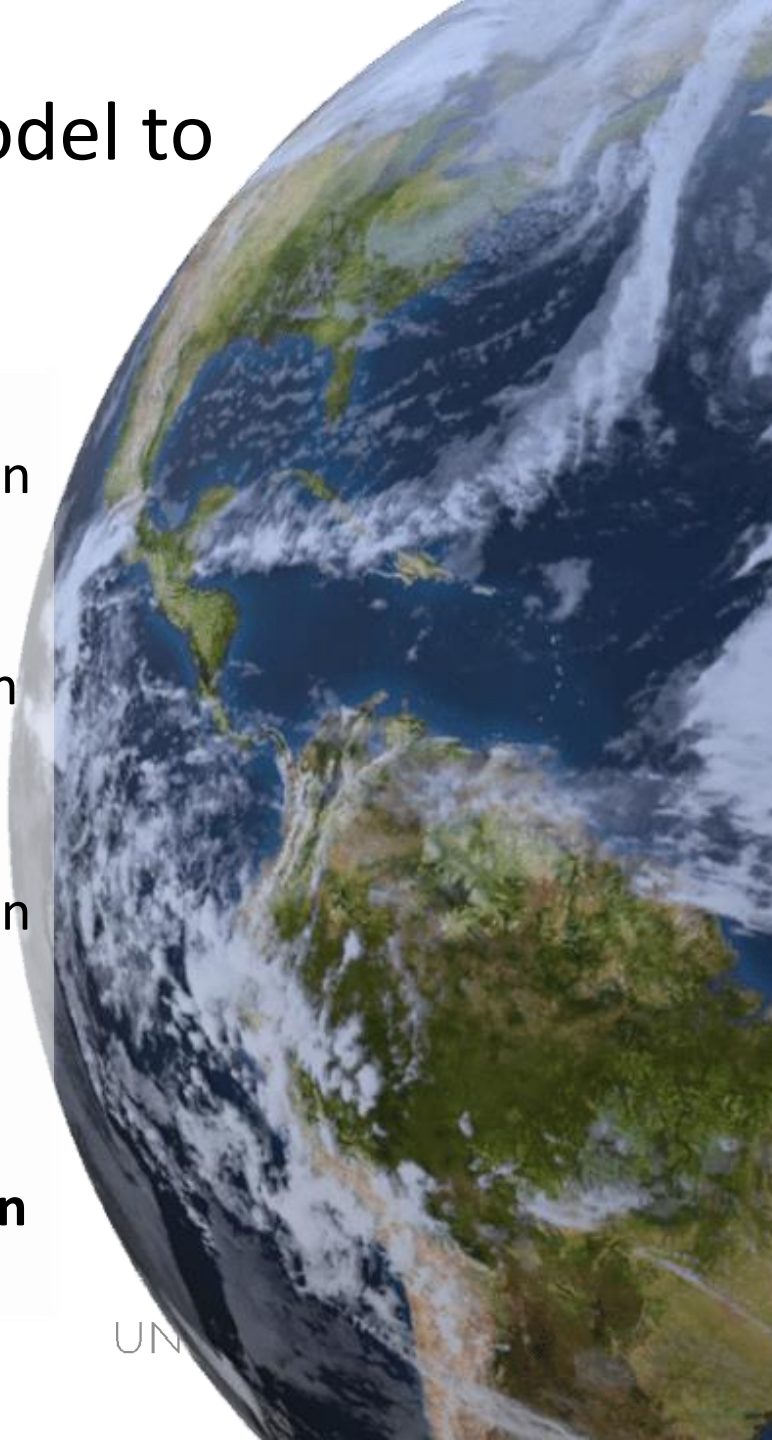
Infra BIM, Machine Control Model, Inframodel

- Common InfraBIM Requirements YIV2021, 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



Development from Inframodel to **ISO 15143 ”ISO LandXML”**

- ISO/TS 15143-3:2020 Earth-moving machinery and mobile road construction machinery — Worksite data exchange — Part 3: Telematics data, Published (https://www.iso.org/standard/76394.html)
- ISO/AWI TS 15143-4.2 Earth-moving machinery and mobile road construction machinery — Worksite data exchange — Part 4: Worksite topographical data
- **In Japan, Opera research project ongoing is developing an Open Solution for “SWARM Control”**



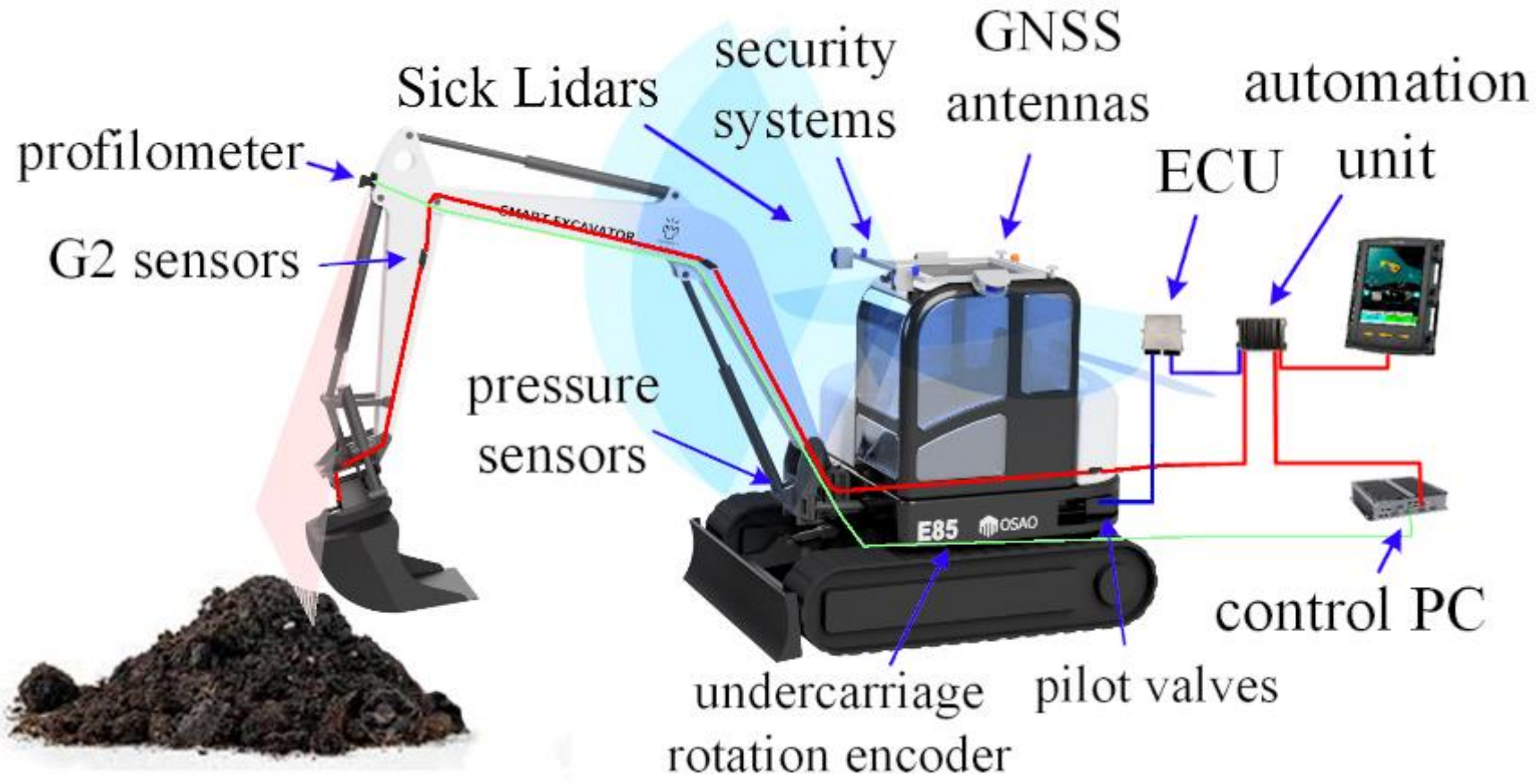
Automated 3-D Machine Guidance and Control

- Integrates Infra BIM (machine control model) to construction control
- Machine control model is processed from design model
- 3-D positioning for machine (blade) movements, RTKGNSS 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*)

Levels of Automation for Infra Construction Machinery

Level	Name	Description of the activity
0	No automation	Human operates machine
1	Remote control	Human operates remotely machine
2	Guidance	Operator supported, the operator drives manually machine and blade using computer user-interface to BIM model
3	Coordinated	Tip control, the operator moves the machine and manages the tool blade manually with the help of inverse kinematics
4	Partial automation	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
5	Autonomous	Machine can operate without human driver
6	Autonomous machine swarm	Autonomous operation of work machines, interactivity and collaboration of working machines

The Smart Excavator (Bobcat E85) of University of Oulu, 2023



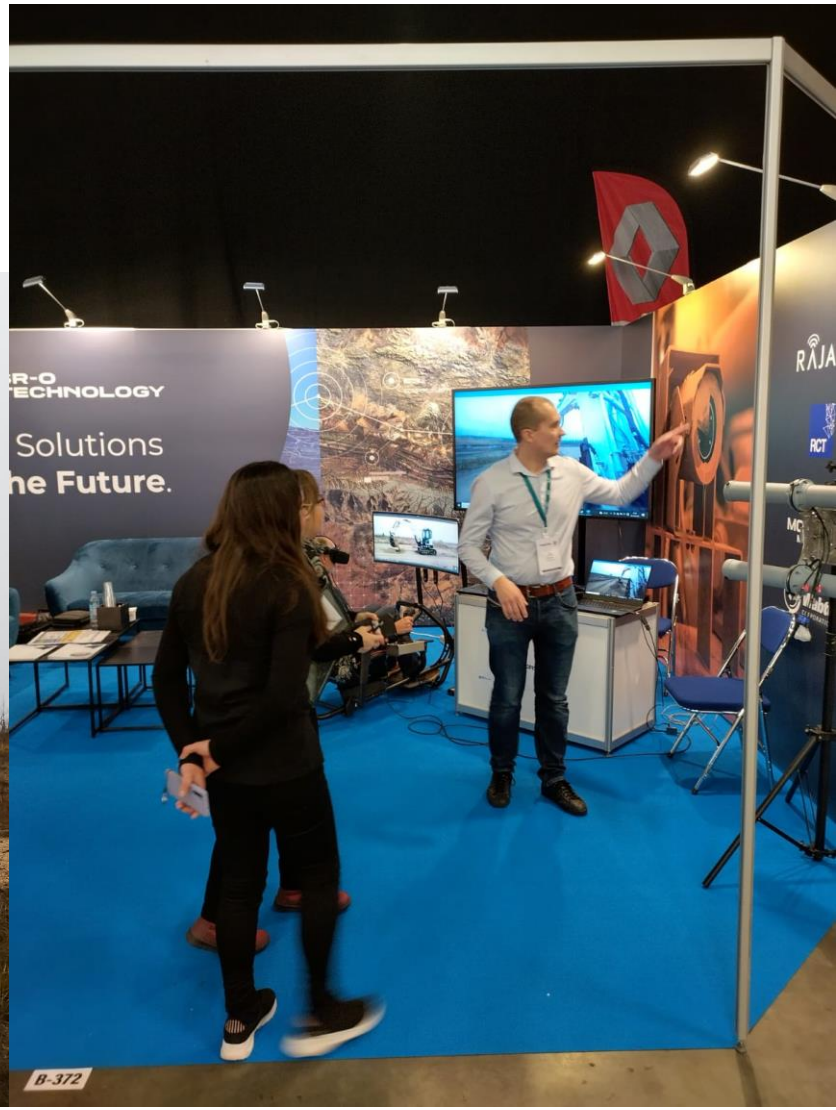
Smart Excavator, Control Methods Available

1) Human Manual
2) Guidance
3) Remote
4) Teach-in
5) Autonomous

Teach-In

Remote

Remote Control Jyväskylä-Ouluzone (400 km, 26.10.2022)



Doka Robo, Kanamoto, 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

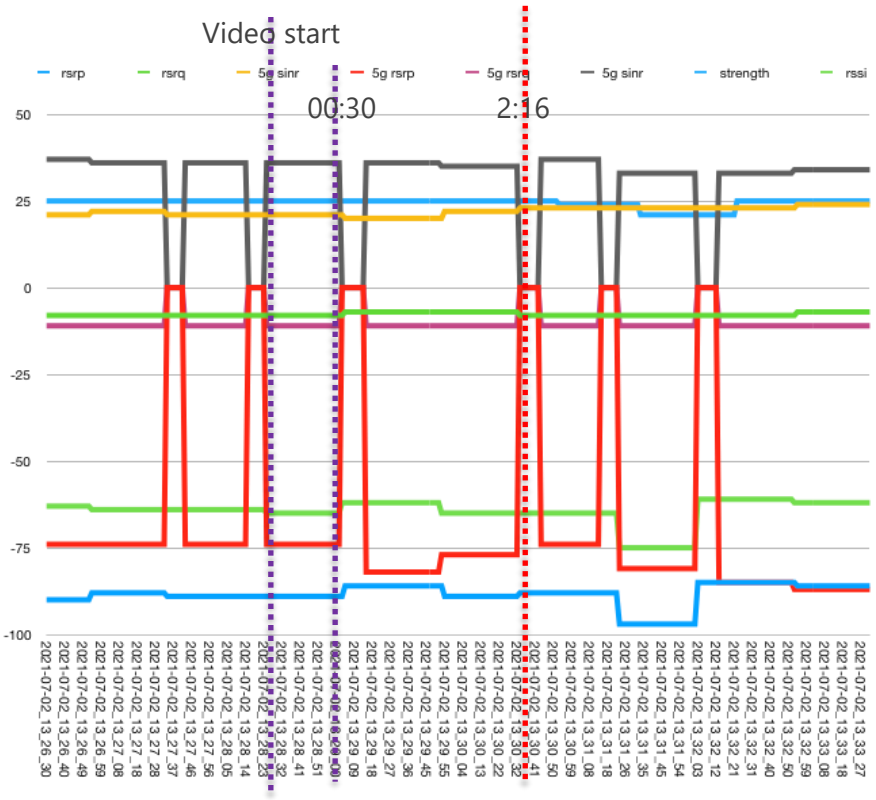

YANMAR

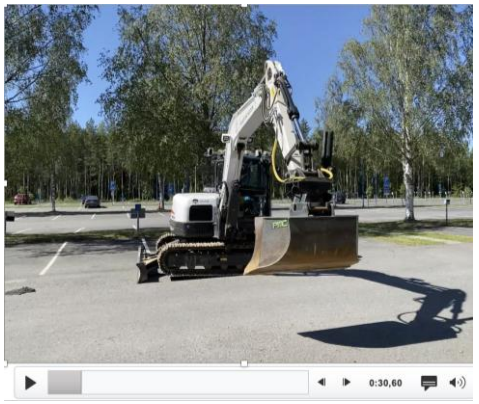
Unmanned - Model based Autonomous Control

Smart Excavator – Drone Cooperation

- Measurement of DTM
- Measuring as-built surface
- Safety monitoring
- Capturing video for remote control
- Creating wireless communication network
- …

Wireless Communication for SWARM – Experiments with 4G, 5G, Rajant, Starlink,..





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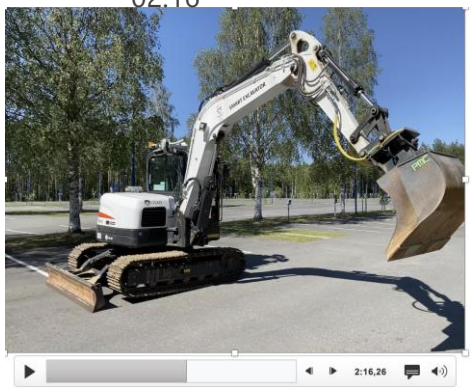


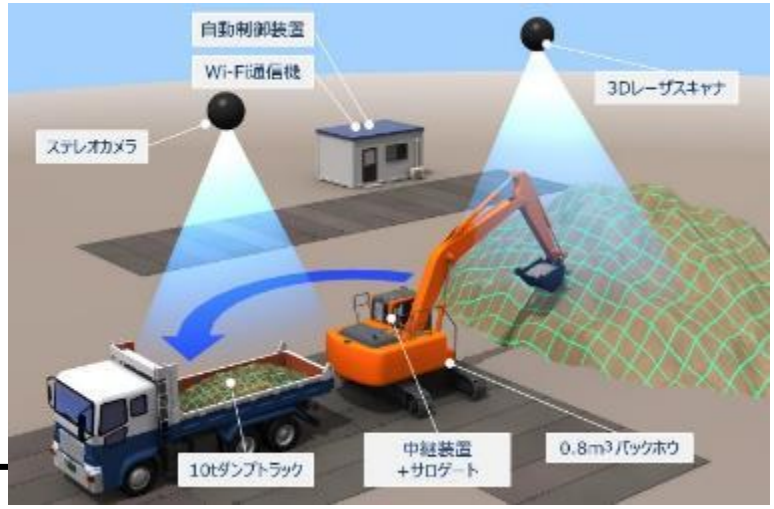
2:16-2:20 5G drops

Heikkilä, R. & Immonen, M. & Keränen, H. & Liinamaa, O. & Piri, E. & Kolli, T. (2022) 5G Wireless Communication for Autonomous Excavation. ISARC 2022.

Case ETH Zurich & Gravis Robotics, Prof. Marco Hutter, 2023

Japanese SWARM Automation Systems

PWRI



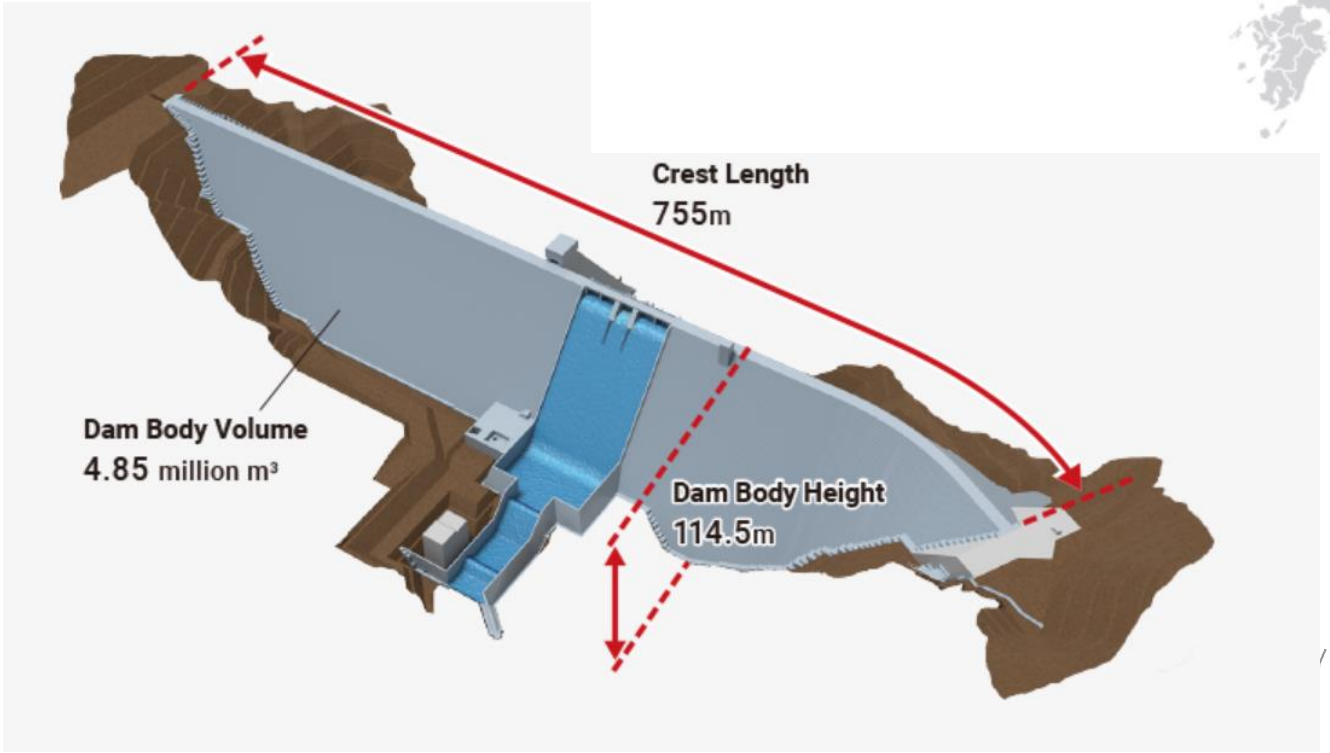
Obayashi Co.

Kajima Co.

Taisei Co.

Autonomous Machine Swarm – Case Kajima, Japan

Naruse Dam Construction Site, Japan 13.9.2022

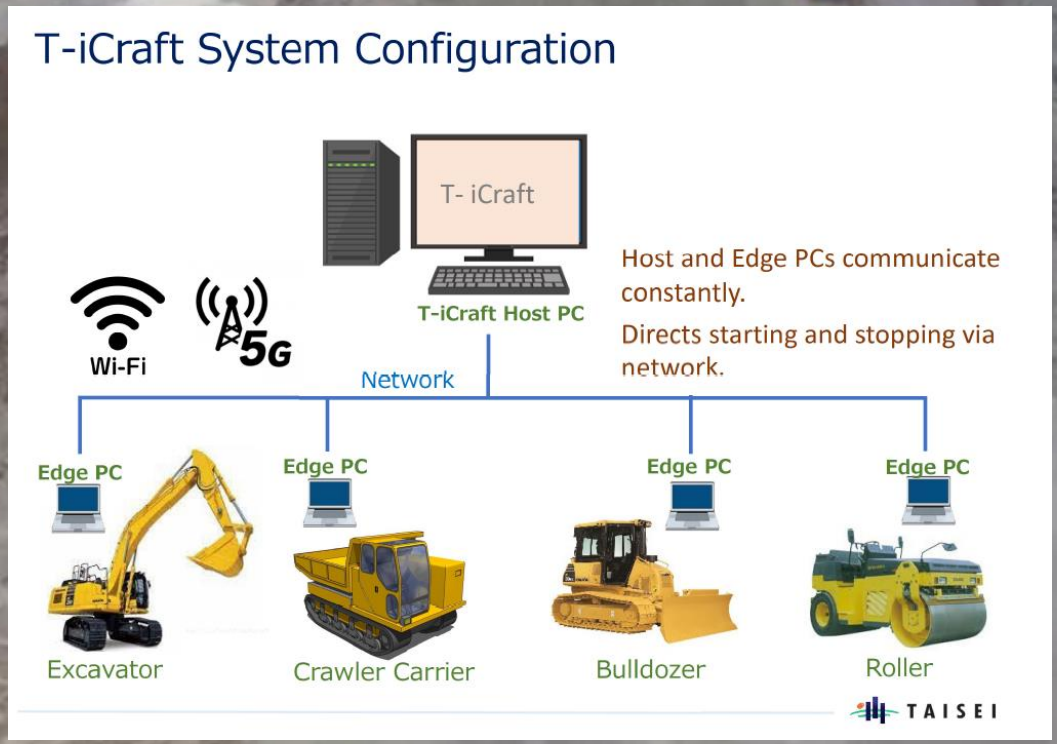



Naruse Dam Construction Site,
Kajima, 13.9.2022

Kajima Swarm Experience in Dam Construction

- Naruse Dam Construction Site, a project incorporating the latest construction methods
- A^{4}CSEL - **Work speeded up by 32%**
- A^{4}CSEL - **83% fewer people working on the site**

Nammah Dam Construction Site, Case Taisei



Autonomous Machine Swarm – Case Taisei

Con-Expo 14.-19.3.2023 Las Vegas, USA – the Emergence of Semi-Autonomous Machines (Teleo, Palo Alto, CA):

- “Today we are excited to announce deals with construction customers John Aarts Group, Teichert, and Tomahawk Construction for remote-operated wheel loaders, bulldozers, and dump trucks, respectively. In addition, we are expanding globally through a new dealer partner network spanning across the United States, Europe, and Canada with partners Dobbs Positioning Solutions, RDO Equipment Co., SMS Equipment Inc. and SR-O Technology.
- Construction and mining work is skilled, physically demanding and often dangerous. According to the Associated General Contractors of America, 91% of construction firms are having a hard time finding workers to hire, driving up costs and project delays. To address this issue, we are introducing an incremental approach to autonomy with Teleo Supervised Autonomy technology, which combines remote and autonomous operations of any make and model of heavy construction equipment. A key benefit is that one operator can control multiple machines from the comfort of a command center.
- Full autonomy, which doesn’t require any human intervention, is still many years away for the construction industry and many others.”

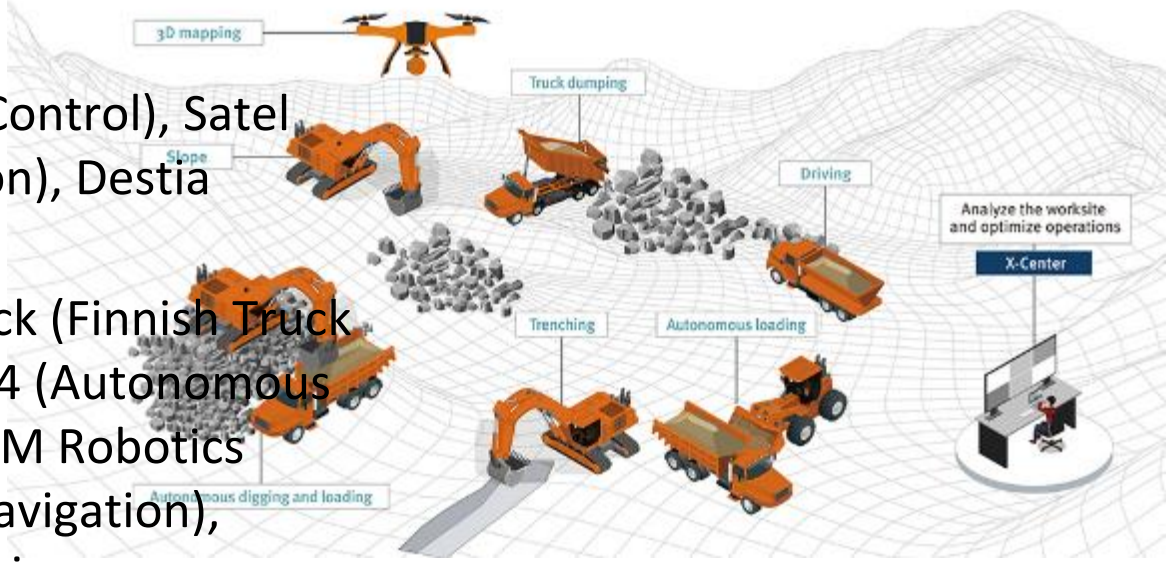
One Operator, Two Machines (Teleo, US)

Teleo at Ouluzone+ 28.6.2023

Supervised Autonomy in Ouluzone 28.6.2023 (Teleo, University of Oulu)

Autonomous Low-Emission Swarm of Infra Construction Machinery

- University of Oulu, Joint research project with a group of key industrial players:
  - Novatron (3D Machine Control), Satel (Wireless Communication), Destia (Contractor)
  - Noptel (LIDAR), Sisu Truck (Finnish Truck manufacturer), Sensible4 (Autonomous vehicles and trucks?), GIM Robotics (Adaptive sensing and navigation), Nokia (5G), Sandvik (Mining Automation, MIM)
- 5 MEUR, 2022-2024
- The work machine swarm: Excavator, bulldozer, compaction machine, dump truck



Picture: Concept-X Vision, Doosan

Swarm Oulu - Machines

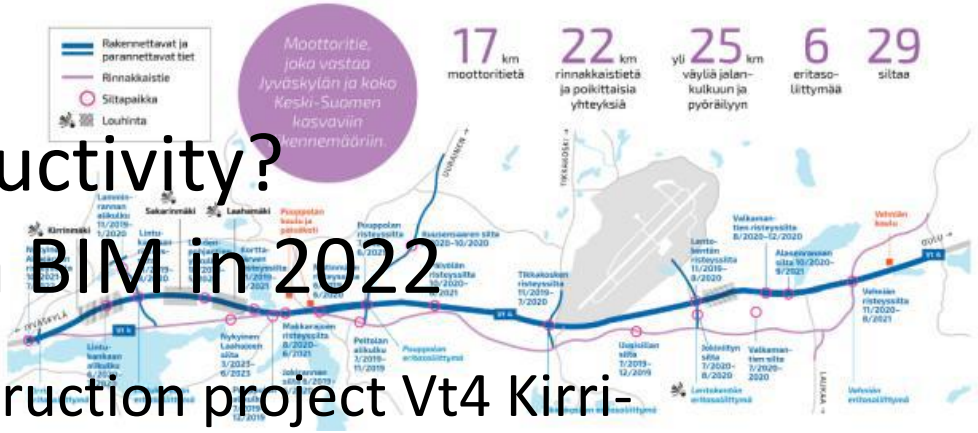
CAT D6K2 (2016)
14 tn

Bomag
BW177BVC-5
with Vario
Control
System

Developing Ouluzone++
www.ouluzoneplus.com

Basecamp

Improvement of Productivity? Benefits of Open Infra BIM in 2022



- Highway Design and Construction project Vt4 Kirri-Tikkakoski (2019-2022):
  - The motor way was opened to **traffic 8 months ahead of the schedule**
  - **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 been preventing potential faults at an early stage during construction

Heikkilä, R. & Kolli, T. & Rauhala,T. (2022) Benefits of Open InfraBIM – Finland Experience. ISARC 2022.

Findings of the Productivity Workshop 27.4.2023 (University of Oulu, Finnish Transport Infrastructure Agency)

- BIM-based method has made it possible
  - Better forecasting
  - Clear outline of the plans
  - Enables doing the right thing at once
  - Overlaps are easy to identify
- These have a clear connection to productivity
- At the industry level, measuring productivity development is challenging
- Contractors have no need/obligation to disclose contributions (inputs))
- Determining the outputs is also challenging due to the increased requirements

Conclusion

- Remarkable benefits based on Open InfraBIM and Automation observed from Infra design and construction projects in Finland, Automation offers more and more latent possibilities
- The common statistical measures used do not show and follow accurately the productivity development in infra sector
- New type of measuring methods, measures and units will be needed to follow productivity development
- The key players of the infra construction industry needs to be motivated to the continuous productivity improvement
- The next R&D ”productivity improvement” project under planning at the moment

Thank you!

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Digital Twins - Nokia RXRM System in 5G