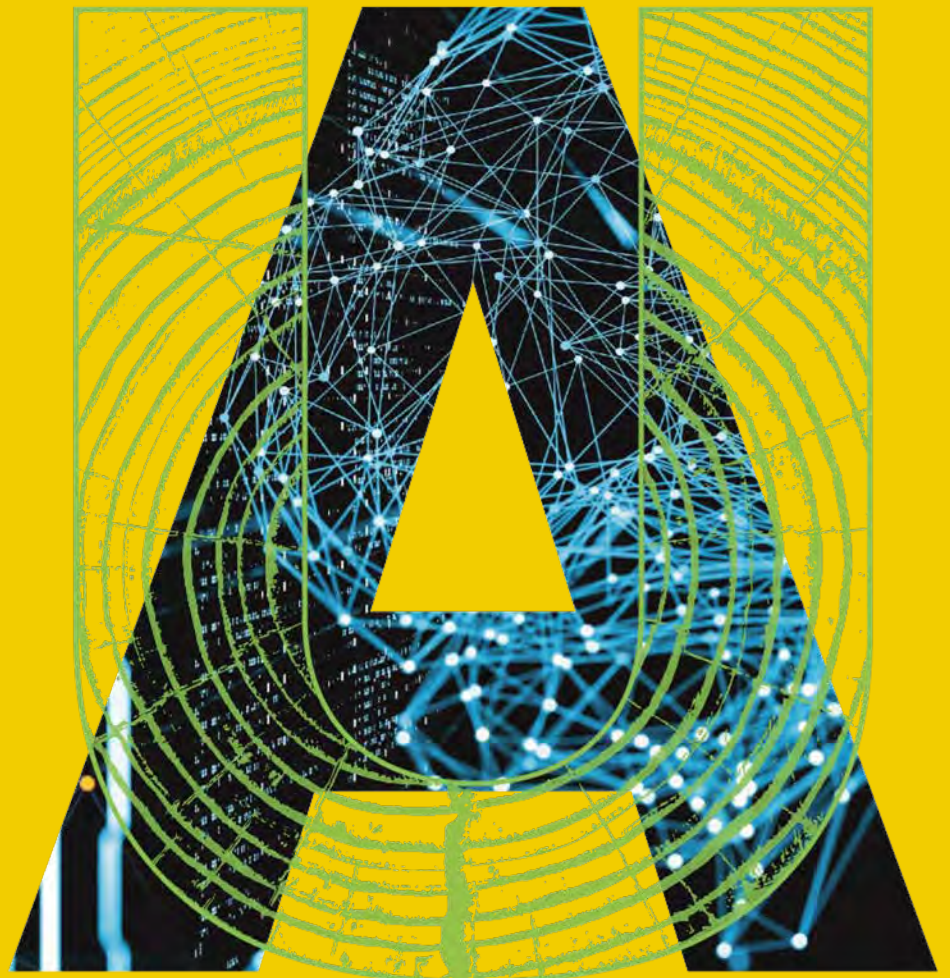
DIGITALISATION OF THE CONSTRUCTION INDUSTRY THROUGH LEAN CONSTRUCTION 4.0

Prof. Vicente A. Gonzalez
Tier 1 Canada Research Chair in Digital Lean Construction

Hole School of Construction Engineering
Department of Civil and Environmental Engineering
Faculty of Engineering

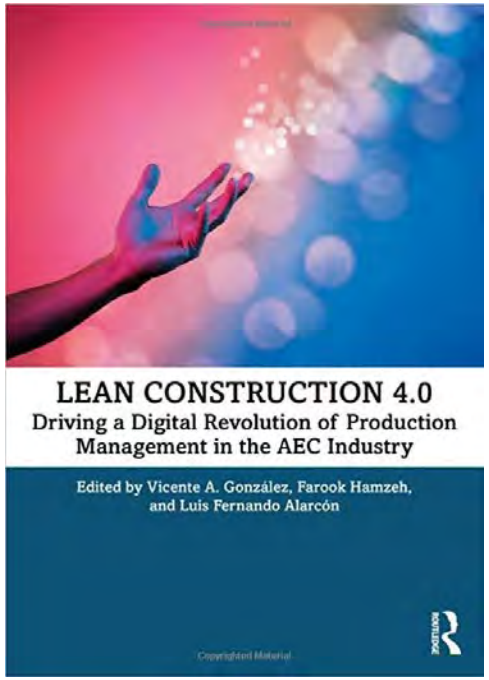
UNIVERSITY OF ALBERTA



Why to listen

- 14+ years of research experience is at the **interface** of **Lean Construction** and **Computer Science**.

- Publication of the **Lean Construction 4.0 book**… Basically, a reflection of how we can digitally transform the construction industry with the support of Lean Construction.



#IHT Lab

Infrastructure and Human Tech Lab

Infrastructure Human Tech Lab (IHT Lab) aim is to develop Tailored, Sustainable, Inclusive solutions designed to enhance safety, productivity, and sustainability in the Architecture, Engineering, and Construction (AEC) industry, grounded on solid engineering science and the power of cutting-edge digital and smart technologies, with a strong emphasis on human-centred solutions.

Nature of Projects

UNIVERSITY
OF ALBERTA

Nature of Projects

Before we start … Let's understand what the nature of a project is.

Source: https://www.invensislearning.com/blog/project-managers-in-construction-industry/

Nature of Projects

Socio-Technical Systems in the Construction industry

CONSTRUCTION PROJECT

Source: https://www.invensislearning.com/blog/project-managers-in-construction-industry/

Nature of Projects

Socio-Technical Systems in the Construction industry

- Construction is a social or human activity
- Well-understood by social science (Koskela, 2008)

SOCIAL VIEW

Source: https://www.invensislearning.com/blog/project-managers-in-construction-industry/

Nature of Projects

Socio-Technical Systems in the Construction industry

PHYSICAL/PRODUCTION VIEW

Source: https://www.invensislearning.com/blog/project-managers-in-construction-industry/

- Social behaviour embedded in physical and production contexts.
- It follows specific laws such as queuing theory.
- Natural science has more to do in this case (Koskela, 2008).

Nature of Projects

Socio-Technical Systems in the Construction industry

TECHNICAL VIEW

Source: https://www.invensislearning.com/blog/project-managers-in-construction-industry/

- Construction engineering and management (CEM) can be better understood by complementing these views with an engineering-driven technical perspective: Design Science, where the development of an artefact to solve a practical problem brings new knowledge (Koskela, 2008).

Nature of Projects

Socio-Technical Systems in the Construction Industry

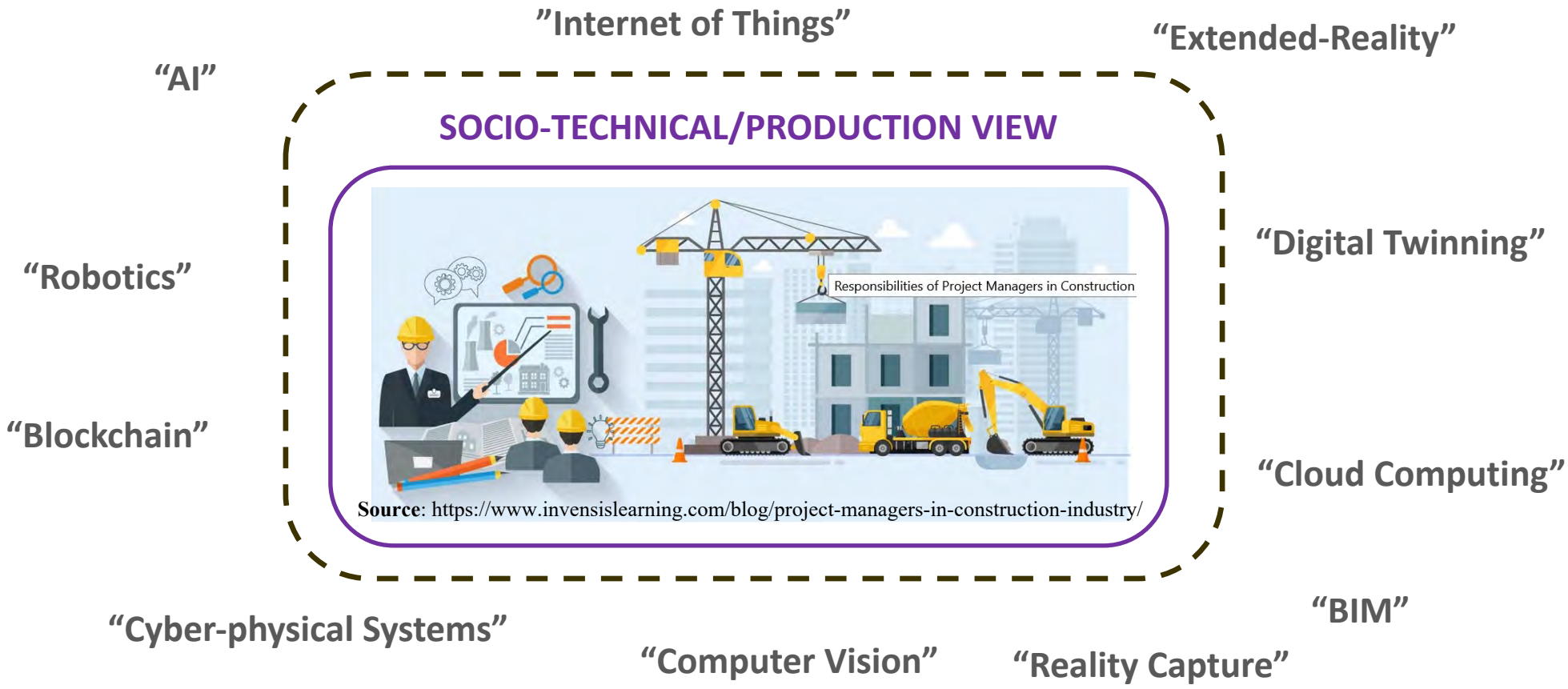
SOCIO-TECHNICAL/PRODUCTION VIEW

Source: https://www.invensislearning.com/blog/project-managers-in-construction-industry/

- Construction project's organisations in the Construction industry can be perceived as socio-technical systems.

Nature of Projects

Socio-Technical Systems in the Construction industry



Lean Construction 4.0 in a Nutshell

UNIVERSITY OF ALBERTA

Why Lean Construction 4.0

- **Confronting the industrial transformation**

Icons made by Becris, Smashicons, Eucalyp, surang, Freepik, ultimatearm from www.flaticon.com

	Industry 1.0 Mechanisation, steam power	2.0 Electrical energy	3.0 Digitisation, computers, IT systems	4.0 Cyber-physical systems, IoT, artificial intelligence, big data, sensor-based technologies
Manufacturing	Power loom, machine and milling tools	Mass production, assembly line	Automation, assembly robotics, CAD	Smart factory, autonomous systems (control, maintenance, prediction)
Construction	Circular saw, cut nails	Heavy equipment, power tools	Prefabrication, construction robotics, CAD, BIM	Smart site (IoT, artificial intelligence, big data, sensor-based technologies)

Fully integrated/adopted Partially integrated/adopted Yet to be integrated/adopted

SOURCE: SimCon Group, The University of Auckland

Construction at stage I3.0

Manufacturing at stage I4.0

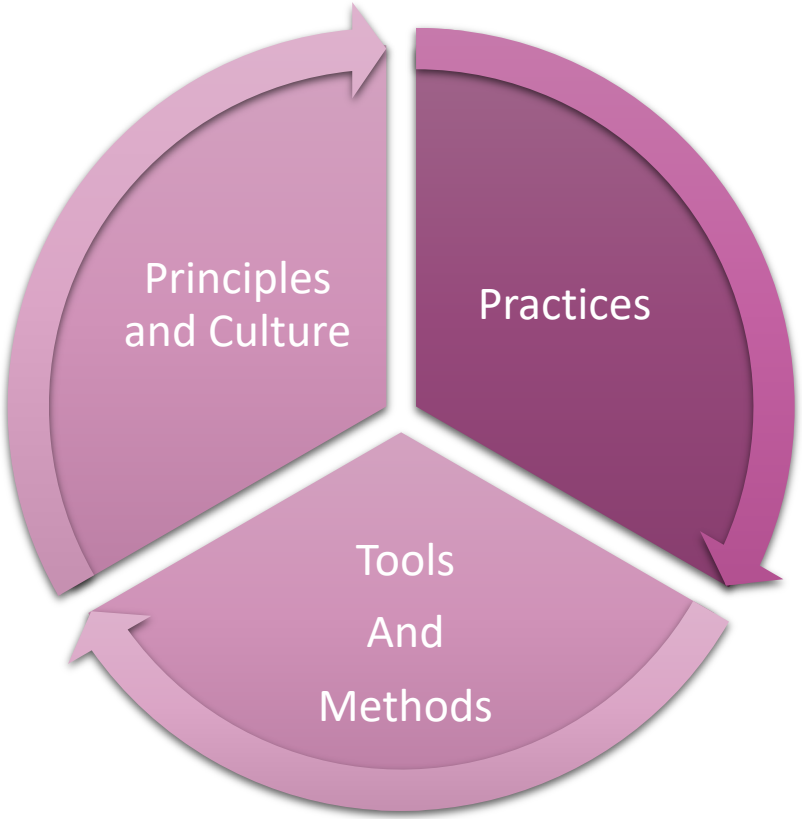
- **Lean Construction impact:**

Limited (Gonzalez et al, 2022)

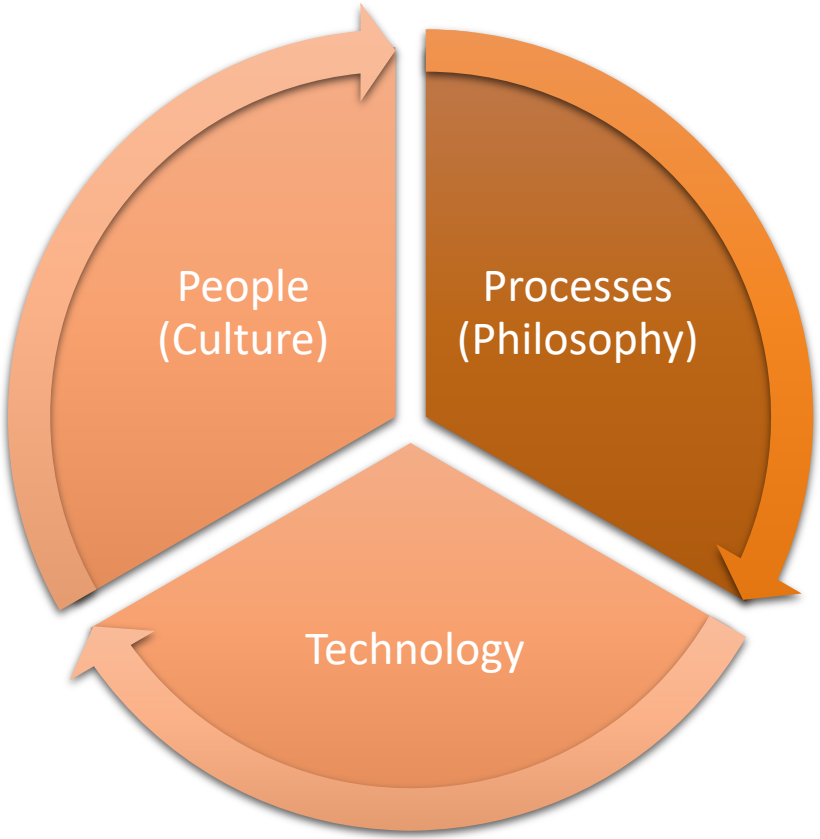
Nowhere near the scale of improvements seen in other sectors (Pantazis et al, 2022).

Lean Construction 4.0 in a Nutshell

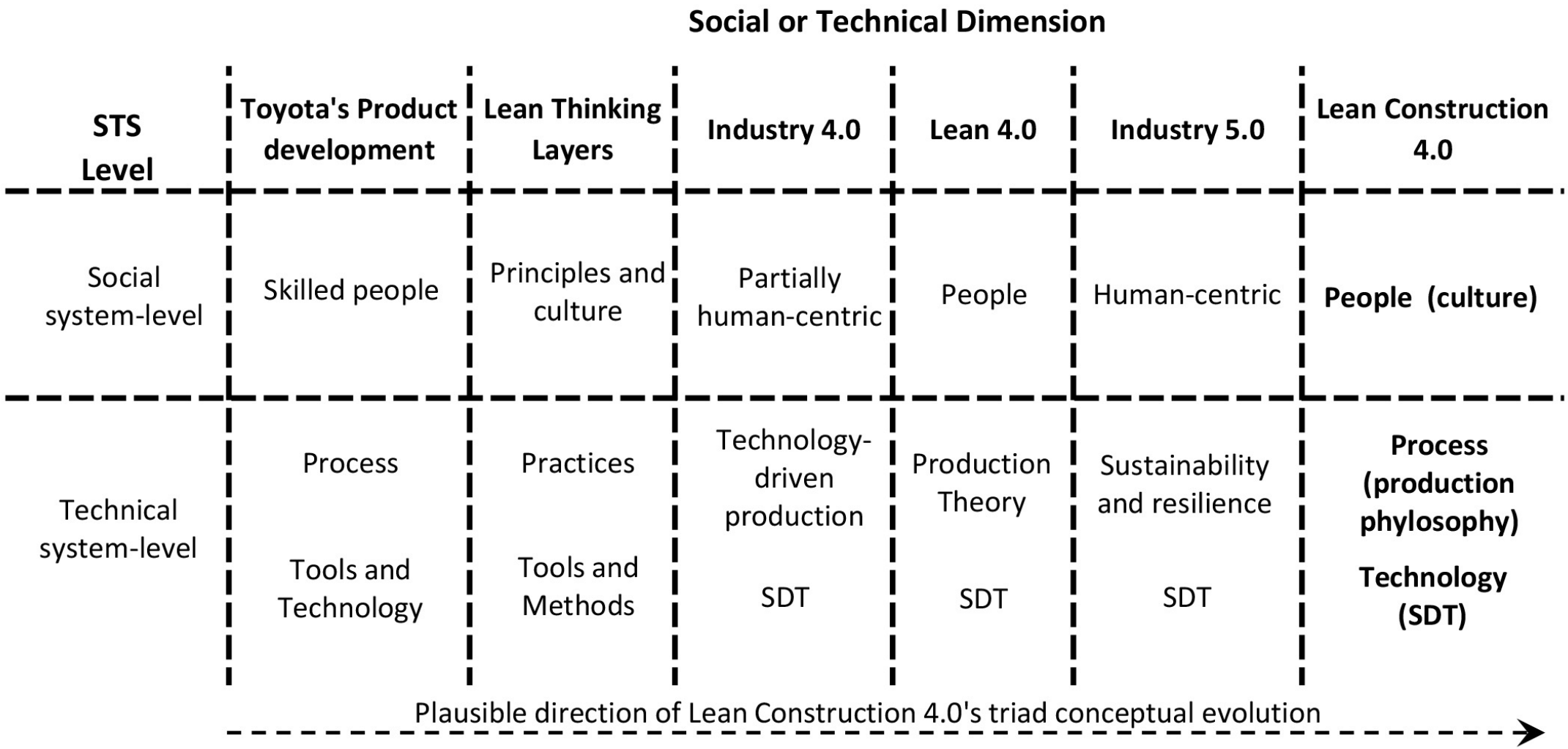
- Layers of Lean Thinking (Pekuri et al., 2012)



- Layers of Lean Construction 4.0



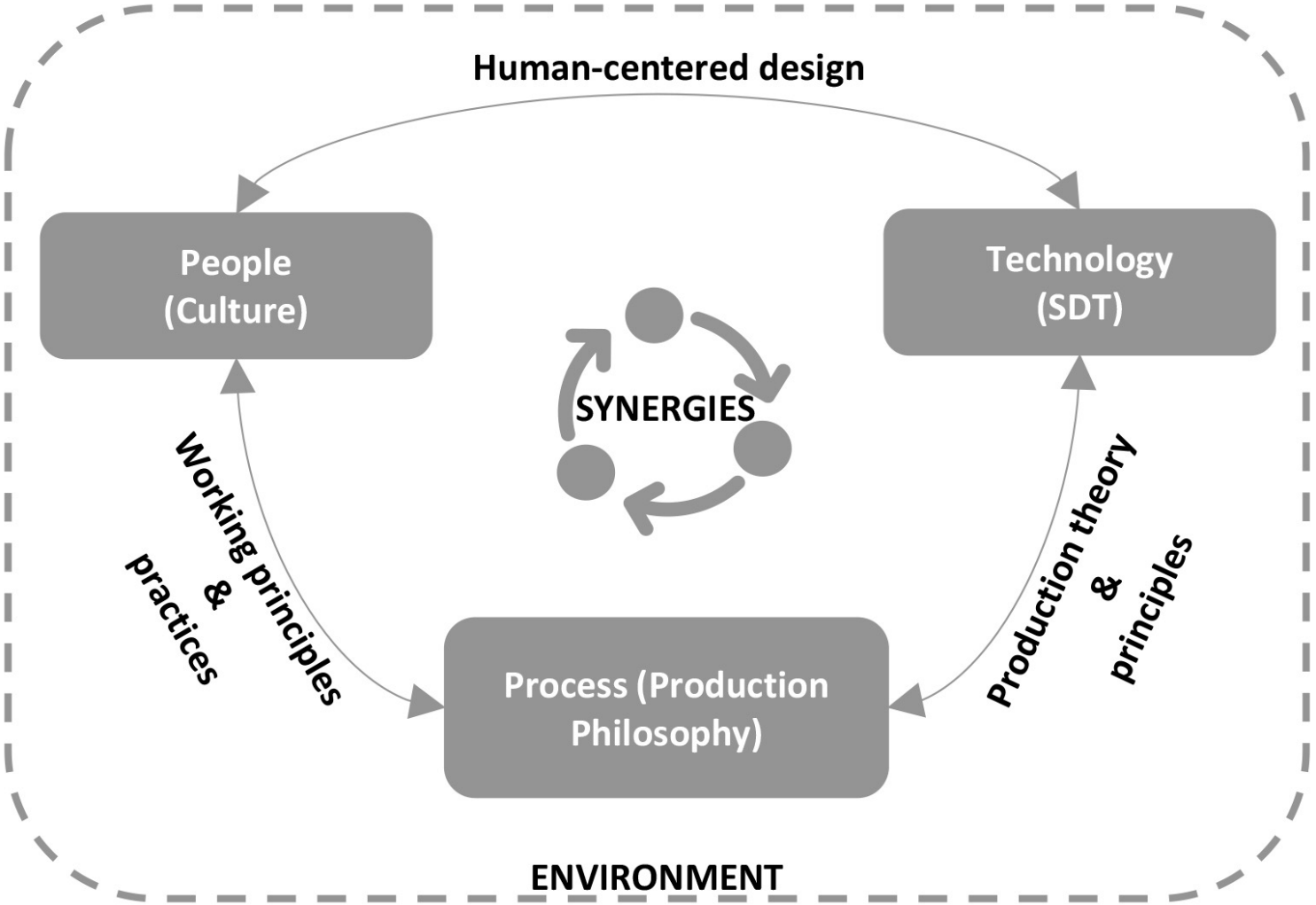
Lean Construction 4.0 in a Nutshell



Source: González, V. A., Hamzeh, F., & Alarcón, L. F. The Future of Lean Construction 4.0. In *Lean Construction 4.0* (pp. 325-336). Routledge.

Lean Construction 4.0 in a Nutshell

A Process-People-Technology Function Model



Source: González, V. A., Hamzeh, F., & Alarcón, L. F. The Future of Lean Construction 4.0. In *Lean Construction 4.0* (pp. 325-336). Routledge.

Examples of Lean Construction 4.0 Research

UNIVERSITY OF ALBERTA

DIGITAL TWIN BASED LPS DECISION SUPPORT SYSTEM

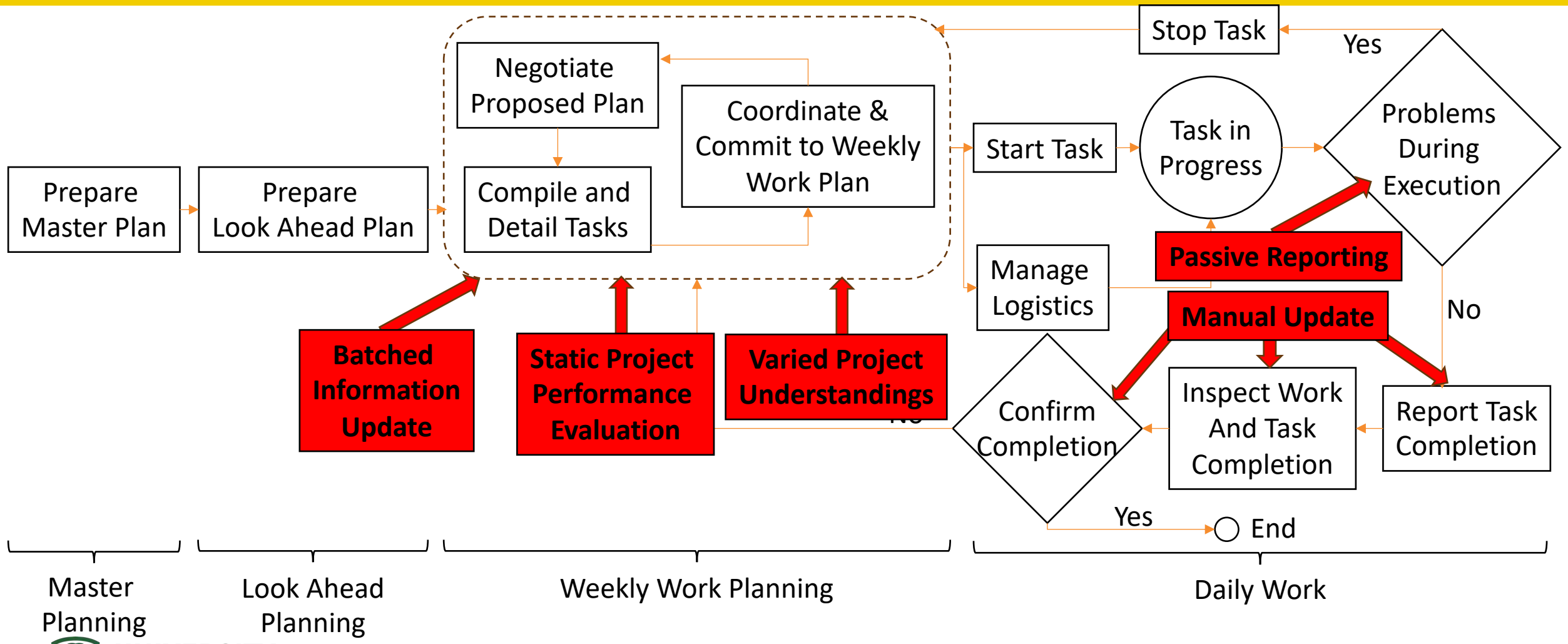
PhD Researchers
Zhong Wang
Mohamed Sabek
Yulun Wu

UNIVERSITY OF ALBERTA

Problems

- Traditional Last Planner System (LPS) visual tools lack dynamic and real-time capabilities.
- LPS's make-ready process can experience delays due to manual constraint updates.
- Integrating IoT and BIM with LPS on modern construction sites has proven to be still very challenging.

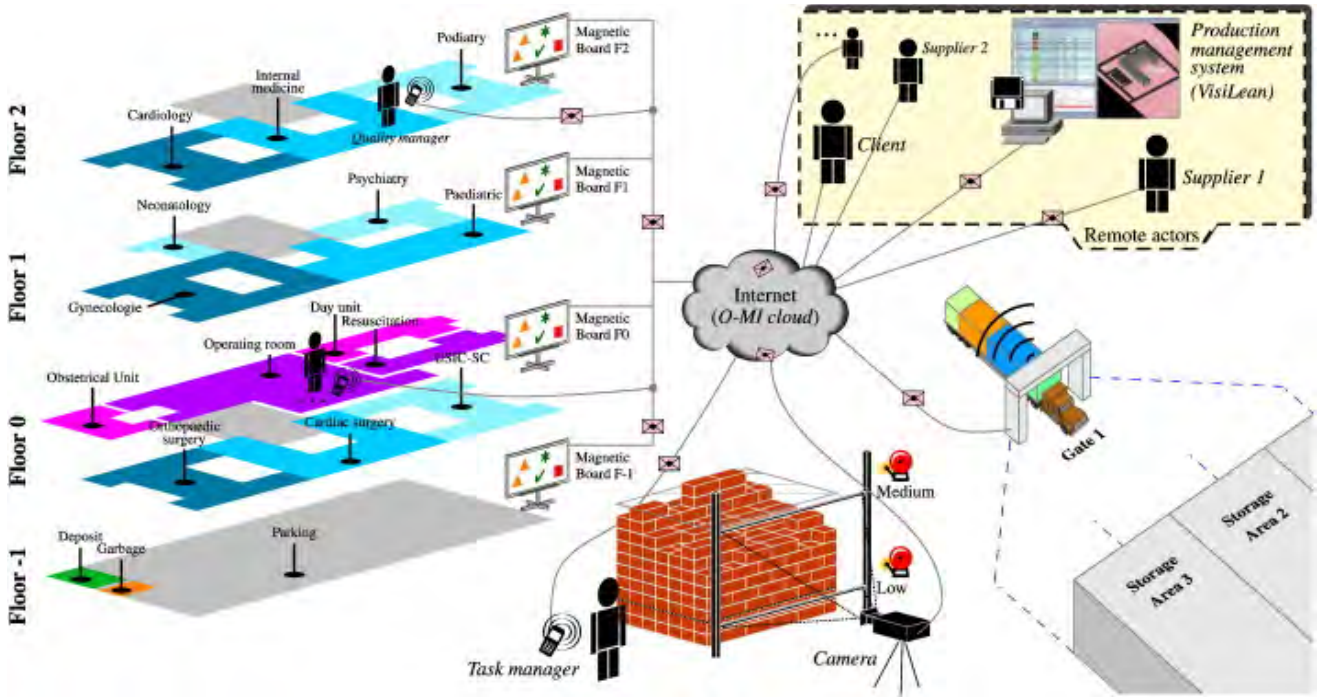
LPS Process Flow



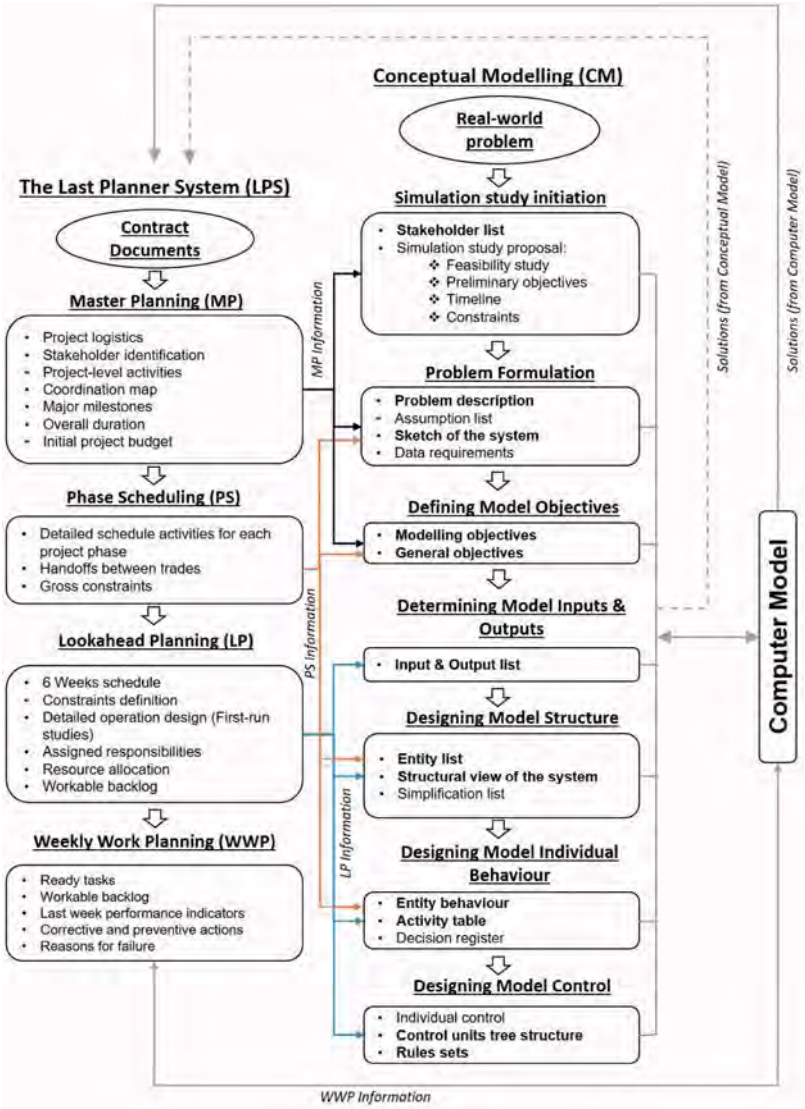
UNIVERSITY OF ALBERTA

Adapted from Sacks, R., Radosavljevic, M. & Barak, R. Requirements for building information modeling based lean production management systems for construction. *Autom Constr* **19**, 641–655 (2010).

Related Works



VisiLean - IoT based construction management tool, Dave et al. (2016)



Integrated CM/LPS framework, Abdelmegid et al. (2019)

System Framework

Image/Point Cloud/Video

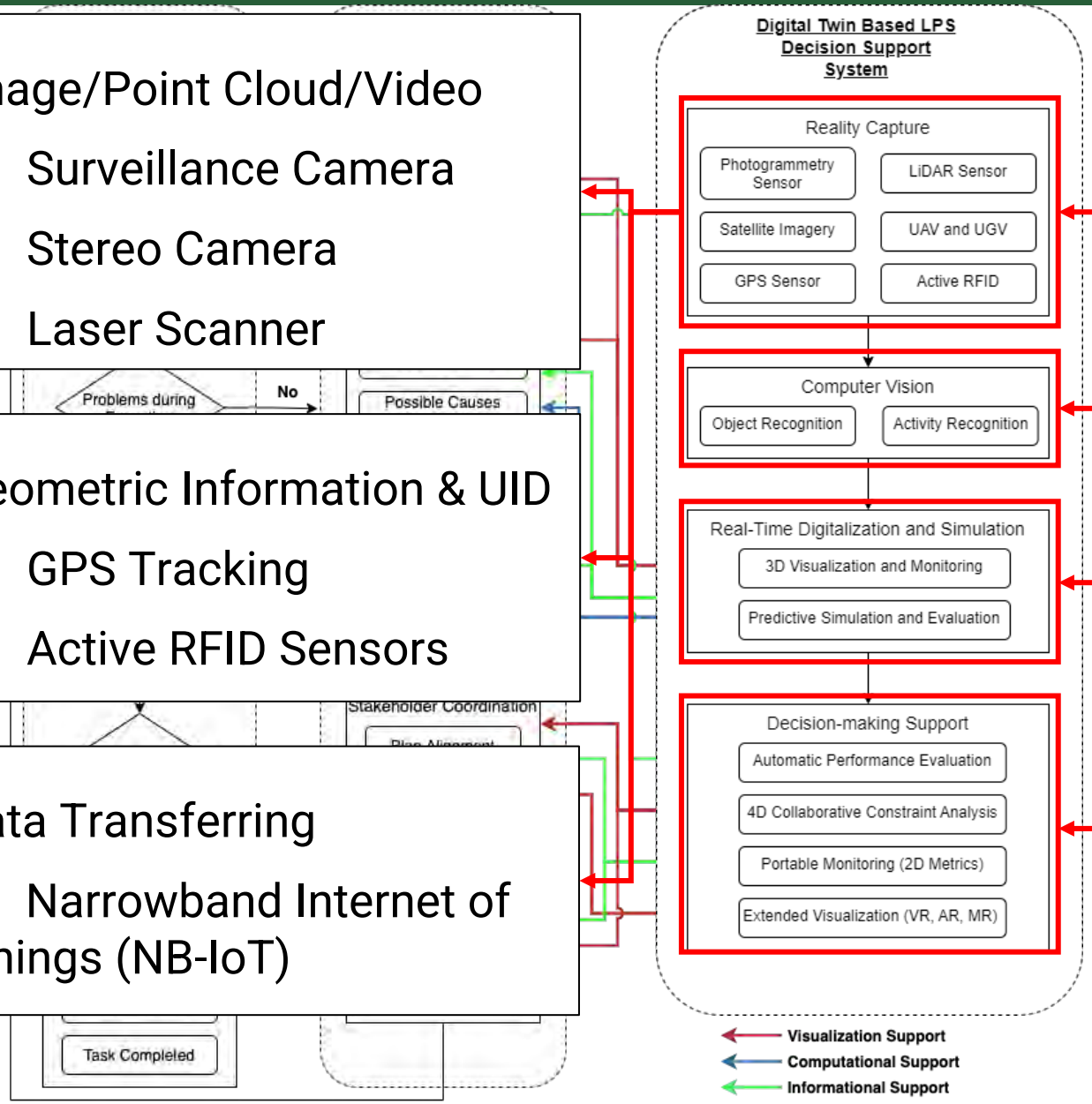
- Surveillance Camera
- Stereo Camera
- Laser Scanner

Geometric Information & UID

- GPS Tracking
- Active RFID Sensors

Data Transferring

- Narrowband Internet of things (NB-IoT)



Reality Capture

Computer Vision

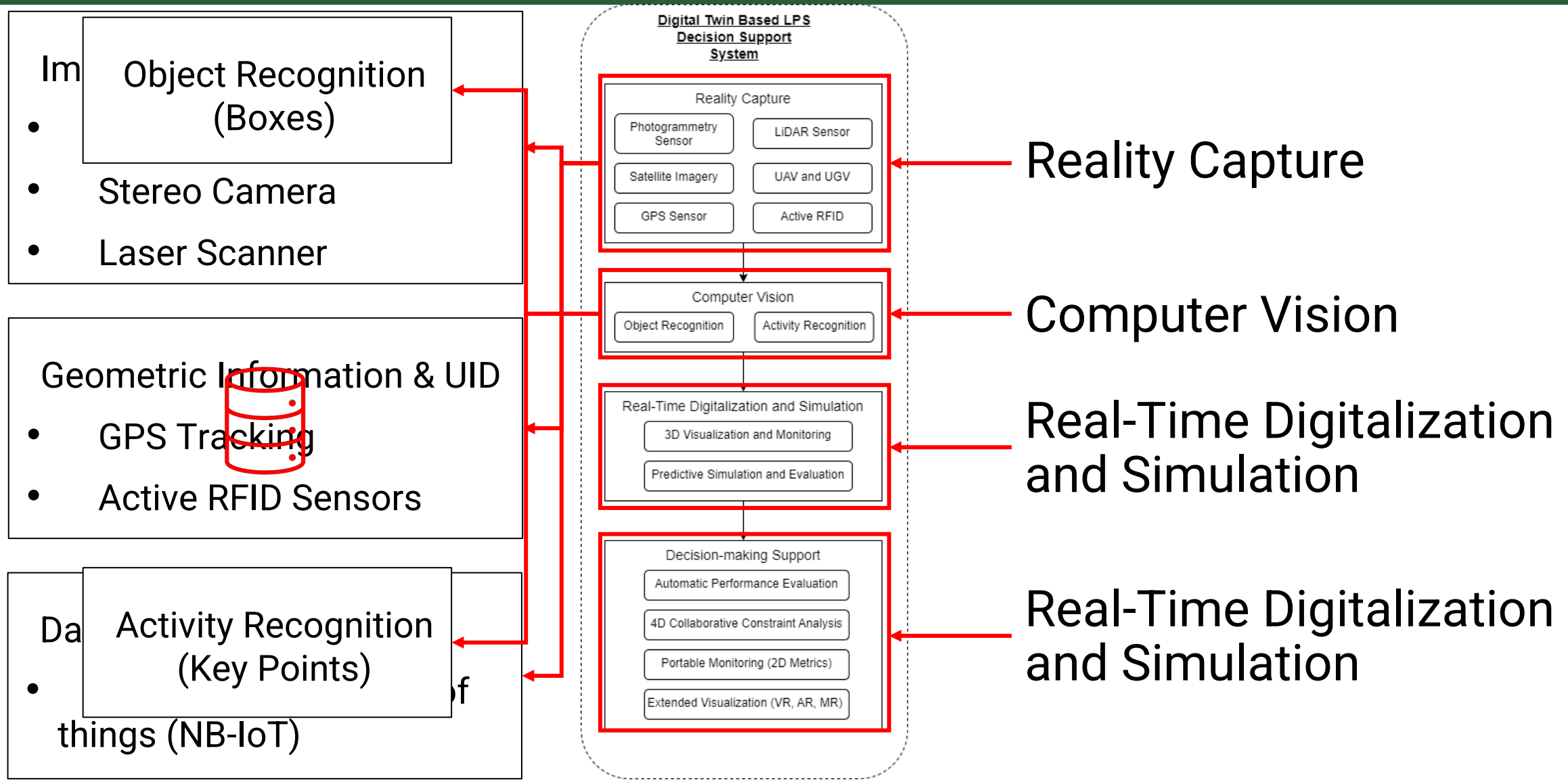
Real-Time Digitalization and Simulation

Decision-making Support Applications

Reality Capture - Satellite

UNIVERSITY OF ALBERTA

System Framework



System Framework

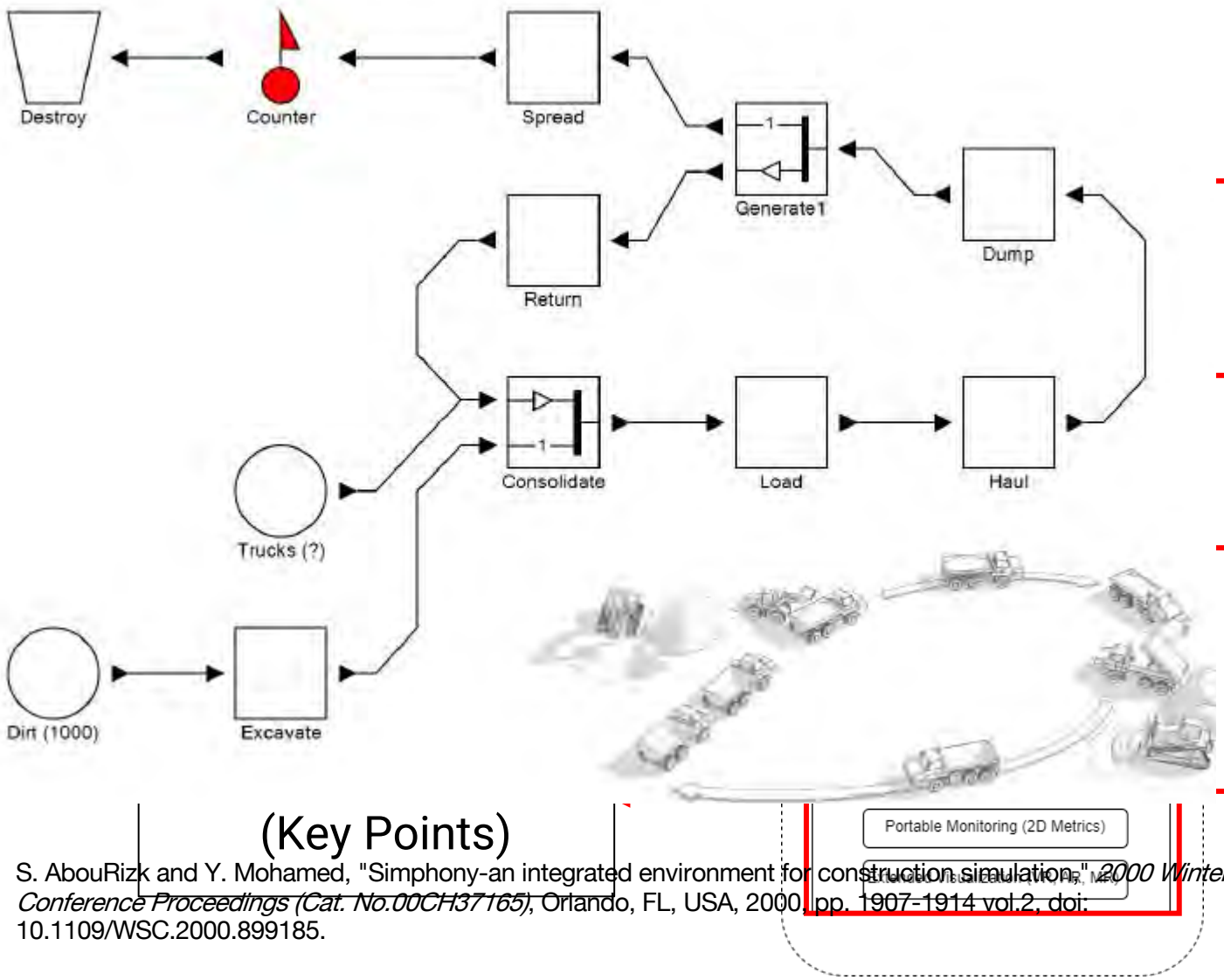
Object Recognition (Boxes)

Entity Initialization

Activity Recognition (Key Points)

Activity Synchronization

System Framework



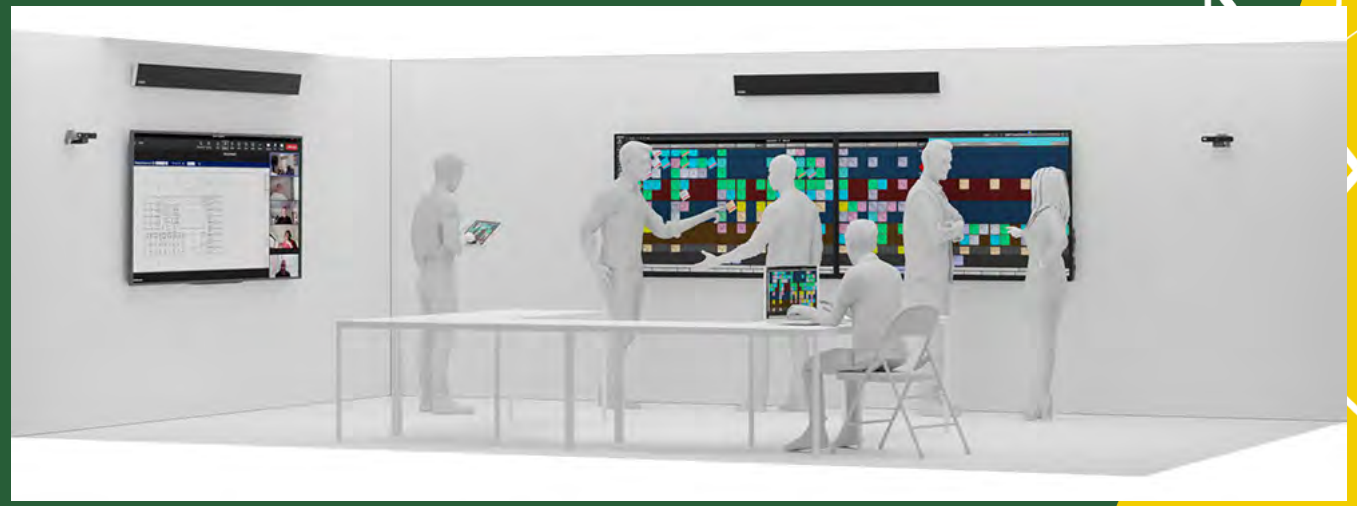
(Key Points)

- Reality Capture
- Computer Vision
- Real-Time Digitalization and Simulation
- Decision-making Support Applications

S. AbouRizk and Y. Mohamed, "Simphony-an integrated environment for construction simulation," *2000 Winter Simulation Conference Proceedings (Cat. No.00CH37165)*, Orlando, FL, USA, 2000, pp. 1907-1914 vol.2, doi: 10.1109/WSC.2000.899185.

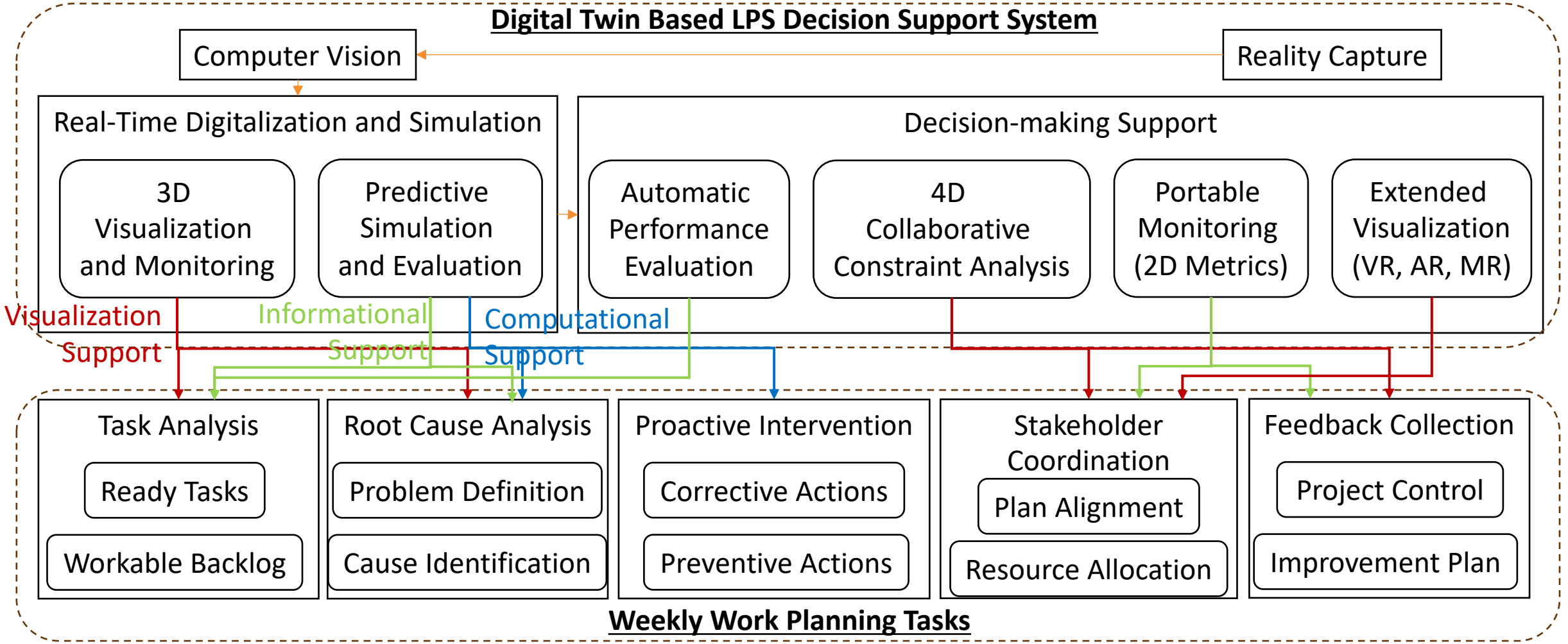
Monitoring App Wireframe

Digital Visual Planner



UNIVERSITY OF ALBERTA

Summary


Digital Twin Based LPS Decision Support System
Computer Vision
Reality Capture
Real-Time Digitalization and Simulation
3D Visualization and Monitoring
Predictive Simulation and Evaluation
Decision-making Support
Automatic Performance Evaluation
4D Collaborative Constraint Analysis
Portable Monitoring (2D Metrics)
Extended Visualization (VR, AR, MR)
Visualization Support
Informational Support
Computational Support
Task Analysis
Ready Tasks
Workable Backlog
Root Cause Analysis
Problem Definition
Cause Identification
Proactive Intervention
Corrective Actions
Preventive Actions
Stakeholder Coordination
Plan Alignment
Resource Allocation
Feedback Collection
Project Control
Improvement Plan
Weekly Work Planning Tasks

A validation of an Immersive Virtual Reality-based Last Planner System (LPS) Simulation Game to Study the Social Mechanisms Produced by LPS

Researcher: Canlong Liu

PhD Candidate in Civil Engineering

THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

ENGINEERING

Motivation of this research

- The barriers of LPS implementation (Liu et al. 2020):
  - Resistant to change
  - Lack of cooperation
  - Limited understanding of the LPS knowledges
  - ……
- The effectiveness of LPS implementation can be improved by identifying the missing or ineffective social mechanisms engendered during its implementation process and managing it more effectively within the socio-technical dynamics of the LPS.

- It is necessary to examine how LPS's tools and procedures influence the social interactions and emergent cognitive, affective states within project teams, as well as how these dynamics enhance positive teamwork (Asadian and Leicht 2022; Liu et al. 2020)

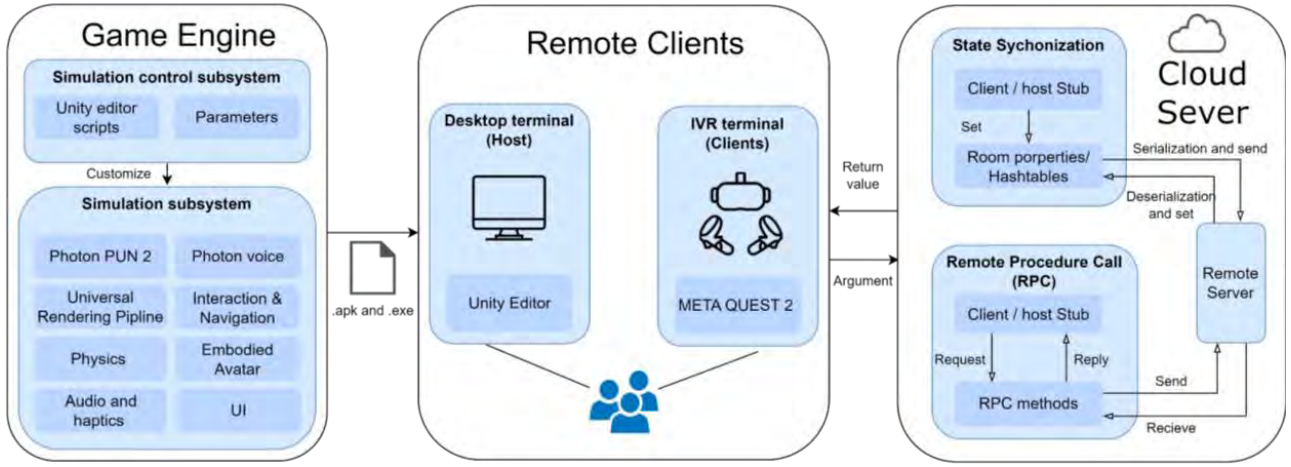
Motivation of this research

- Limitations of the traditional research approaches for studying social mechanisms engendered by the LPS (Liu et al. 2023):
    - Case study: lack of experimental control, retrospective data collection.
    - Computer simulation: limitations to simulate irrational social behaviours or individuals' behaviours.
    - Hands-on simulation: Lack of social-technical realism.

- Instead, we propose the use of immersive virtual reality (IVR) to investigate the social mechanisms that LPS engenders in projects. Advantages of IVR (Feng et al. 2020): Experimental control, enhanced ecological validity, easy to integrate biometric sensors.

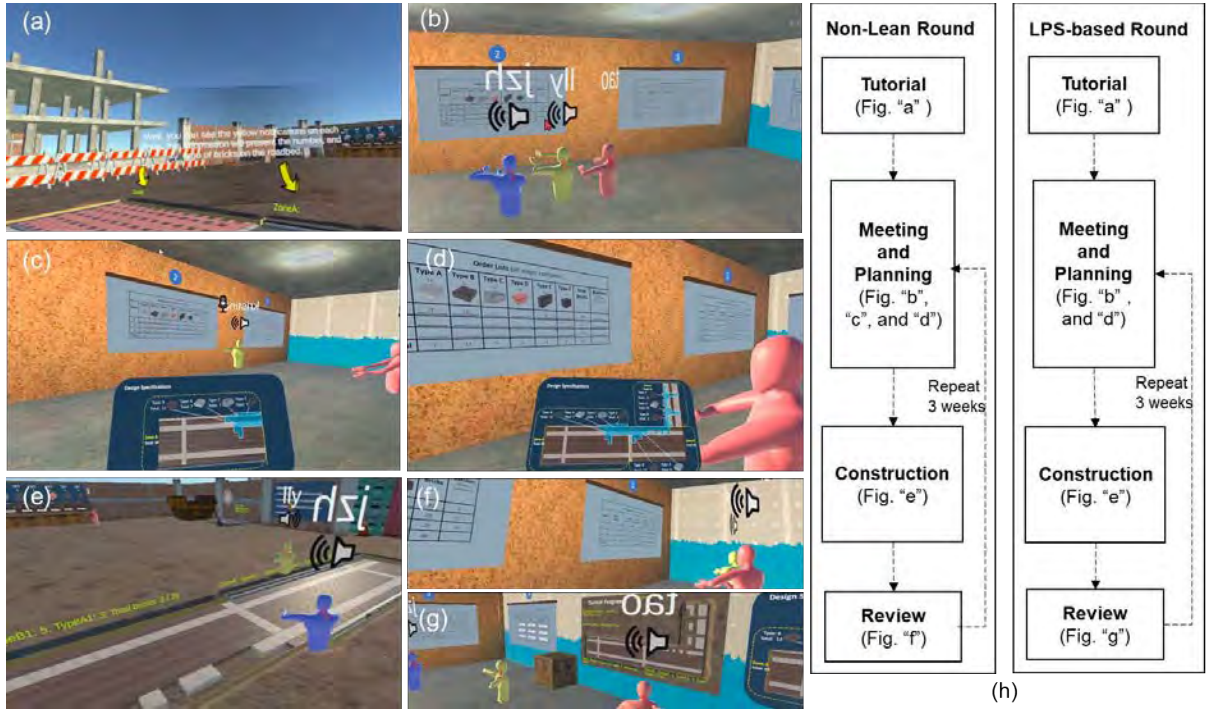
- We have developed a Multi-user Immersive Virtual Reality-based LPS (MILPS) as a research tool.

MILPS Framework



System architecture

Storyline



MILPS Framework

LPS elements	Simulation controls and rules in two rounds	
	Non-Lean	LPS-based
Decision-making	Only manager make the plan	All users negotiate the plan
Transparency	Only manager have master plan design, others only have zone-specific designs; Only manager can get access to progress information	All users have master plan design; All users can get access to progress information
Pull flow	Not applied, the manager pushes the plan on others	The subcontractor should request resources when needed verbally and directly to the supplier
Lookahead planning	Not applied, users can only order one week's materials	Users can pre-order materials
Commitment planning	Not applied, tasks released by manager's requests	Tasks released by users' commitments
Continues improvement	Only PPC measure	Users should review and analyze the PPC, RNC.
Continuous Flow	Not applied, number of Batch is limited	Number of Batch can change if needed

Simulation controls and rules in MILPS.

Research Aim and Objectives

- MILPS user's experience and usability have been tested. However, the ecological validity of MILPS is under examination.

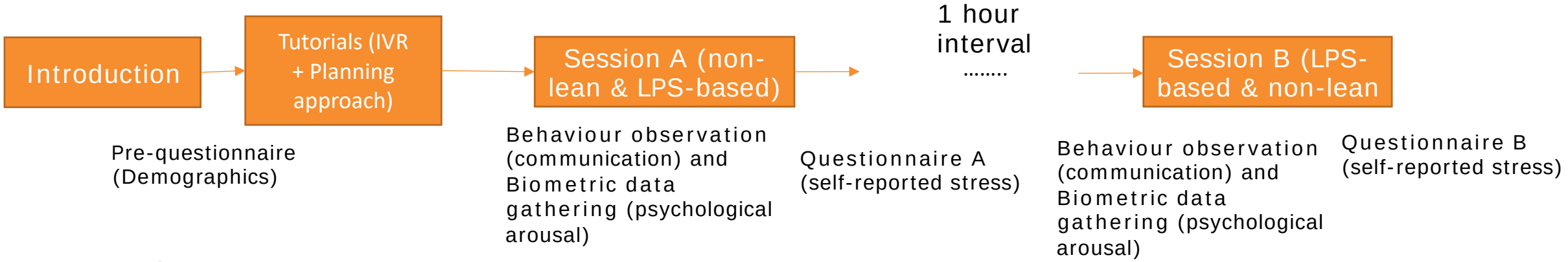
- Aim: To evaluate the ecological validity of a multiuser IVR research tool to study the social mechanisms that LPS engenders in projects.

  - Objective 1: To assess whether the key social mechanisms associated with LPS can be captured in an IVR environment.

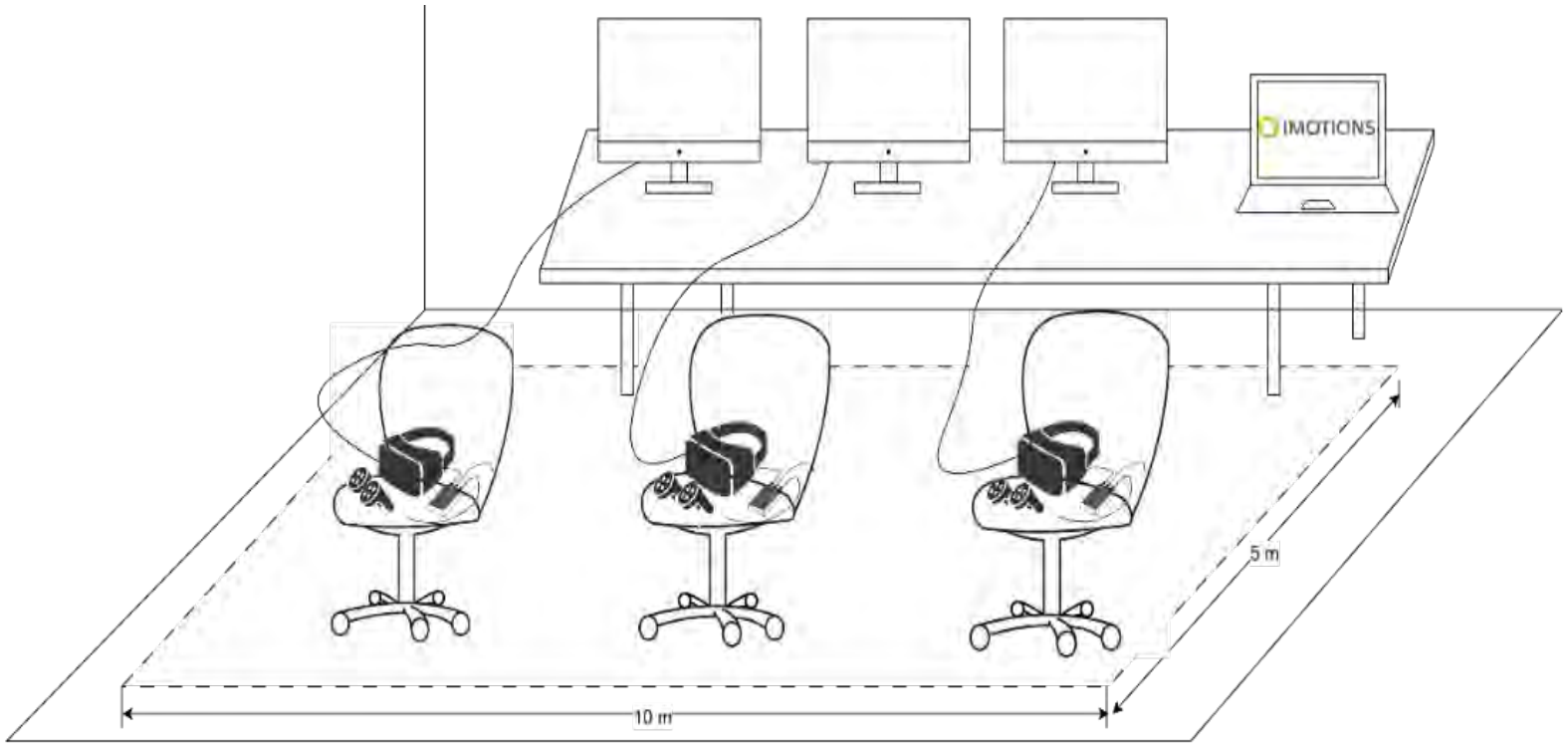
  - Objective 2: To assess whether the findings in the IVR environment are consistent with the existing empirical evidence from literature.

Research method

- We assessed two key social mechanisms associated with the LPS use: reduced stress level and improved communication.
- Participants: 90 university students were organized into teams of three participants each. Participants were randomly assigned to each group.
- Within-subject design: 30 groups needed to play two rounds of simulation (Non-Lean and LPS-based rounds) in random order and at one-hour intervals.
- Measures: Stress (self-reported stress score and physiological data measuring heart rate, interbeat interval, skin conductance level), Communication (Behavioral coding on task-based interactions, positive/negative relational interactions)
- Procedure:



Experiment setup and devices

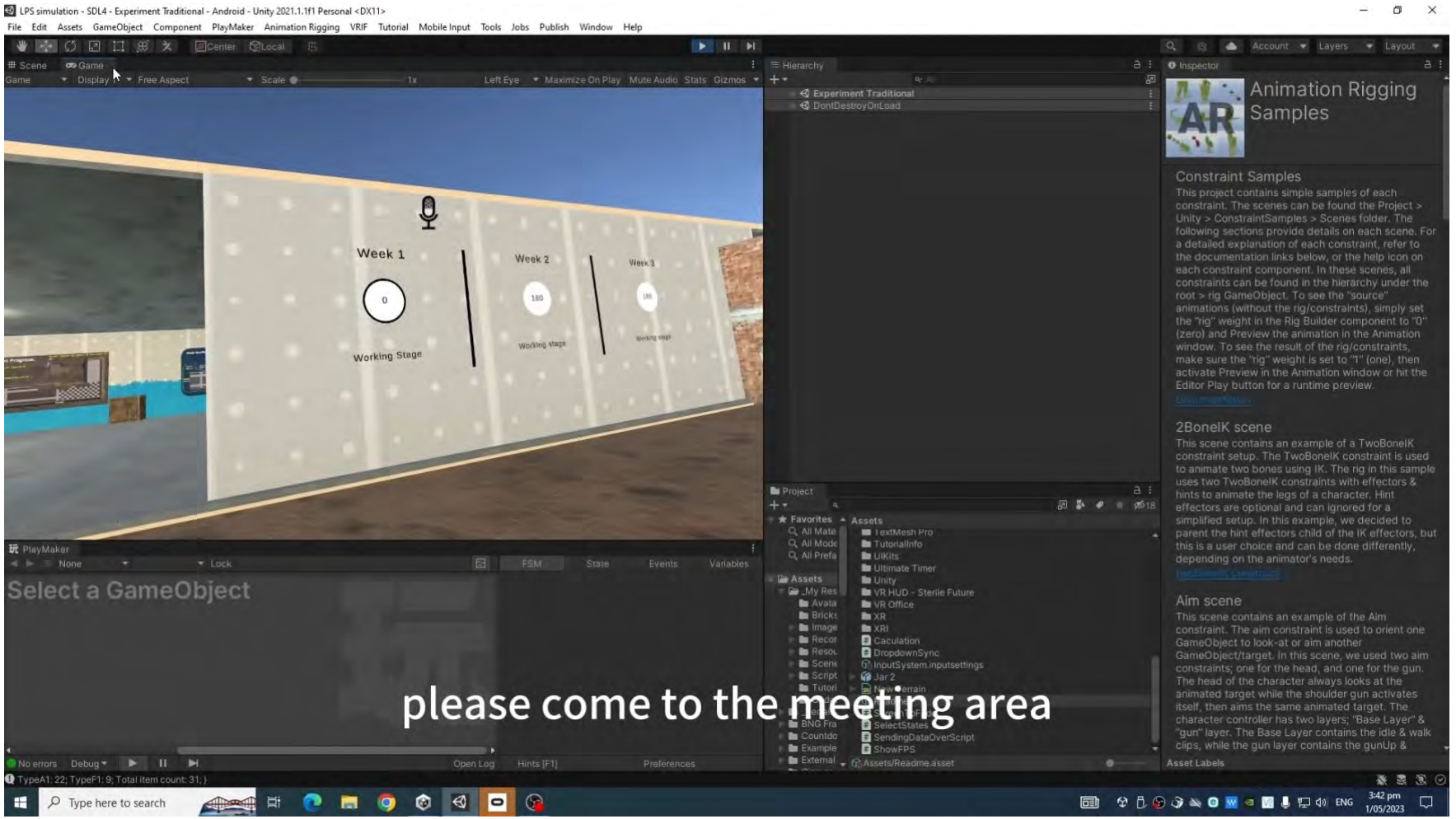


- Three Oculus quest 2 (tendered mode), each of them were connected with a desktop.
- The desktop was used for behaviour coding and observation.
- Shrimmer GSR plus sensors (GSR electrodes and PPG ear clips) was installed to every participants to collect biometrical signal.
- Laptop was used for receiving the signal from sensors and for data analyses

Simulation Video

-An example of the Manager

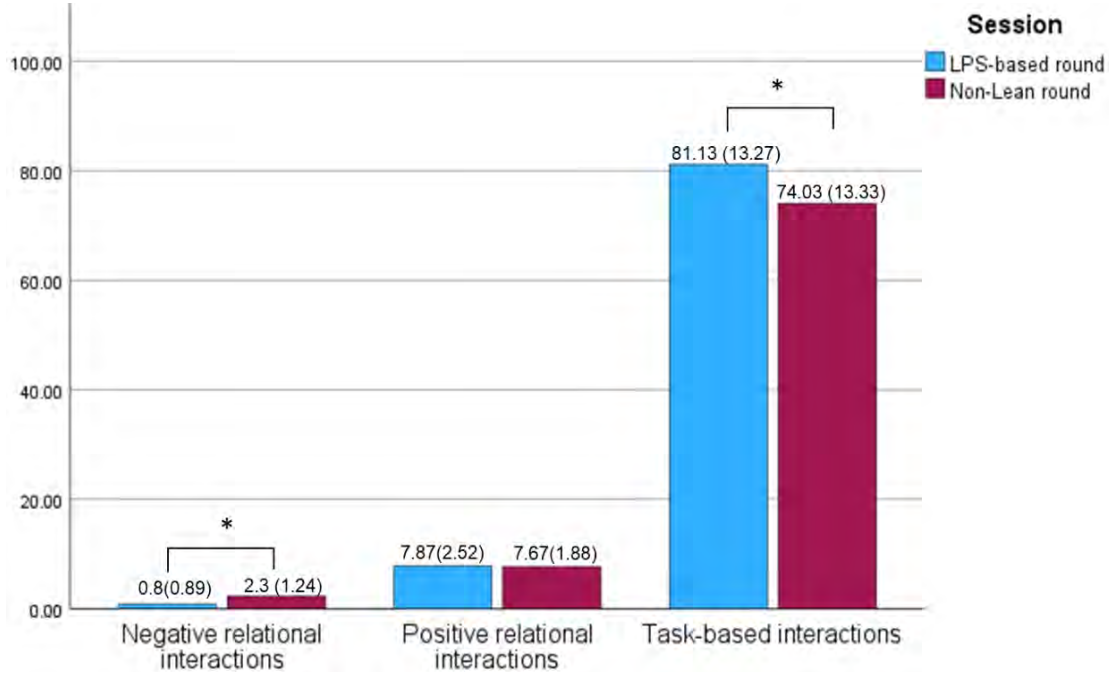
- The video shows that the Manager is making the plan and discussing with other participants at the 2nd week's meeting.



Results

- We compared the difference of these variables in two rounds. Then these results were compared to evidence in existing literature

- Communication:
- More task-based interactions but less negative relational interactions were founded in the LPS-based round
- No significant difference found on positive relational interactions between LPS-based and Non-Lean round (consistent with Ghosh et al., (2019)'s research)
- Stress level:
- Physiological data: higher emotional arousal in Non-Lean round compared to LPS-based round
- Self-reported data: lower level of stress reported in LPS-based round (consistent with Mossman (2019)'s research)



Note: *Wilcoxon ranked sign test with alpha level: 0.05

Physiological and psychological metric		Non-Lean round (mean SD)	LPS-based round (mean SD)	p value	statistics
GSR and PPG data (N = 86)	Mean SCL (µS/cm)*	1.99 (1.32)	0.74 (1.01)	<0.05**	w = 460
	Mean HR*	2.97(8.1)	1.3 (7.37)	0.09	w = 1619
	Mean IBI (µs) *	-16.77 (57.73)	-16.76 (90.75)	0.375	w = 2268
Questionnaire data (N = 90)	Mean stress scores	13.14 (1.3)	12.33 (1.22)	<0.05**	t = 5.51

Note: Wilcoxon ranked sign test (w), T-test (t)

Discussion and conclusion

- Based on the results from behavior observation, psychological and physiological measurements, the difference in stress level, and communications between the Non-Lean round and the LPS-based round were evaluated.

- This study established the MILPS environment's validity by showing the consistency of behavioral and psychophysiology data collected in IVR and empirical evidence identified from Lean literature.

- This study confirms that IVR environments can enable the gathering of valid behavioral, psychological and physiological data, and has ecological validity to study some of the key social mechanism that LPS engenders in real projects in the context and given the scope of this research.

DIGITALISATION OF THE CONSTRUCTION INDUSTRY THROUGH LEAN CONSTRUCTION 4.0

Prof. Vicente A. Gonzalez
Tier 1 Canada Research Chair in Digital Lean Construction

Hole School of Construction Engineering
Department of Civil and Environmental Engineering
Faculty of Engineering

UNIVERSITY OF ALBERTA