Integrating Stereo Vision and Machine Learning for Autonomous Robotic Masonry Block-Laying

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Introduction

Masonry construction involves highly repetitive, sequential movements that make it well suited for robotic automation. Existing masonry robotic systems (Hadrian X, SAM100) achieve high block and brick and block placement performance. However, to do so reliably, these systems require a combination of encoders, laser-guided sensors, fiducial markers, and specialized hardware, all of which are needed to continuously measure and track spatial variables such as block position, orientation, and alignment through the operation. This hardware dependency add costs, setup time, and complexity, limiting adoption beyond large specialized projects.

To address these hardware limitations, we developed a simpler approach: a single stereo camera mounted on a collaborative robot arm, paired with an AI model trained to recognize concrete masonry units (CMUs). The camera captures a 3D view of the workspace, the AI model identify target blocks, and the system calculates their exact position and orientation.

Objectives

Develop a single-camera framework for autonomous CMU handling. The system is designed to:

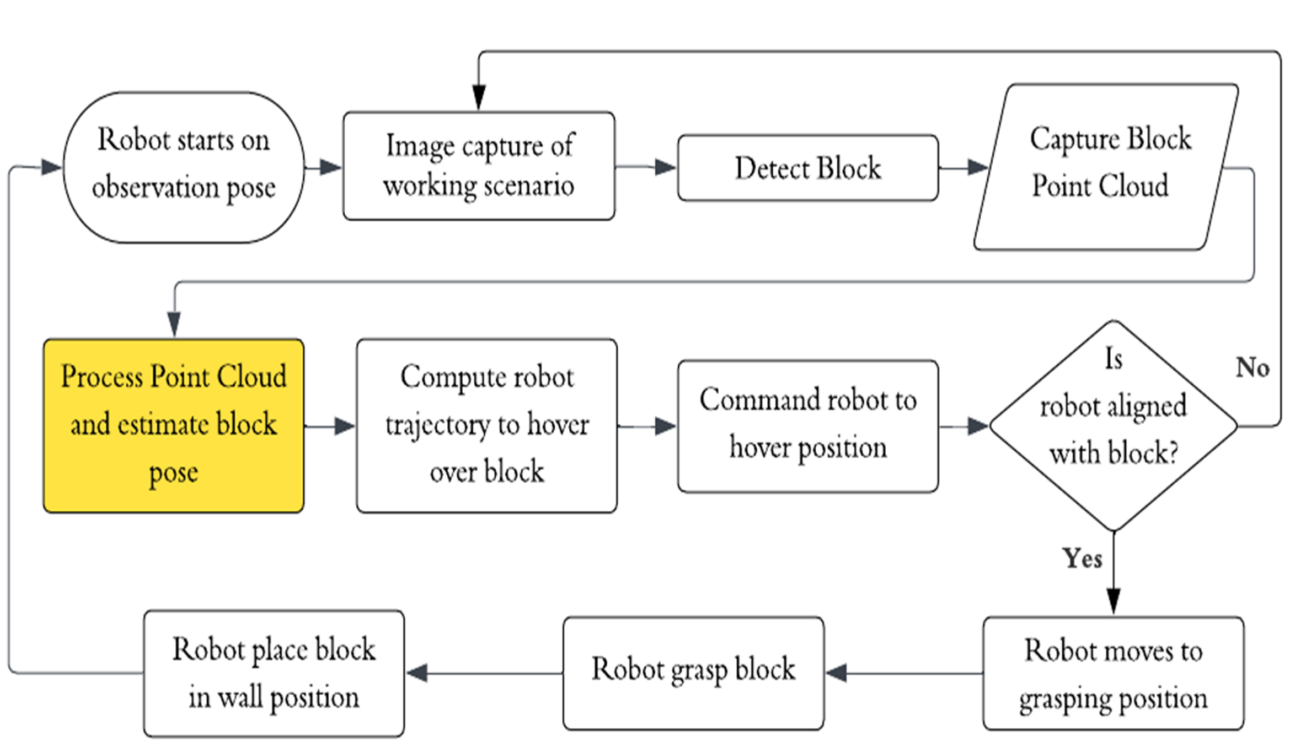
1. **DETECT** masonry blocks using an AI model (YOLOv8) trained to recognize CMUs from camera images.
2. **DETERMINE** each block's exact 3D position and orientation from stereo point-cloud data.
3. **AUTOMATE** pick-and-place operations by translating the block pose into robot motion commands.

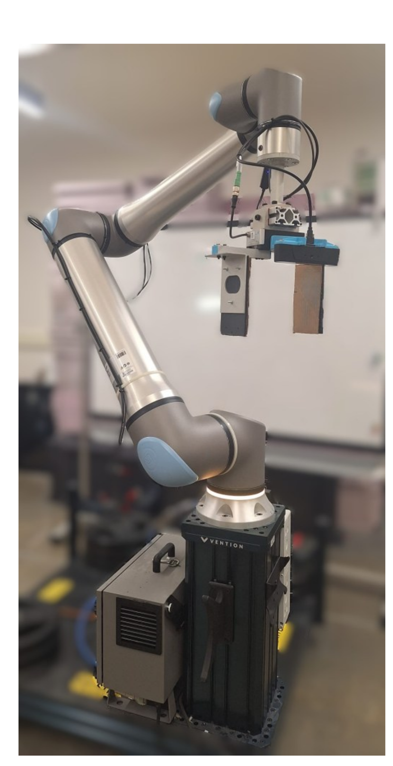
Materials and Methodology

The main materials are: UR20 robotic arm + ZED 2i stereo camera (robot mounted) + electric parallel gripper with custom CMU pallets.

The methodology integrates three capabilities into one closed-loop automated workflow:

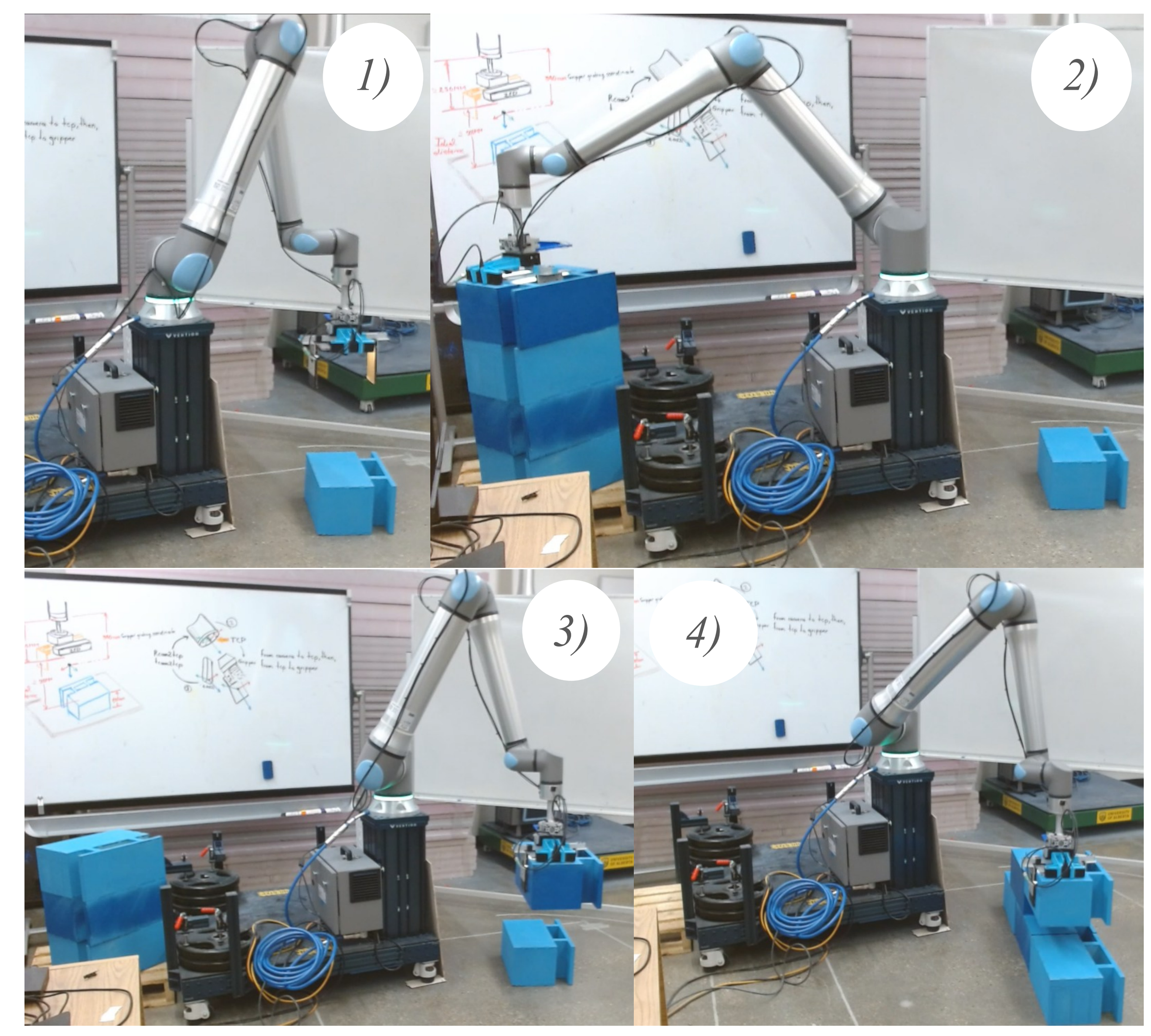
- **Detection:** AI model (YOLOv8) scans the camera image and identifies CMU blocks with 99.9% accuracy. The detected region is mapped from the 2D image into the 3D point cloud.
- **Pose Estimation:** Color filter removes noise → plane-fitting (RANSAC) extracts the block's top surface → orientation analysis (PCA) defines the block's axes → full 3D position and orientation obtained.
- **Automated Grasping:** Block pose converted to robot coordinates → arm hovers above block → descends → grasps → places at wall position. Cycle repeats automatically.





Proposed system workflow: from camera observation to automated block placement as well as robot arm setup

Results and Discussion



Robotic masonry system working with the proposed methodology in a closed loop system.

Following the proposed methodology, the user sets a CMU where the masonry wall should be built, serving as a reference starting point, then inputs the number of rows, blocks and direction in which the masonry assembly should be. The system then autonomously scans and locates the reference block (1), moves to the pallet zone where CMUs are stored (2), grasps the target block (3), and places it at the required wall position (4). The process repeats until the full assembly is complete.

75 trials | 96% success rate

Avg. position error: 1.25 mm
Max. position error: 2.98 mm
Avg. orientation error: 0.76°
Max. orientation error: 3.38°

Full video sample here

Conclusions

- The proposed system was successfully validated: a single stereo camera combined with an AI model is sufficient to detect masonry blocks, determine their position and orientation, and guide a robot to pick and place them autonomously.
- By eliminating the need for laser guides, fiducial markers, and multiple sensors arrays, this approach reduces hardware complexity and simplifying the adoption of robotics systems in masonry construction.
- The system achieved millimeter-level accuracy and a 96% success rate, demonstrating that stereo vision is robust enough to be implemented in construction tasks.
- Next steps include improving the accuracy of the detection model, as well as test the system under real job-site conditions, including variable lighting, dust and outdoor environments.

Acknowledgement

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Autonomous Drone Navigation for Structural Inspection Using 3D Gaussian Splatting and Optimization-based Path Planning

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Introduction

1. Infrastructure Condition at Risk

Many civil engineering structures, particularly bridges, are now operating well beyond their originally intended design service lives. As these structures age, regular inspection becomes vital to detect damage and prevent catastrophic failures.

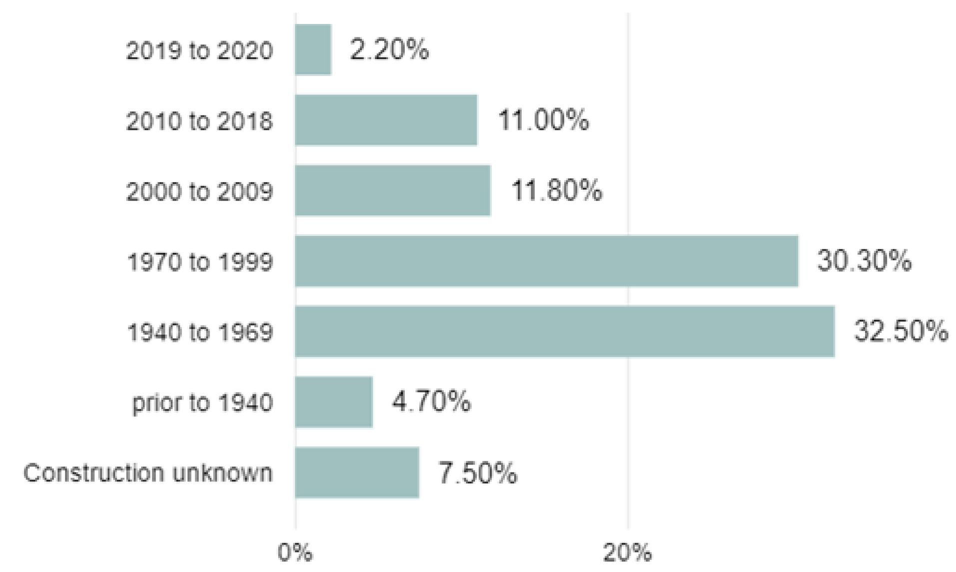

Figure 1: Year of construction of rural highways and bridges in Canada (Statistics Canada, 2020).

2. The Bottleneck: Labor-intensive Methods

Traditional inspection methods rely heavily on manual access such as scaffolding, under-bridge units, or rope-supported inspections, exposing personnel to safety risks and requiring prolonged traffic closures. Data quality is inconsistent, depending on the inspector's line of sight and subjective judgment.

Figure 2: Manual crack measurement on bridge surface.

Objectives

1. To develop a **fully autonomous drone inspection pipeline** integrating 3D Gaussian Splatting (3DGS) with optimization-based path planning.
2. To demonstrate that 3DGS can deliver high-fidelity, georeferenced 3D models directly from video capture within minutes, enabling **near real-time** field deployment.
3. To establish a robust link between reconstructed 3D models and autonomous path planning, allowing the drone to execute optimized, **repeatable flight missions**.
4. To validate the framework through both simulation and field testing on the **Low Level Bridge in Edmonton**, Canada.

Methodology

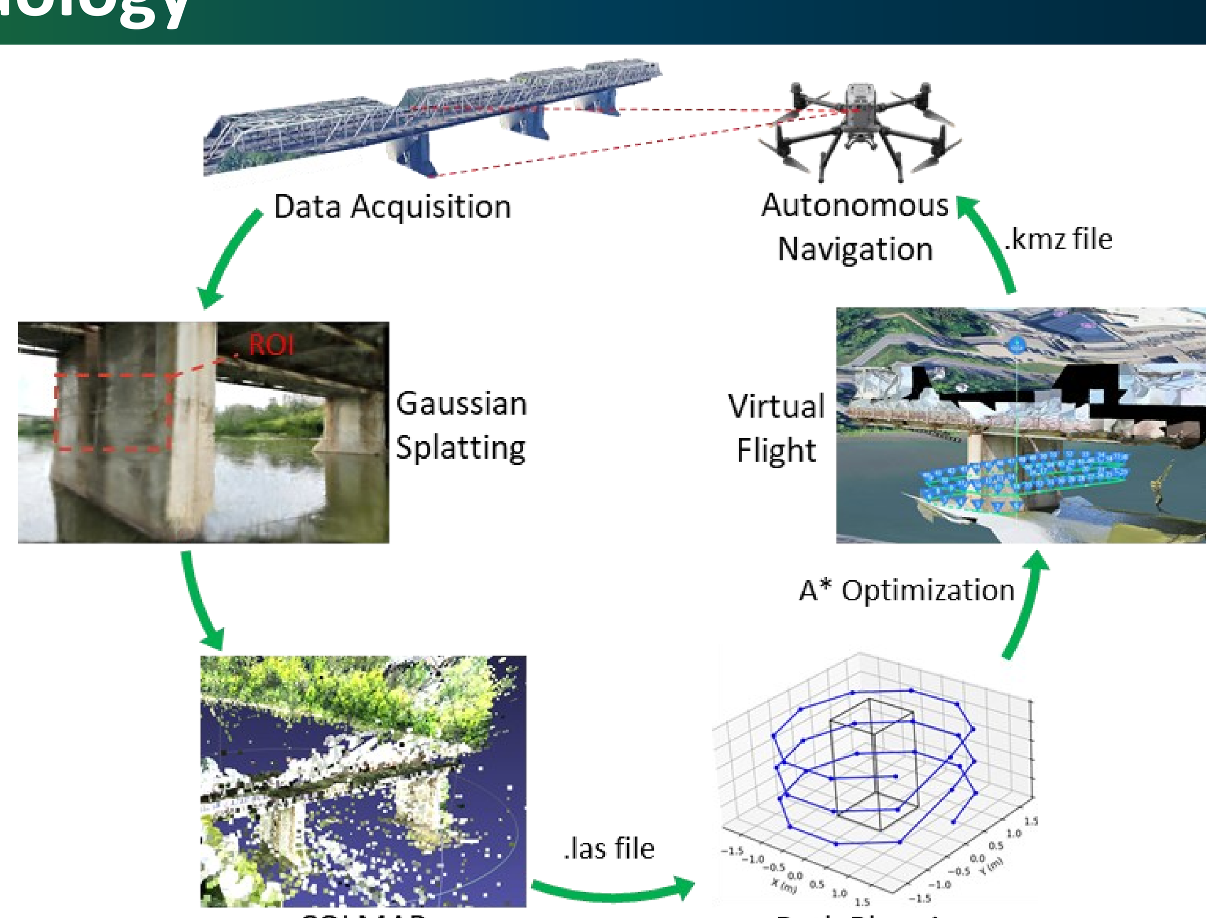

Figure 3: Overview of the proposed autonomous drone inspection framework.

Results

1. Field Test: Low Level Bridge, Edmonton

The framework was evaluated on the Low Level Bridge (opened 1900) in Edmonton, Canada. A DJI Matrice 350 RTK with Zenmuse H30T camera captured continuous 4K video of the first concrete pier on the southern approach.

Figure 4: Field data collection on the pier.

2. 3D Gaussian Splatting Reconstruction

The 3DGS model was trained using 160 image frames for 30k iterations on an NVIDIA A6000 GPU, completing in 23 minutes 33 seconds with 988,970 Gaussian primitives.

(a) Ground truth (b) 7k training (05 min 07 s) (c) 30k training (23 min 33 s)

Figure 5: Visual progression of 3DGS reconstruction.

Key Finding: By 7k iterations (~5 minutes), the renderer already produces photorealistic previews sufficient to localize and mark ROI in the field.

3. Path Planning and Optimization

45.8% reduction in flight time relative to the default route in DJI FlightHub 2.

Table 1: Comparison of Flight Path Performance.

Mission Type	Default Route	Optimized Route
Flight Distance (m)	999.0	**387.9**
Flight Time (s)	1433	**776**
Coverage (%)	100.0	**91.4**

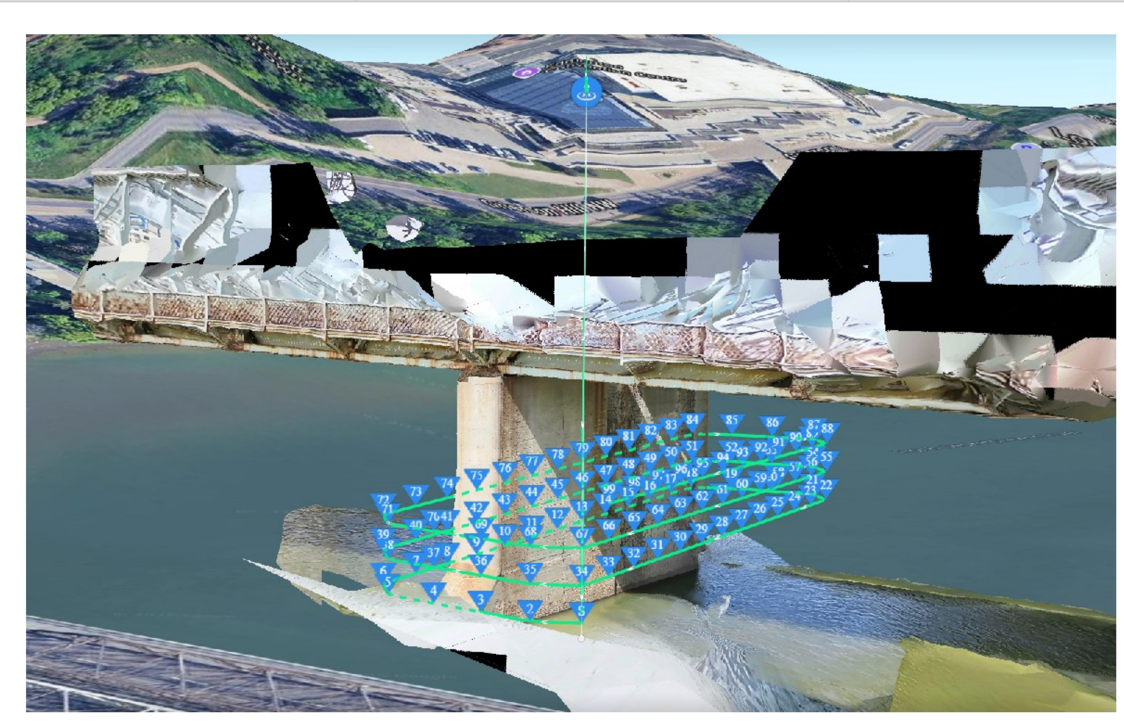

Figure 6: Optimized flight path.

Conclusions

1. The proposed pipeline successfully reconstructs georeferenced 3D models of bridge structures using 3DGS, with photorealistic previews generated in **~5 minutes** of training.
2. The optimization-based path planning module (3D A* + TSP) effectively generates collision-free flight routes with controllable standoff distances.
3. Virtual simulations demonstrate a **45.8% reduction** in total mission time vs. the default route.
4. Field verification on the Low Level Bridge confirms the **reliability and repeatability** of the optimized mission for ongoing structural inspections.

Acknowledgement

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Mapping Trust in Construction: A Multidimensional Framework for Collaborative Project Delivery

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CONSTRUCTION INNOVATION CENTRE
Research Driving Change

Introduction

Construction projects are inherently people-driven enterprises, yet persistent adversarial relationships, fragmented teams, and poor collaboration culture continue to undermine project outcomes globally. Trust is widely recognized as a cornerstone of collaborative project delivery, enabling open communication, shared risk-taking, and mutual commitment.

Despite this recognized importance, the AEC literature offers only four trust frameworks specifically tailored to construction projects. The most cited, Wong et al. (2008), is nearly two decades old. Existing frameworks do not capture modern system-level or environmental trust factors, conflate interpersonal and inter-organizational trust, and none have been validated against North American construction practitioners.

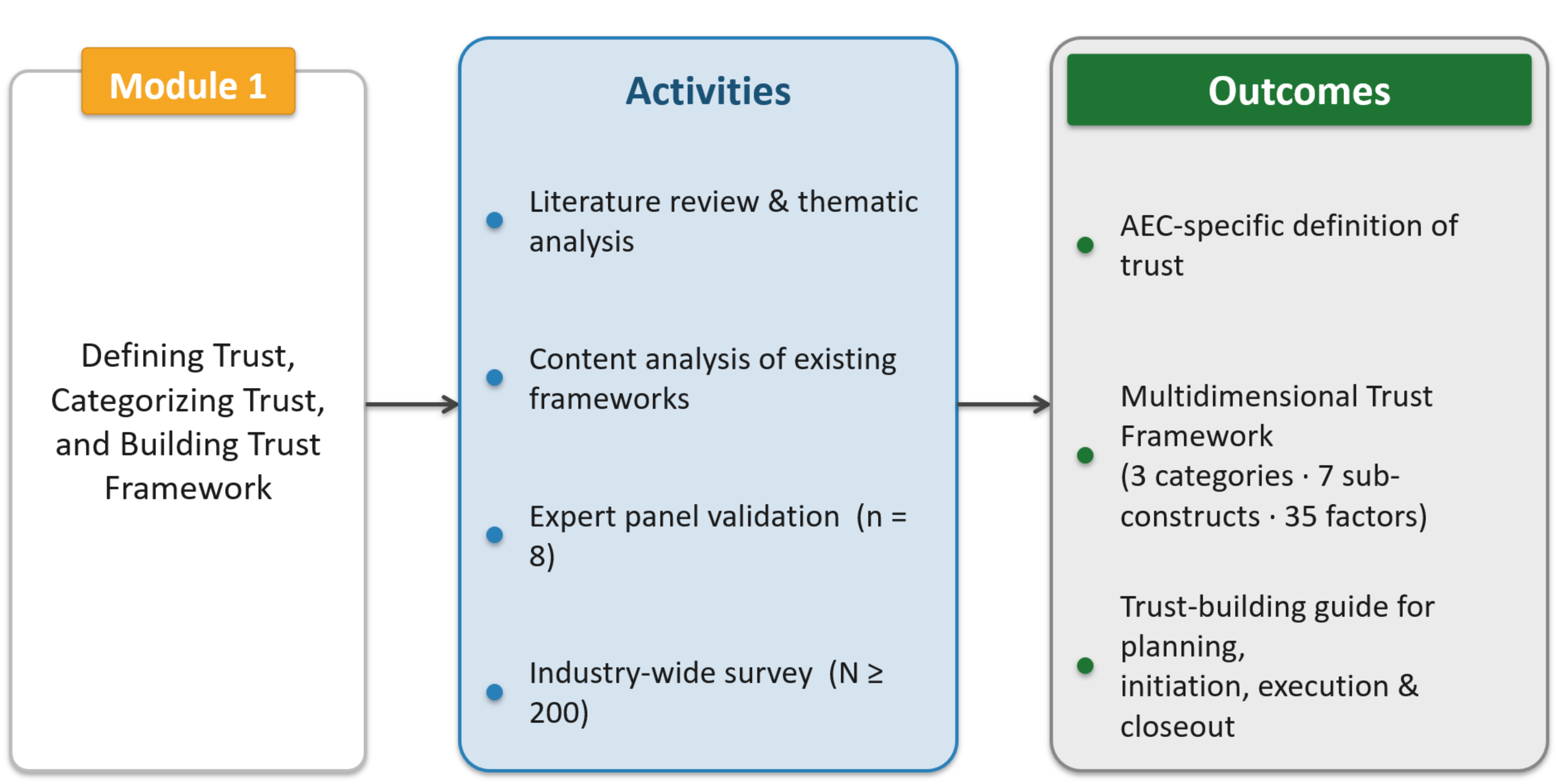
This research fills this gap by developing and empirically validating the first comprehensive, AEC-tailored Multidimensional Trust Framework for construction project delivery in North America. This research embodies the CIC Forum theme "Built by People, Powered by Technology"; Our framework conceptualizes the people-side of project collaboration, while positioning digital platforms and information systems as system-based trust enablers.

Objectives

1. Develop an AEC-specific definition of trust through thematic analysis of 45 definitions from multidisciplinary literature, producing a thematic map of trust and a construction-specific definition.
2. Categorize types of trust on construction projects through systematic review of 14 existing trust categorizations, framework construction, and expert panel validation (n=8).
3. Develop a trust-building guide outlining methods for trust planning, initiation, and development across project stages (procurement, mobilization, execution, closeout), validated by industry experts.

Materials and Methods

Design Science Research (DSR) methodology was applied, guided by Hevner's (2007) three-cycle framework: relevance (practical problem), rigor (knowledge base), and design (iterative artifact development).

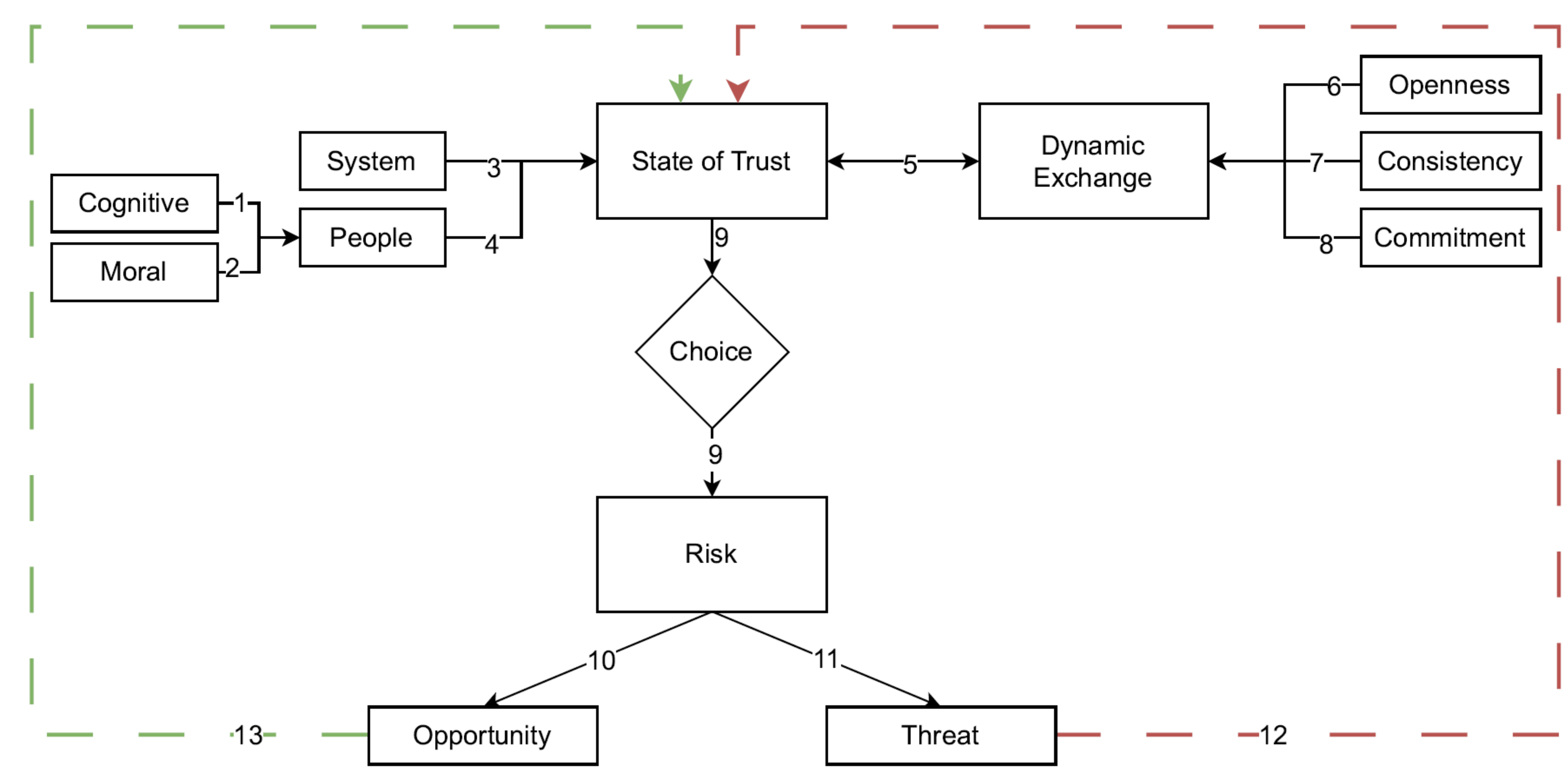


Phase 1 — Trust Definition: Thematic analysis of 45 trust definitions from multidisciplinary literature; produced thematic map and AEC-specific definition. Published: Malaeb & Hamzeh (2025).

Phase 2 — Framework Development: Systematic review of 14 existing trust categorizations; DSR-guided framework construction; expert panel validation with 8 senior AEC professionals from North America.

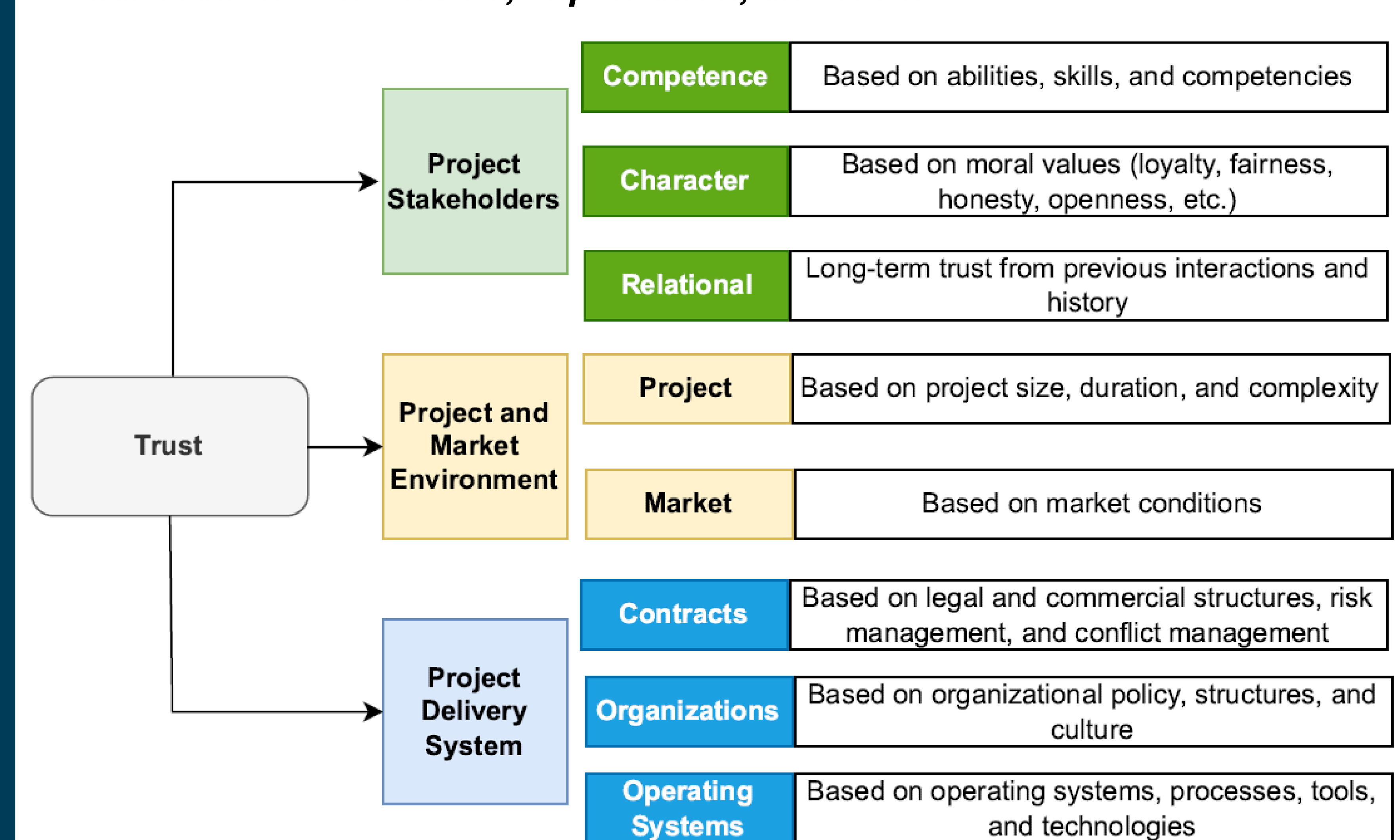
Phase 3 — Empirical Validation: Industry-wide survey targeting N≥200 North American AEC practitioners. Analysis: Relative Importance Index (RII), Cronbach's α, Pearson correlation, Exploratory Factor Analysis (EFA), and PLS-SEM.

Results and Discussion



Thematic Map of Trust

*"Trust is a **state of mind** and is earned, built, grown, and maintained through the **dynamic exchange** between project stakeholders. It is based on the trustor's perception of (1) **people**, being the project stakeholders, presented through **cognitive** and **moral** factors and (2) **systems**, being the project delivery system, presented through the **contract, organizational structure, and operating systems**. To trust is a voluntary choice to take a **risk**. As a risk, trust carries **uncertainty** and mandates becoming **vulnerable** by relying on others. It can lead to **positive opportunities, mutual benefits, and collaboration** or to **threats, exploitation, and loss.**"*



Trust Framework for the AEC Industry.

Conclusions

1. Presents a comprehensive, empirically validated trust framework specifically tailored to AEC project delivery.
2. Addresses a longstanding gap in the construction management literature and provides a shared conceptual reference for consistent measurement of trust across studies.
3. Equips project managers and practitioners with a structured, AEC-specific tool to diagnose trust conditions and guide trust-building strategies across all project stages.
4. Supports collaborative delivery models by operationalizing trust as a manageable, diagnosable project construct.
5. Lays the foundation for ongoing research: social network analysis of trust in project teams (Objective 2) and an agent-based simulation tool for trust-informed team selection (Objective 3).

Acknowledgements

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Automated Construction Activity Sequencing:
A Review and Reframing Through Multidomain Activity Attributes

CONSTRUCTION INNOVATION CENTRE
Research Driving Change

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Introduction

In real construction processes, the sequence of activities arises from the interplay of multiple constructability domains, including structural support, spatial accessibility, trade coordination, safety requirements, and overall project context. Existing automated scheduling methods rarely make these cross-domain interactions explicit when determining activity order. Therefore, sequencing should be reframed as a multidomain feasibility evaluation problem, where precedence relationships emerge from the interactions among activities rather than from predefined rules.

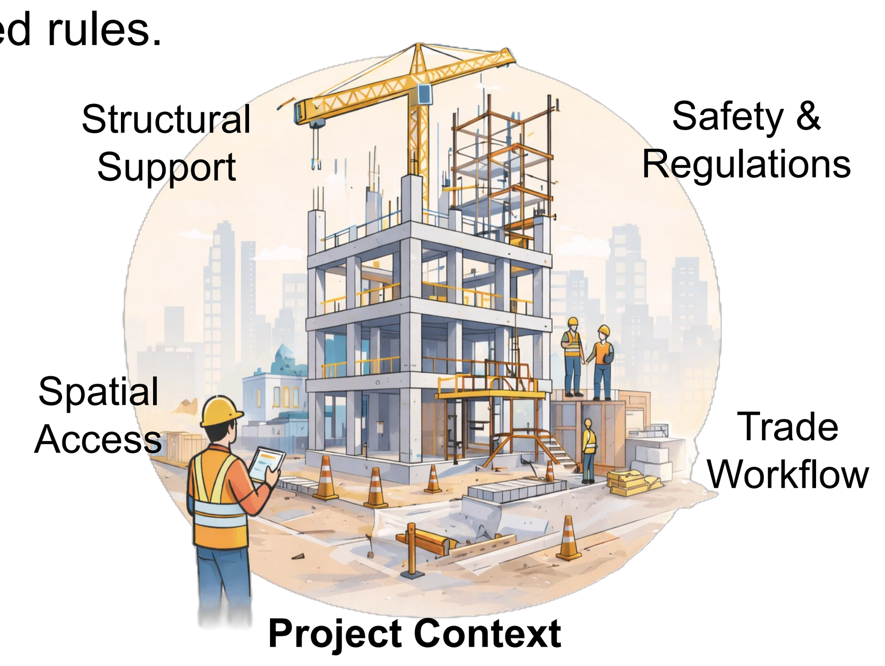


Figure 1: Activity sequencing emerges from interactions across multiple constructability domains

Objectives

1. Critically review existing automated approaches to construction activity sequencing in the literature
2. Examine how activity representation and sequencing knowledge govern precedence generation and identify structural limitations in existing sequencing paradigms
3. Propose Attribute-Based Activity Sequencing Framework (ASF) as a multidomain feasibility-driven framework for sequencing.

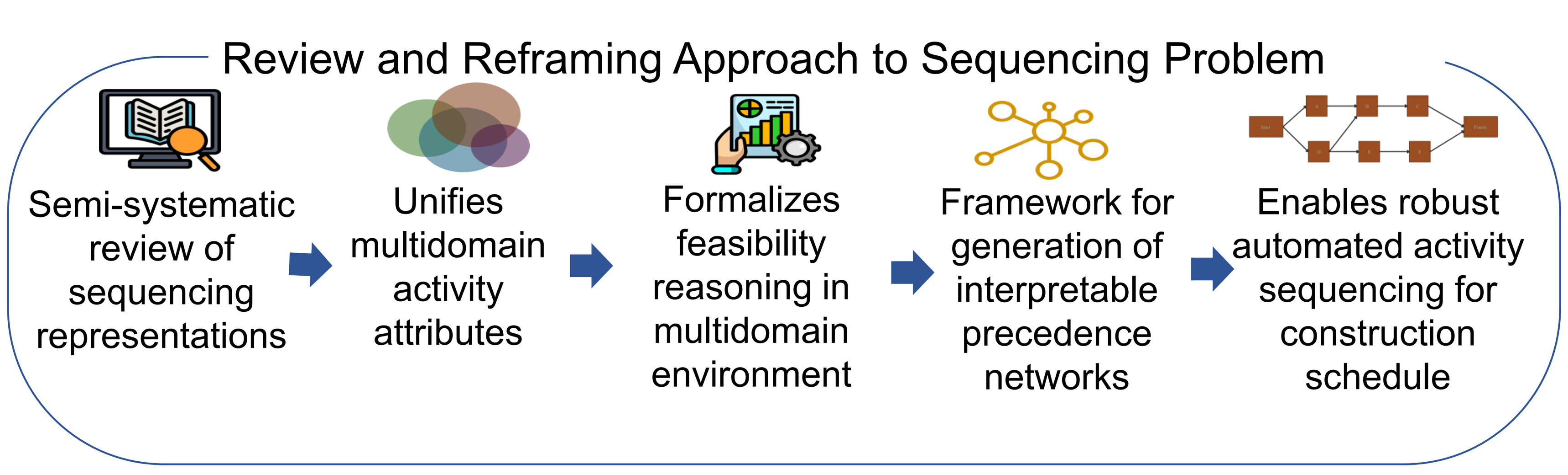
Materials and Methods

A semi-systematic literature review was conducted using Scopus and Web of Science.

The analysis focused on three key dimensions:

- Activity representation
- Knowledge encoding mechanisms
- Precedence generation logic

The synthesis leads to a conceptual reformulation of sequencing as domain-aware feasibility evaluation across constructability conditions.



Results and Discussion

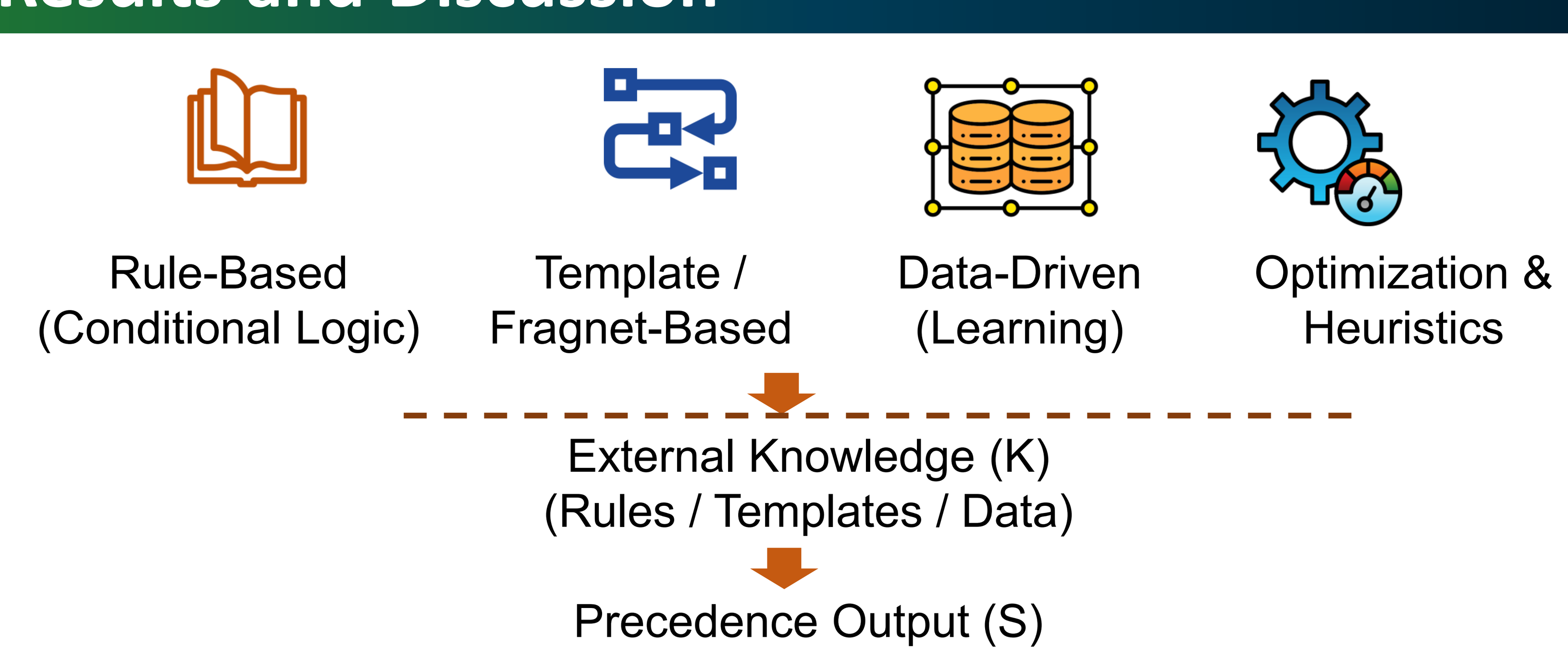


Figure 2: Conventional Approach to Deriving Precedence Relationships

Result and Discussion

Limitations of Existing Approaches

- Dependence on predefined rules and templates
- Reduction of activities to symbolic representations
- Limited capture of real constructability conditions
- Poor adaptability to dynamic construction environments

Key Synthesis:

Sequencing is not a rule activation problem- it is a constructability evaluation problem

Table 1: Comparison of Activity Sequencing Paradigms and the Proposed ASF Framework

Paradigm	Knowledge Source	Key Limitation
Rule-Based	Expert rules	Poor scalability
Dependency Lists	Manual input	Non-generative
Template-Based	Workflow templates	Limited flexibility
BIM-Based	Model semantics	Limited constructability logic
Data-Driven	Historical data	May not ensure feasibility
ASF (Proposed)	Attributes + Context	Feasibility-driven, adaptive

Attribute-Based Activity Sequencing Framework

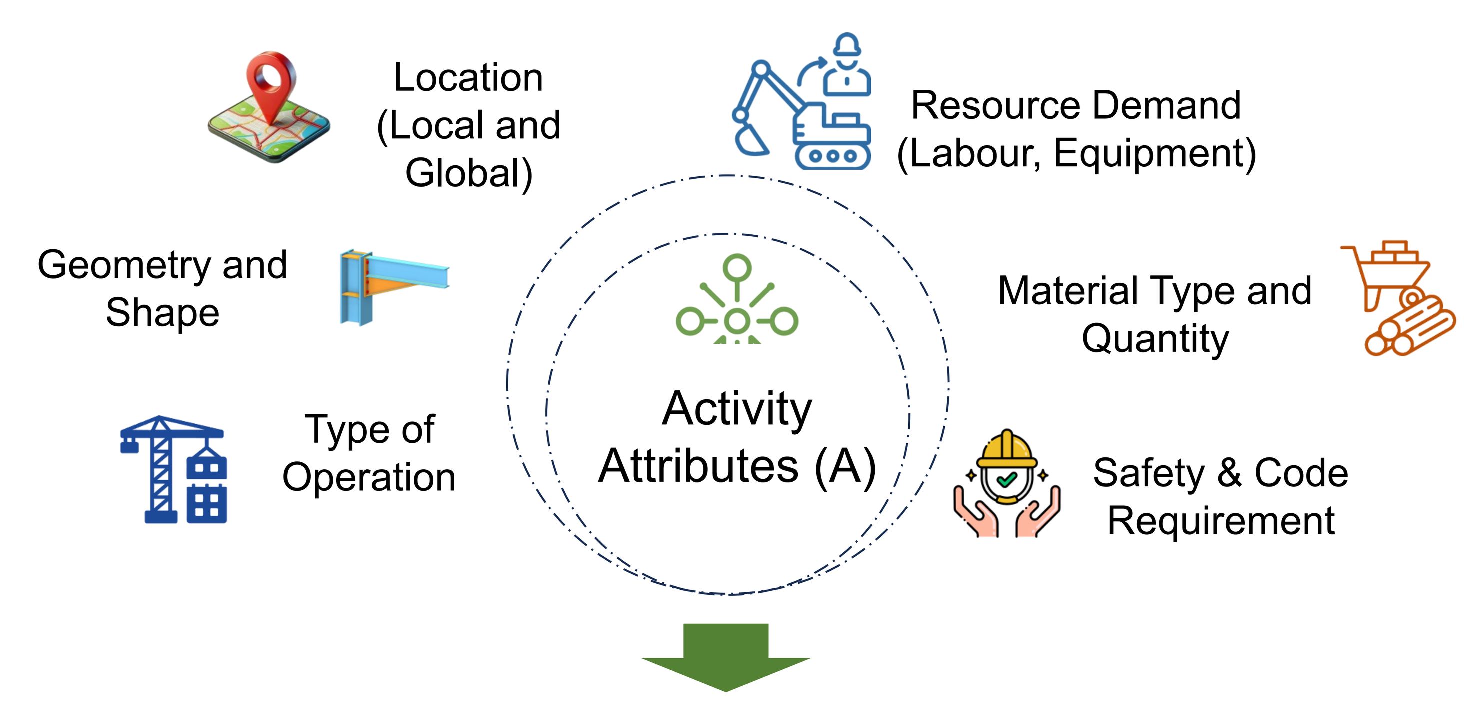


Figure 3: Attribute Based Multi Domain Feasibility Evaluation
→ Precedence Network (S)

Transparent • Explainable • Constructability-Aware

Conclusions

Existing automated construction sequencing approaches rely on external logic with activities often reduced to symbolic representations. The proposed ASF instead defines sequencing as a multidomain feasibility evaluation, where precedence emerges from interactions among activity attributes. Sequencing relationships are evaluated across five domains: structural support, spatial accessibility, trade coordination, safety and regulatory constraints, and project context, capturing real constructability conditions. Therefore, ASF improves transparency, adaptability, and scalability, while providing a strong foundation for AI-driven scheduling, digital twin integration, and physics-based validation of construction process.

Acknowledgement

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CONSTRUCTION INNOVATION CENTRE *Research Driving Change*

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Advancing Workforce Competencies in Off-Site Construction: A Scoping Review and Expert Interviews

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CONSTRUCTION INNOVATION CENTRE
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Introduction

The construction industry plays an important role in the economy, yet it faces a persistent **shortage of skilled workforce**. Despite the large number of the workforce in Canada, there remains a consistent demand for **skilled labor**.

Number of Construction Workers in Canada (Canadian Construction Association, 2025)

The shortage of skilled workers in OSC is a multifaceted issue.

Inadequate Training and Education
There is a lack of adequate vocational training that is suited for OSC (Ginigadarra et al., 2022).

Skills Mismatch
OSC relies on technologies and the workers do not have the necessary skills (Taylor, 2022)

Aging Workforce
More than 245,100 construction workers are expected to retire by 2032 (BuildForce Canada, 2023).

Low Job Attractiveness
Younger generations are less attracted to construction due to negative perceptions (BDO, 2024).

Objectives

01 Identify competencies reported in the literature related to trade workers in OSC.

02 Analyze the extracted competencies into key themes and map them to KSAO.

03 Refine the preliminary framework through interviews with experts.

Materials and Methods

SCOPING REVIEW	THEMATIC ANALYSIS	EXPERT INTERVIEWS
Identify competencies	**Analyze competencies**	**Validate Framework**
1.1 Search Strategy	2.1 Familiarization	3.1 Participant Selection
1.2 Study Selection	2.2 Coding	3.2 Data Collection
1.3 Data Extraction	2.3 Theme Development	3.3 Data Analysis
1.4 Data Charting	2.4 KSAO Mapping	3.4 Framework Refinement

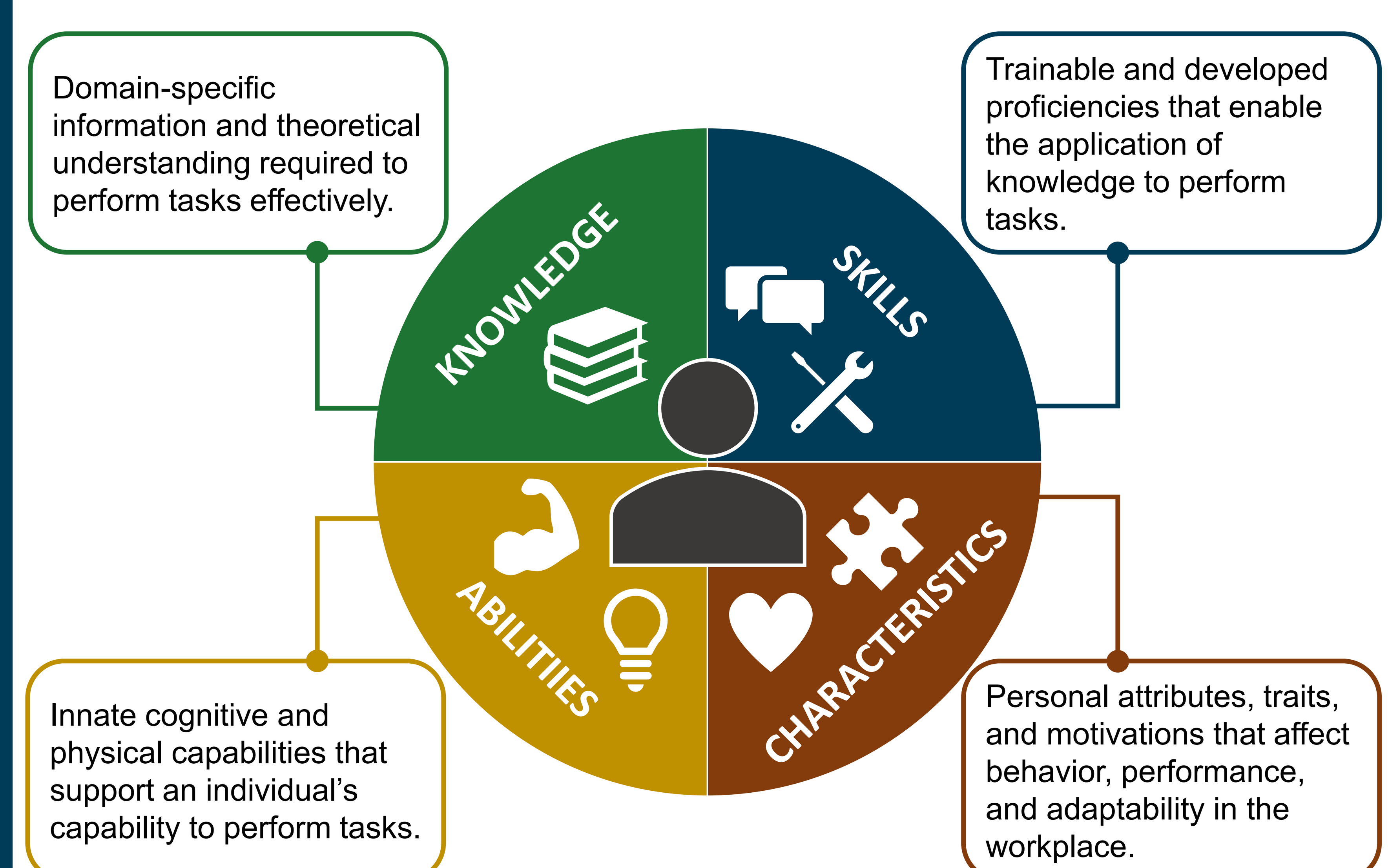
Results and Discussion

Findings suggest that OSC competency requirements are multidimensional, combining industry knowledge, trade-specific technical skills, abilities, and behavior to support performance in evolving production environments.

Assembly *Tool Operation* *Protocols* *Teamwork* *Analytical* *Installation Guidelines* *Manufacturing Processes* *Creativity* *Flexibility* *Willingness to Learn* *Decision Making* *Prefabricated Components* *Safety* *Manual Dexterity* *Problem-solving* *Lean Principles* *Collaboration* *Adaptability*

Terms Identified in the OSC Literature

KSAO Framework for OSC Workforce Competencies



Conclusions and Future Work

This study found that workforce competencies in off-suite construction and multidimensional, extending beyond technical trade skills to include social, cognitive, and adaptive capabilities. By integrating findings from the scoping review with thematic analysis, an initial competency framework was developed to organize the skills identified in the literature.

Ongoing work includes conducting interviews with OSC experts to examine the importance and current prevalence of social and cognitive skills among trade workers.

Future work will further investigate specific competencies to better inform targeted workforce development, training design, and future research in OSC.

Acknowledgement

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AirSanix: A Chemical-Free HVAC Air Sanitization Platform

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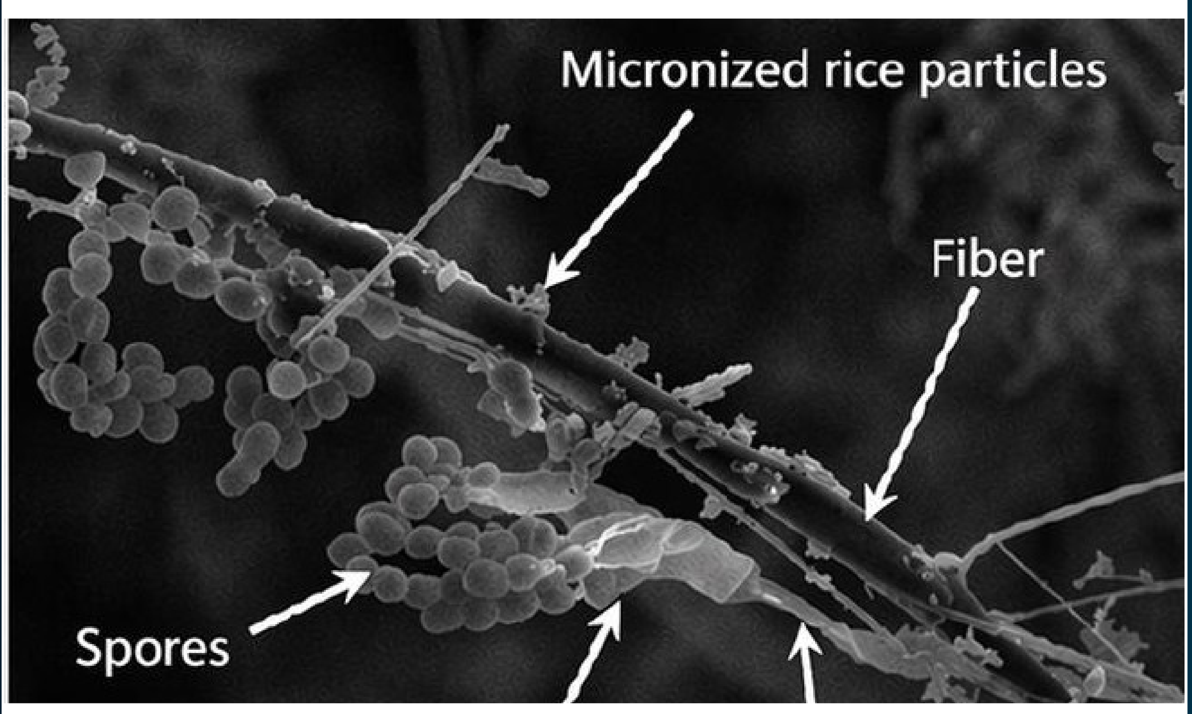
1 The Problem

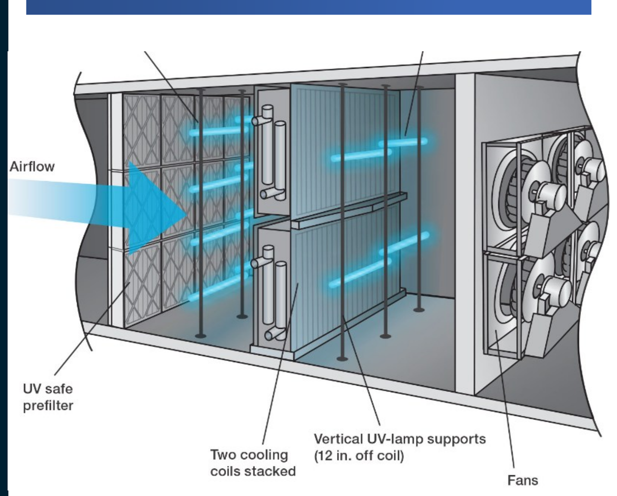
- HVAC filters capture pathogens but do not neutralize them.
- Viable bacteria and fungi can accumulate and multiply on filter media.
- Airflow fluctuations can re-release contaminants into occupied spaces.
- Filter biofouling may contribute to reduced filter life and maintenance burden



Microscopic image of a single filter fiber showing microbial growth

2 Why Existing Approaches Fall Short

UVC Benefits



Microbial Inactivation with UV

Potential Concerns

- Possible ozone / reactive byproduct formation
- Performance variability due to fouling, geometry, and exposure conditions

Passive filtration alone does not address microbial growth or re-release

3 AirSanix Solution

- Localized heat chamber for filter disinfection
- Chemical-free and non-UV-based
- Designed for retrofit into existing AHUs
- Future integration into new commercial HVAC systems

Designed for Application: Built three AirSanix MVPs

Turns passive filtration into active disinfection

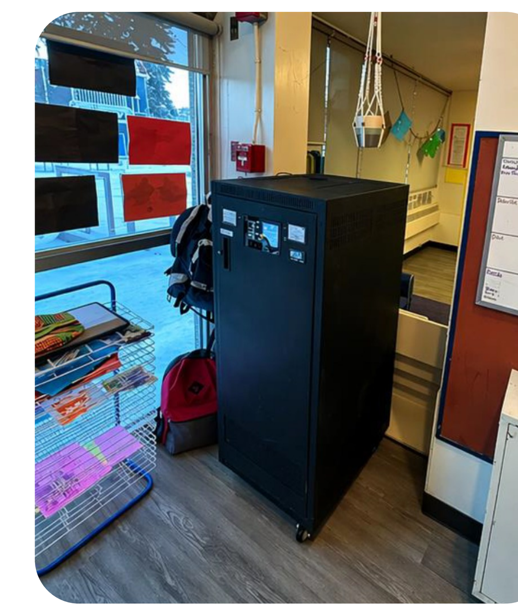
4 Why Building Owners Care

- Potentially longer filter life
- Lower maintenance burden
- Low operating energy
- Cleaner air as a built-in benefit

Focus: Operational value first, air sanitization as an added benefit

5 Current Status & Validation Path

Active pilot at University of Alberta Daycare
Portable unit operating in a live occupied environment; pilot tracking occupant sick-day trends



Municipal pilot development underway
Via City as a Lab program; reference sites: Bonnie Doon and O'Leary Leisure Centers

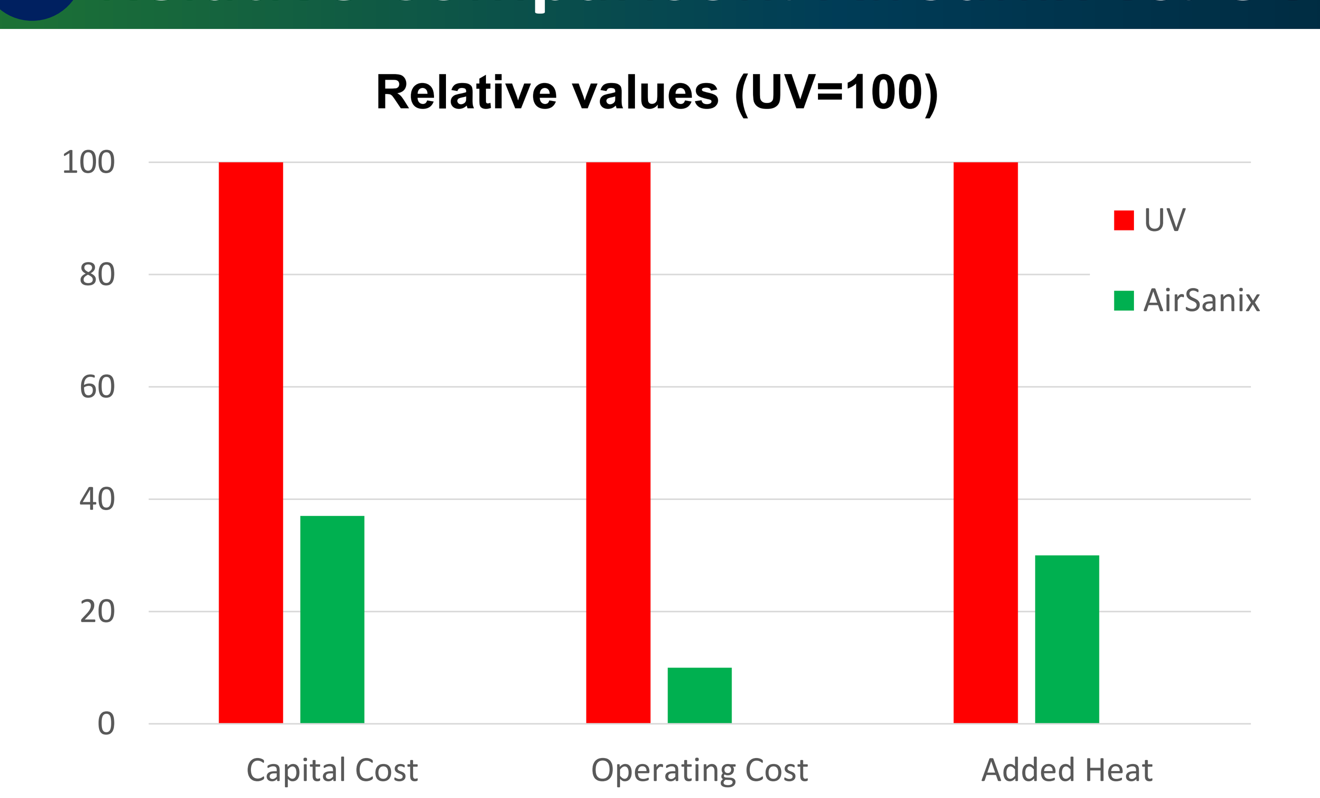
Proposed institutional AHU pilot
Faculty of Engineering / Alberta School of Business, University of Alberta

AirSanix has moved beyond concept into prototype and pilot validation

6 Scalability and Flexibility

- Easy side-by-side retrofit with existing AHU infrastructure
- A network of multiple AirSanix modules offers a scalable solution for any building
- Simple installation; vertical or horizontal installation; lightweight
- Minimal routine maintenance requirements
- Robust design delivers 20+ years of operating life

7 Relative Comparison: AirSanix vs. UV



AirSanix offers lower capital cost, lower operating cost, and lower added heat than UV-based alternatives

Key Takeaways

- Chemical-free in-duct filter disinfection
- Lower operating cost than UV-based alternatives
- Retrofit-ready for commercial HVAC
- Prototype and pilot validation underway
- Potential value through cleaner air and lower maintenance burden

Acknowledgement

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Ontology-Based Semantic Infrastructure for AI-Assisted Steel Fabrication Scheduling

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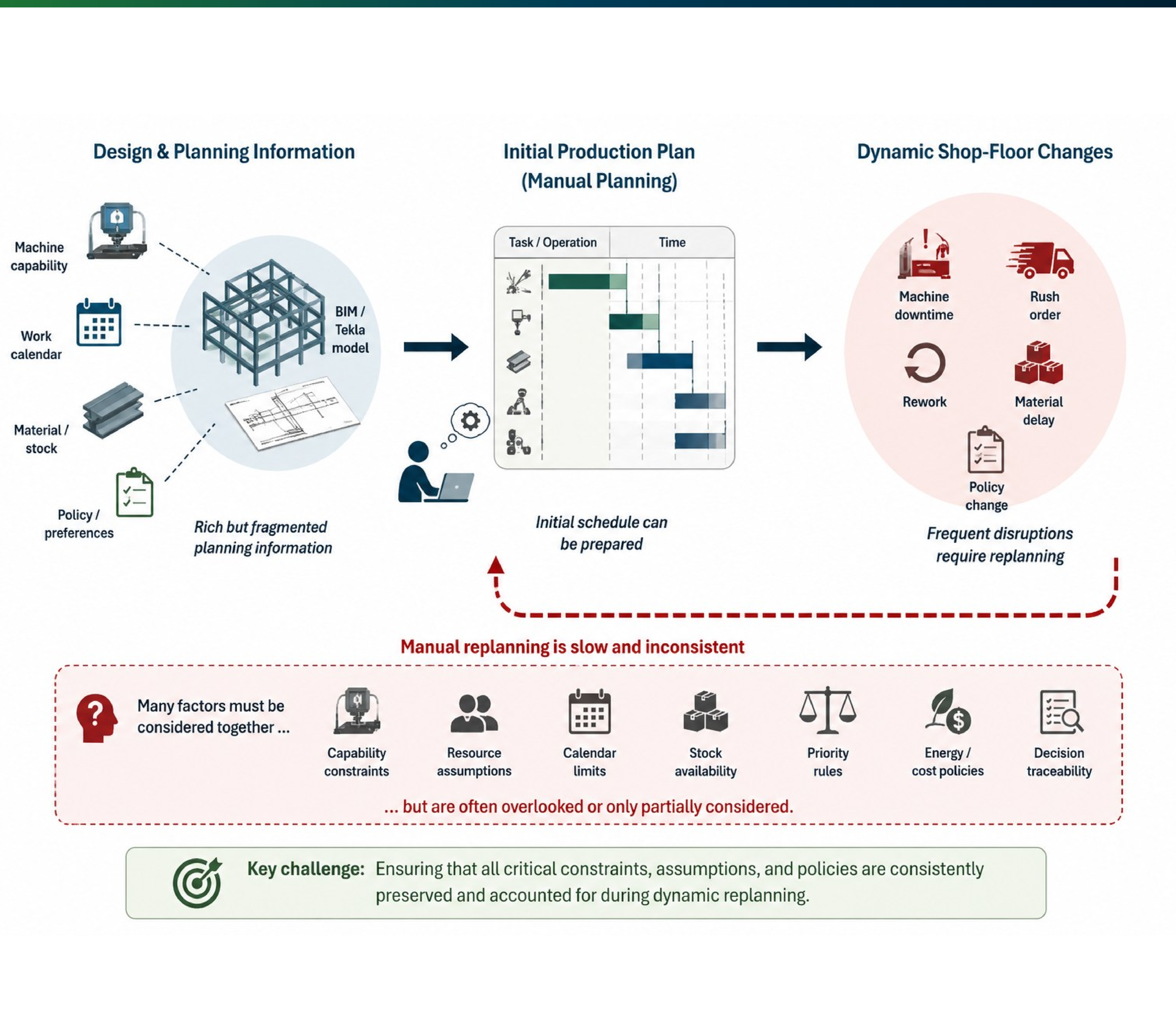
Introduction

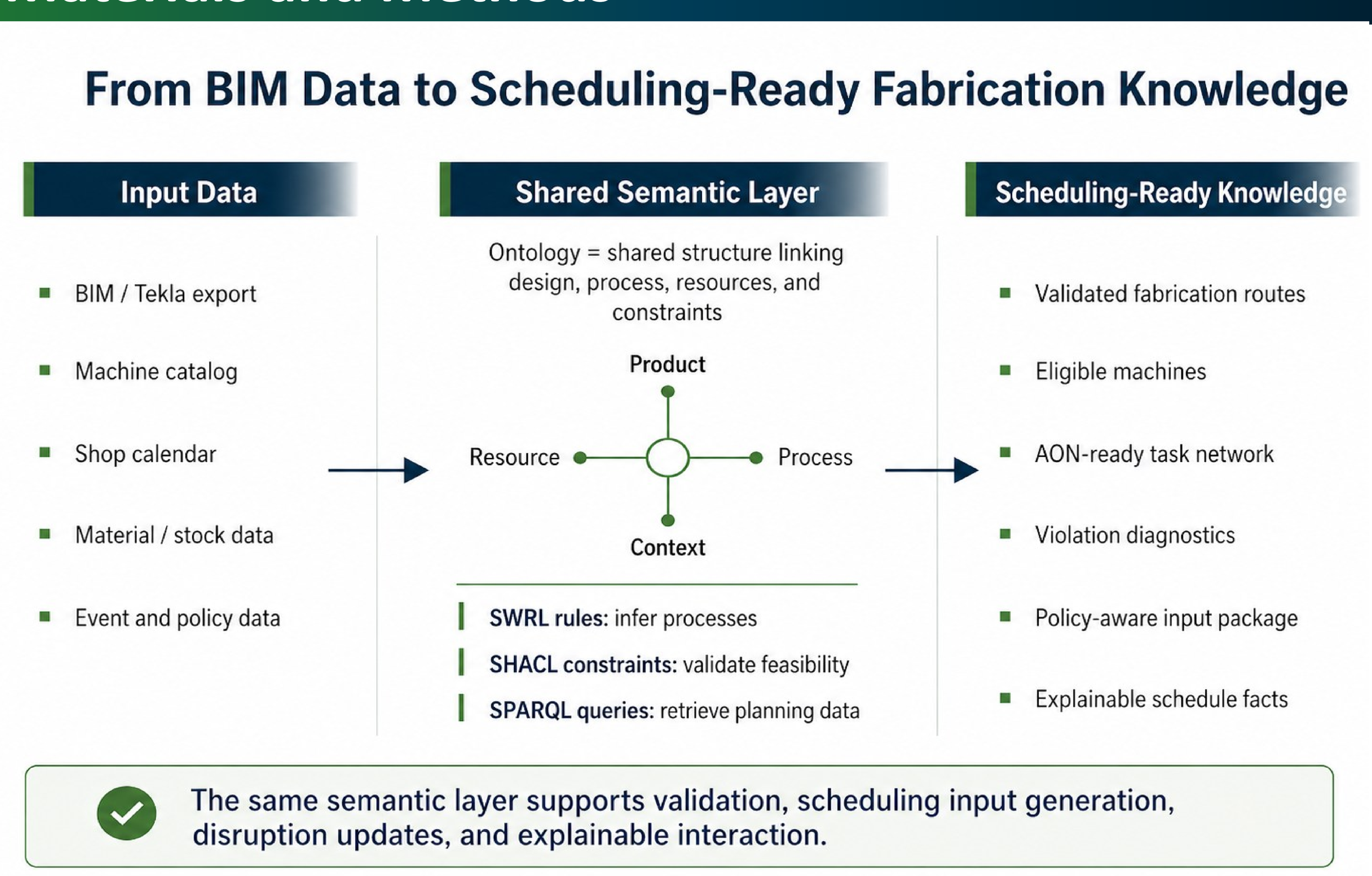


Objectives

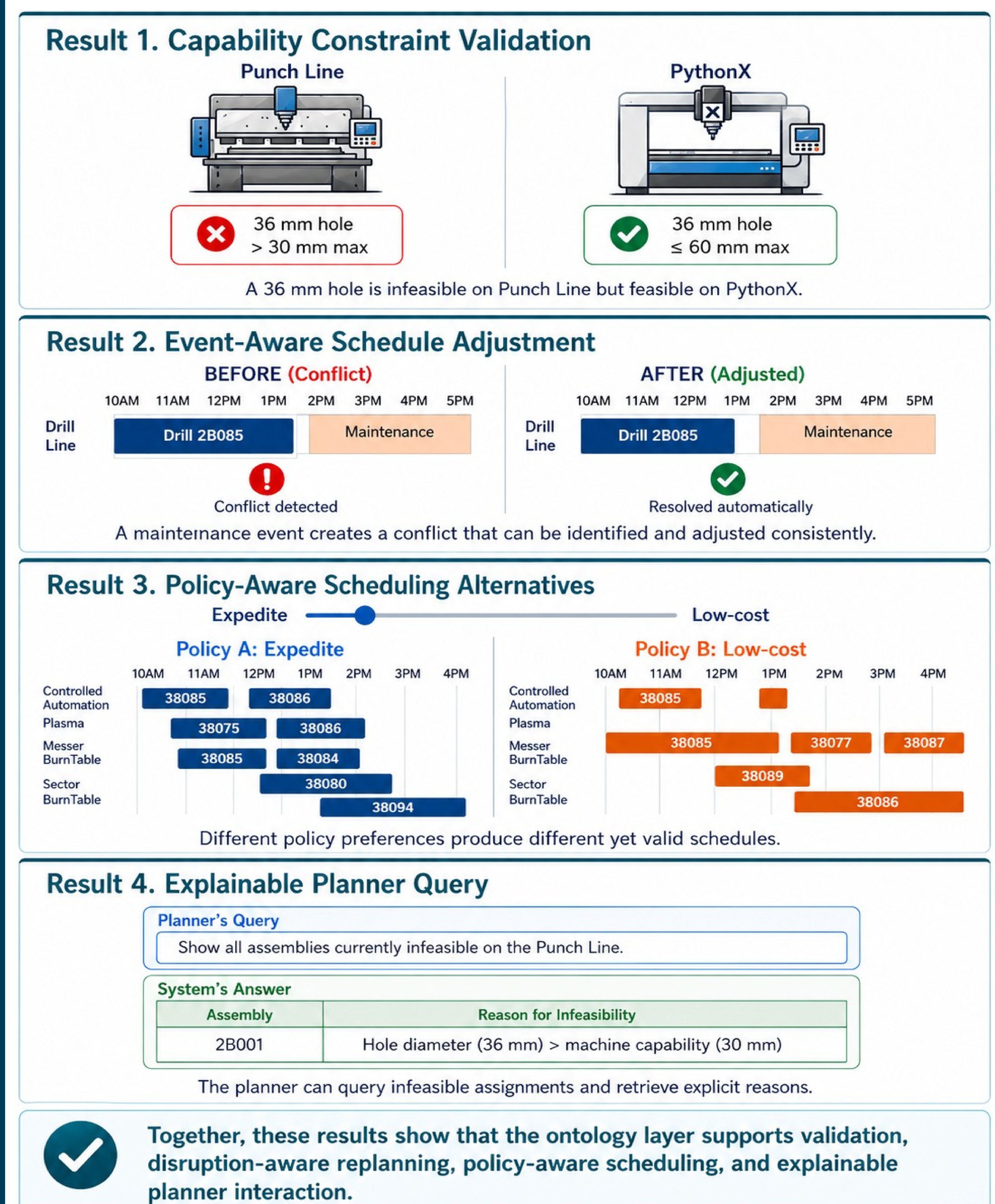
This study aims to develop an ontology-based semantic infrastructure for AI-assisted scheduling in steel structure fabrication.

1. **Formalize**
   Formalize steel fabrication knowledge by connecting product features, fabrication processes, resources, and constraints.
2. **Validate**
   Validate derived fabrication processes against machine capabilities, material availability, calendars, and shop-floor constraints.
3. **Support**
   Support AI-assisted scheduling, replanning policy updates, and planner interaction through a shared semantic layer.

Materials and Methods



Framework



Conclusion

1. This study demonstrates how ontology can serve as a reusable semantic infrastructure for steel fabrication scheduling.
2. The framework connects BIM-derived product features with fabrication processes, resource capabilities, constraints, events, and policy preferences.
3. The case results show that this semantic layer can support capability validation, disruption-aware replanning, policy-aware scheduling alternatives, and explainable planner interaction.
4. By converting design-rich information into machine-readable and explainable planning knowledge, the framework provides a foundation for AI-assisted scheduling and future semantic digital twins.

Acknowledgement

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A Design Aid for Steel Braced Frame Connections

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CONSTRUCTION INNOVATION CENTRE

Research Driving Change

Introduction

- ❑ Steel concentrically braced frames (CBFs) are widely used for lateral resistance due to their stiffness, stability, and cost-effectiveness under seismic and wind loads.
- ❑ Their performance depends strongly on connection design, especially gusset plates, which must resist axial forces and allow inelastic deformation.
- ❑ Steel connections, consisting of bolts, welds, and gusset plates, are essential for force transfer and overall system performance.
- ❑ Material weight is often used as a cost metric, but about 60% of total cost comes from fabrication and erection, requiring a broader evaluation approach.
- ❑ Existing tools improve analysis but still require multiple iterations and do not fully optimize connections for cost and performance.
- ❑ Traditional design relies on iterative calculations and conservative assumptions, leading to inefficiencies in time, material use, and fabrication.
- ❑ This research develops an automated tool for designing gusset plate connections in CBFs, enabling efficient comparison of alternatives.
- ❑ The approach improves decision-making, constructability, and overall cost efficiency in steel design and fabrication

Steel Concentrically Braced Frame

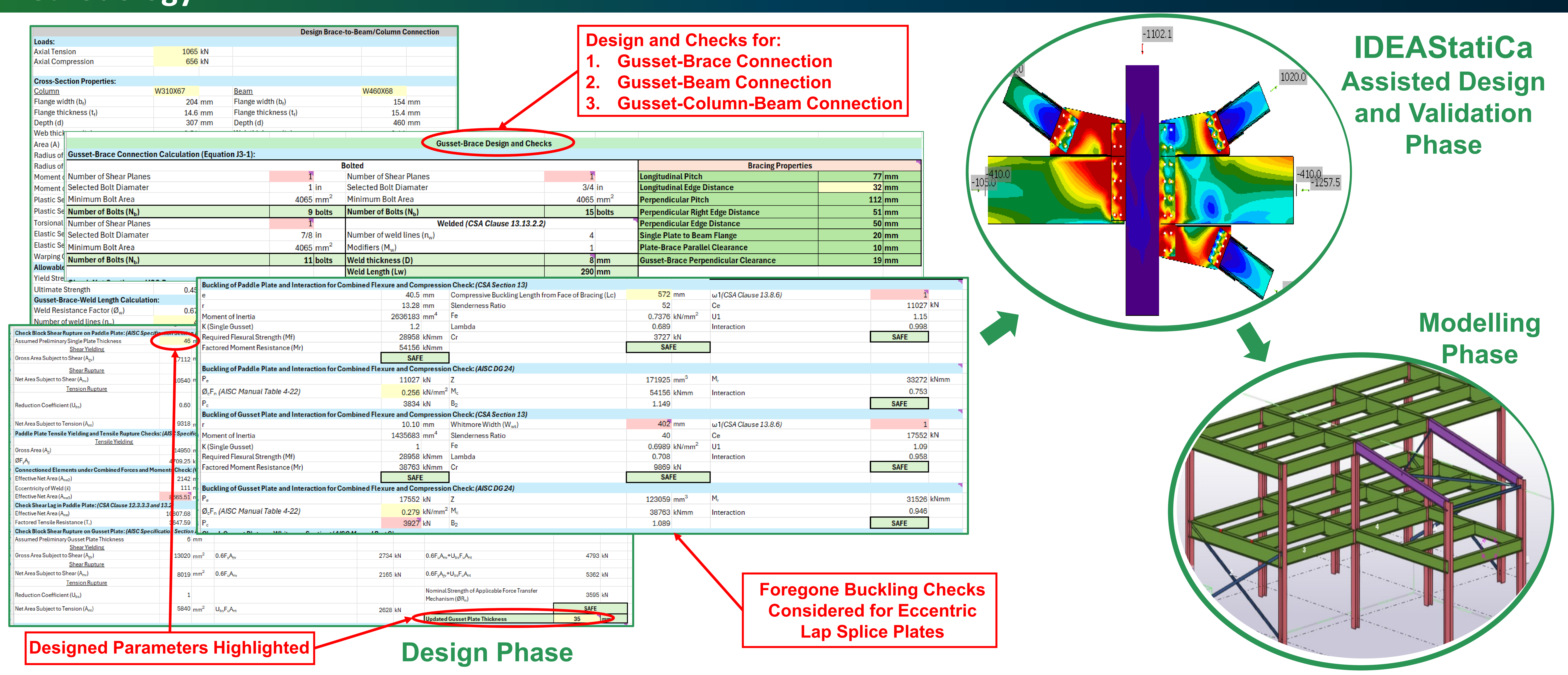
Problems

- Lack of automation
- Overdesigned connections
- Uncertainty in key cost drivers
- Lack of efficient manual tools for complex connections

Objectives

- Automate brace connection design
- Improve economy of brace connections
- Incorporate finite element modelling in connection design
- Implement automated drafting in connection design workflow

Methodology



Ongoing Research

- ❑ **Automate Spreadsheets**
  - Minimize human inputs as much as possible
- ❑ **Parametric Evaluation**
  - Parametric evaluation to identify key design variables driving cost optimization
- ❑ **Connection Drafting Module**
  - Grasshopper + Tekla integration → automated detailing from Excel design
- ❑ **Automated Drafting Module**
  - Allow design to be utilized by BIM software

Expected Outcomes

Automated Design Aid

- Brace Connection Design Automation
- Improved Connection Economy
- Finite-element Based Connection Design Tool

Acknowledgement

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Integrating Spatial Modeling and Congestion Effects for Construction Sequencing

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Introduction

- **From Block to Construction Planning**

Planning construction is like assembling blocks under constraints (e.g., LEGO or Minecraft). You are given:

- A space to build in
- A set of elements (work packages)
- A set of rules

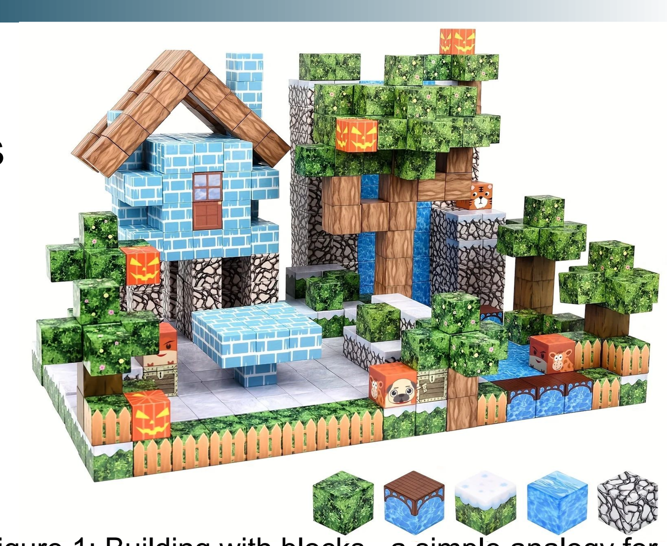


Figure 1: Building with blocks, a simple analogy for complex construction planning.

The challenge is not what to build, but how to build it under constraints.

- **Traditional Scheduling Misses Reality**

Traditional scheduling ignores spatial conflicts

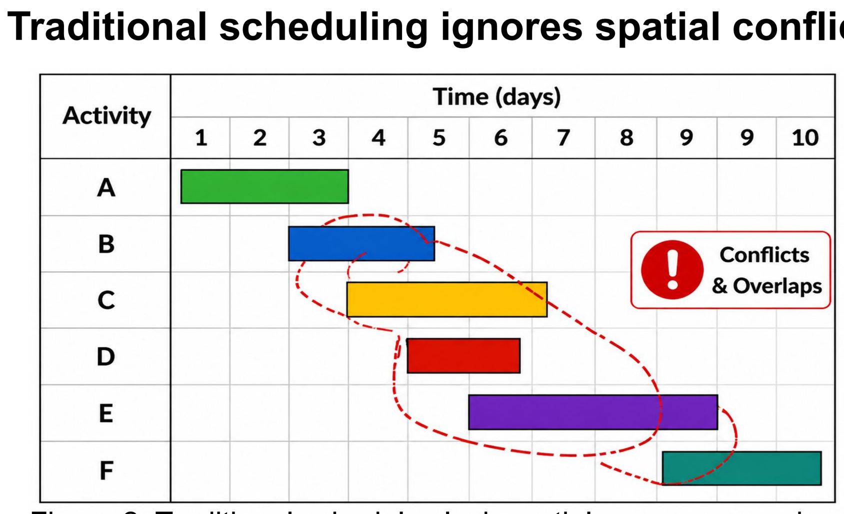


Figure 2: Traditional schedules lack spatial awareness and ignore real construction constraints.

- Schedules are often developed manually
- Limited consideration of:
  - Spatial conflicts
  - Resource constraints
  - Site congestion
- Unrealistic plans
- Poor adaptability during execution

- **Real Construction Constraints**

Precedence Relationships
Some activities must be completed before others.

Resource Limitations
Limited crews and equipment available.

Spatial Interactions
Activities compete for the same space.

Congestion Effects
Productivity can decrease when areas are crowded.

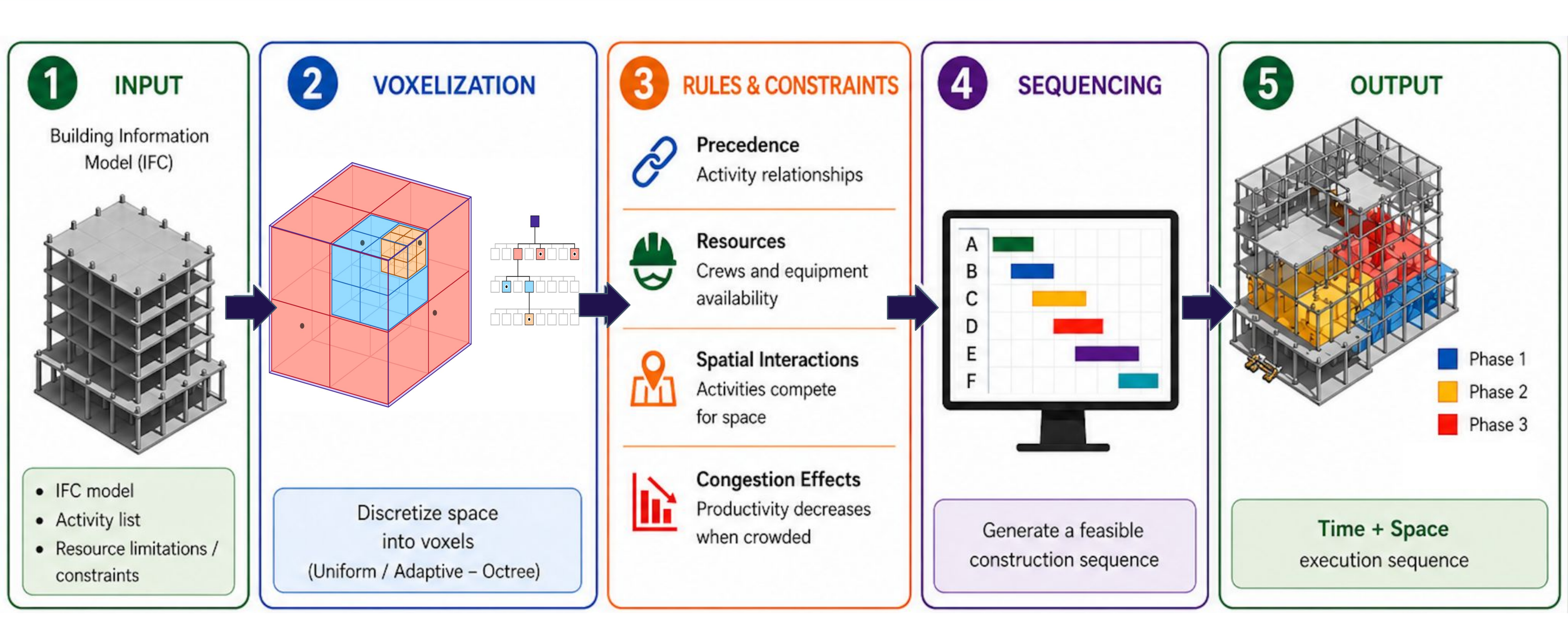
Objectives

Develop an automated, space-aware construction planning approach from IFC models by integrating geometry, resources, and workspace conditions.

Specific Objectives

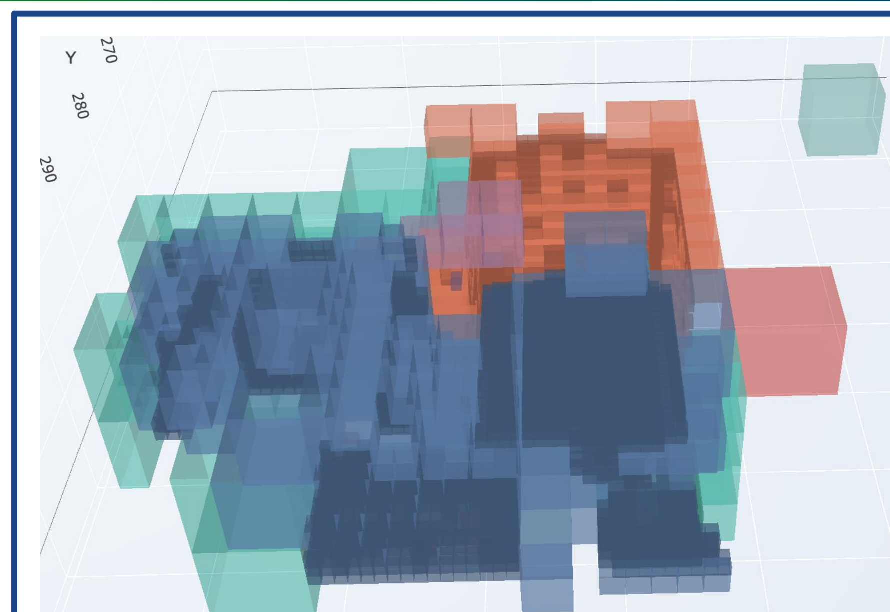
- Generate a baseline construction sequence using spatial modeling and construction logic
- Enable dynamic re-sequencing under time constraints and resource changes
- Model productivity loss due to congestion in shared workspaces
- Develop an adaptive work area representation for complex and congested zones

Methodology



- Daily man-hour limits per discipline (e.g., 80 MH/day)
- Work packages share resources: reduced productivity
- Congestion ratio: decreases effective progress

Results and Discussion



- The building is discretized into 3D voxels representing structured work areas.
- Adaptive resolution captures complex and congested zones.
- Enables direct mapping between space and activities.

Figure 3: Adaptive resolution captures complex and highly congested zones

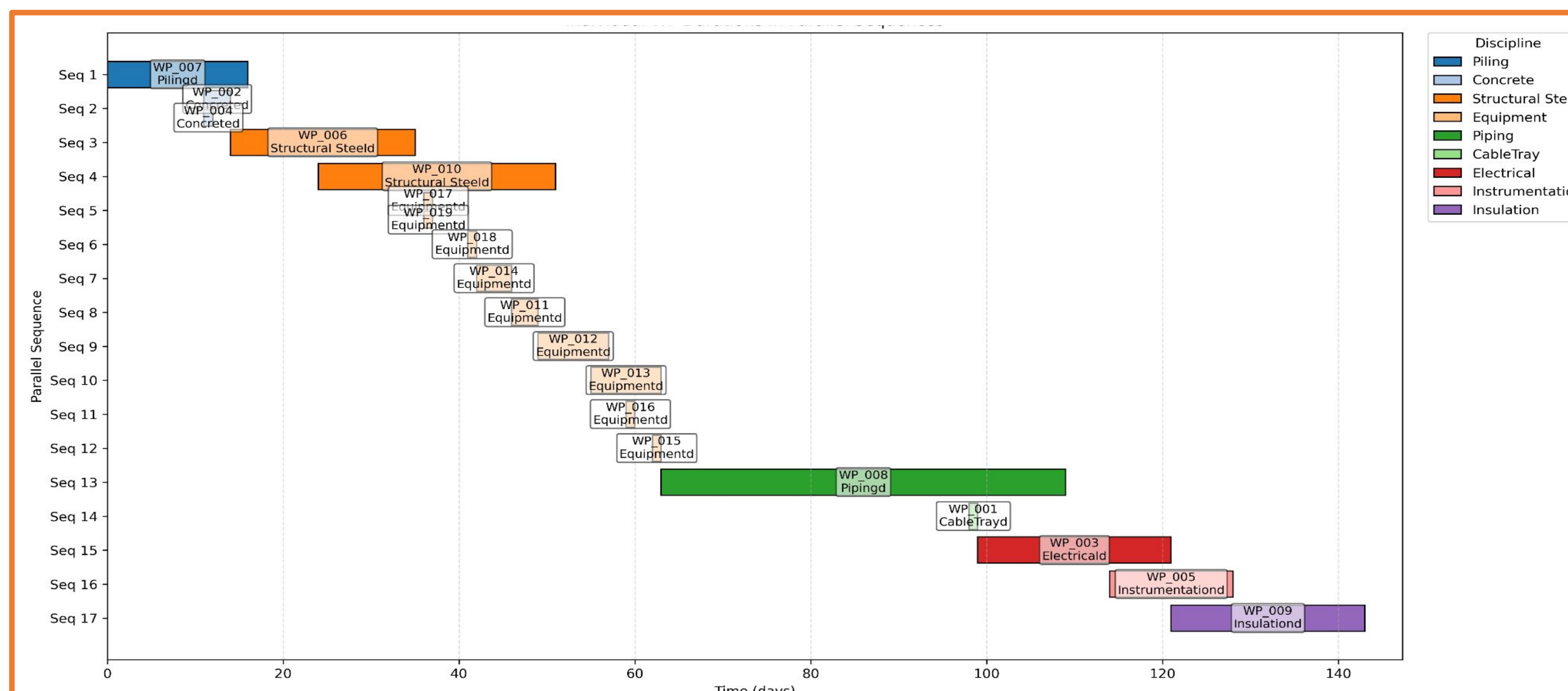
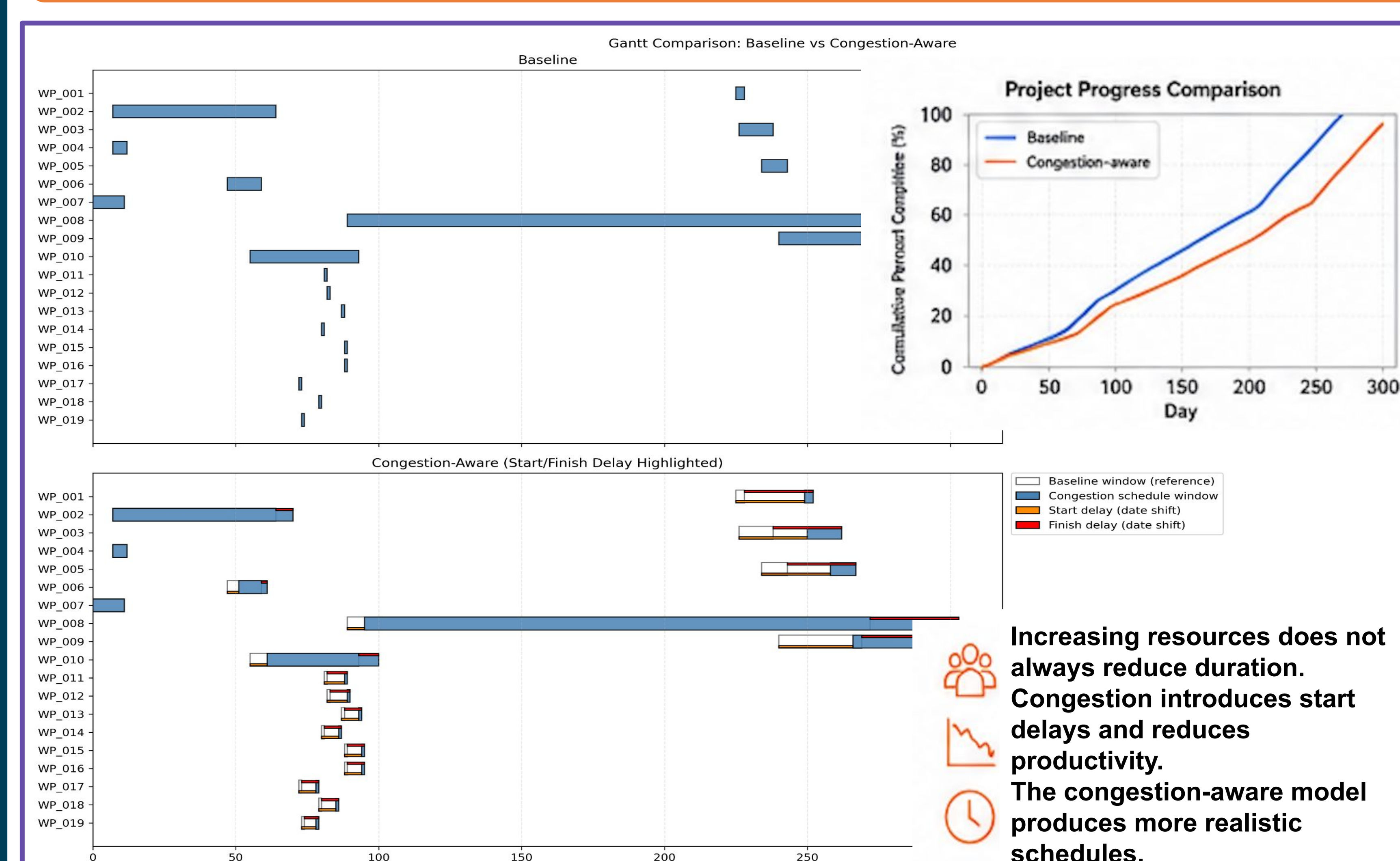


Figure 4: Automatically generated construction sequence



Increasing resources does not always reduce duration.
Congestion introduces start delays and reduces productivity.
The congestion-aware model produces more realistic schedules.

Figure 5: Impact of congestion on schedule and project progress

Conclusions

- Space-aware voxel modeling enables realistic construction planning
- Integrating resources and congestion improves schedule feasibility
- Increasing resources may reduce productivity due to congestion

Future Work:

- Validate the approach on real projects and integrate real-time data for dynamic schedule updates.

Acknowledgement

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CONSTRUCTION INNOVATION CENTRE
Research Driving Change

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Modular Optimization of Pipe Rack Footing Systems for Faster and Standardized Construction

CONSTRUCTION INNOVATION CENTRE
Research Driving Change

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Introduction

Figure 1: Typical pipe rack structures in industrial facilities supporting pipelines and transferring loads to foundation systems
Sources: Sunway Steel (sunwaysteel.com); VisSteel (vissteel.com.vn)

Pipe Rack Systems:

- Steel structures supporting pipelines and utilities
- Common in industrial facilities
- Transfer loads safely to foundations

Current Challenges:

- Repetitive but non-standardized designs
- Time-consuming engineering process
- Limited prefabrication leading to delays in construction
- Conservative due to uncertainty

Objective

Main Objective:
Develop a modular and standardized pipe rack footing system that improves structural performance and reduces construction time.

Specific Activities:
- Enable standardized, repeatable designs for faster construction and prefabrication
- Understand how loading is transferred into foundation elements
- Optimize and test various foundation connections, including baseplate, rods, footings, and other components
- Present standardized foundation connections for pipe rack systems

Design Optimization Framework

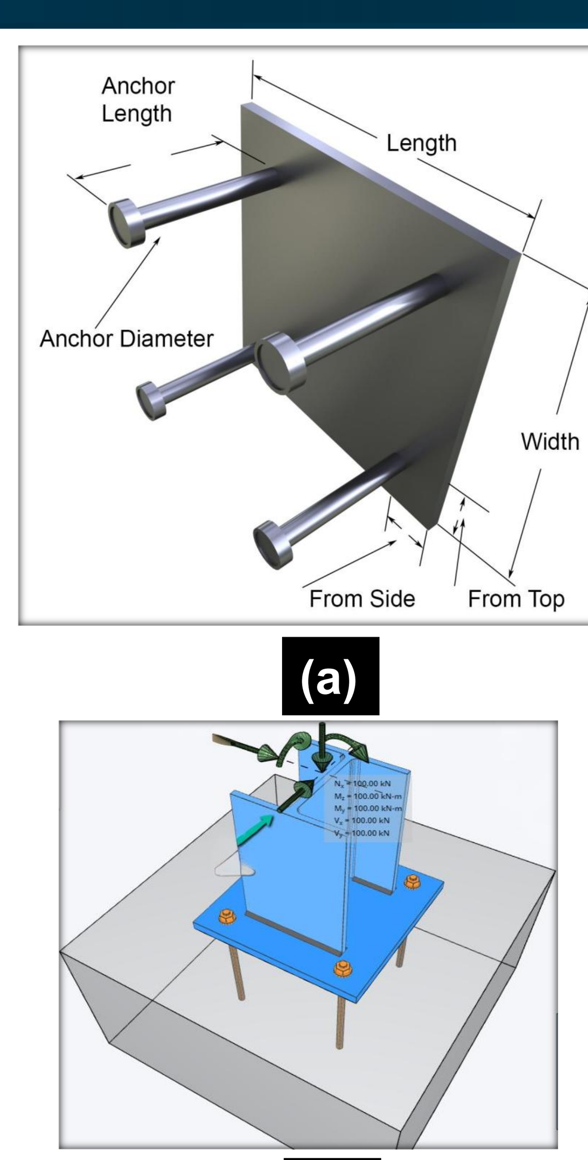
Focus: Optimization of pipe rack foundation connections (base plate, anchor, and footing system)

Geometry:
- Base plate thickness
- Plate dimensions
- Anchor spacing

Material Properties:
- Steel strength (plate & anchors)
- Concrete strength
- Grout behaviour

Loading Conditions:
- Axial load
- Bending
- Shear forces

Performance Criteria:
- **Service:** Deformation & vibration control
- **Strength:** Capacity under worst-case loading (plate bending, anchor tension, concrete response)
- **Constructability:** Ease of installation
- **Applicability:** Range of usable loading conditions
- **Efficiency:** Reduced material and construction effort



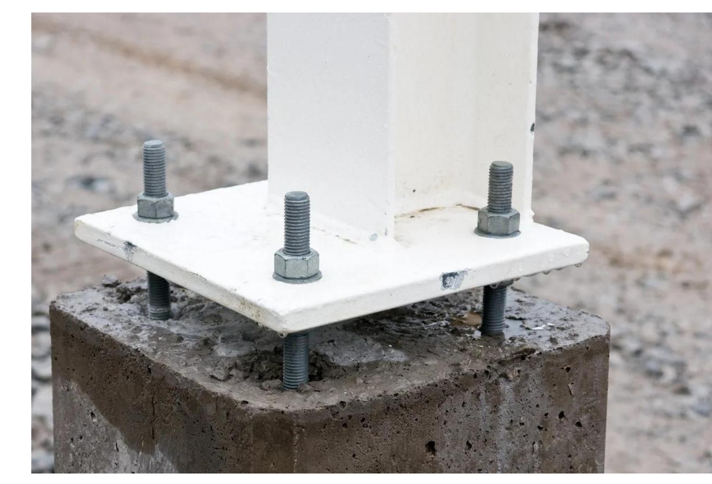
(a)

(b)

Figure 2: Design optimization framework illustrating (a) geometric parameters, (b) loading conditions
Sources: Heckmann Building Products; SkyCiv

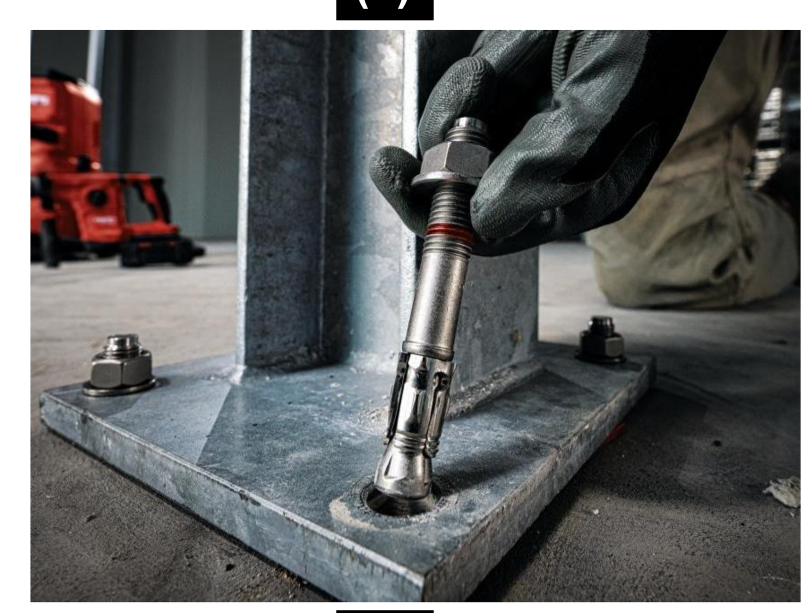
Expected Outcomes and Engineering Insights

Expected Outcomes:
- Development of a framework for typical pipe rack footing modules
- Development of standardized footing modules
- Improved load transfer efficiency
- Reduced overdesign through better understanding of behavior
- Improved constructability and installation efficiency



(a)

Engineering Insights:
- Failure behaviour governs design efficiency
- Designing footing components together to improve the performance
- Optimization standardizes plate design, making it easier to use across different projects
- Modular approach enables repeatable solutions



(b)

Practical Benefits:
- Faster project execution
- Reduced design time
- Improved quality control
- Supports prefabrication

(c)

Figure 3: Illustrations supporting the expected outcomes, showing (a) base plate–anchor systems, (b) improved installation and constructability, and (c) pipe rack structures benefiting from standardized and modular footing design.
Sources: BuildingPoint Scandinavia; Hilti; MECA Enterprises

Next Steps

- Develop a framework based on codes (e.g., CSA, AISC) and industry practices
- Consult with industry to identify practical design requirements, including commonly used sizes, materials, and installation constraints
- Develop optimized footing systems and propose standardized foundation connections
- Conduct physical testing to validate foundation connections

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