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**Transportation Infrastructure Precast Innovation Center**

**(TRANS-IPIC)**

**University Transportation Center (UTC)**

Holistic Quality Management of Precast Concrete Construction for Transportation Infrastructure

PU-23-RP-01

Quarterly Progress Report

For the performance period ending September 30, 2024

**Submitted by:**

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**Submitted to:**

TRANS-IPIC UTC

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Urbana, IL

**TRANS-IPIC Quarterly Progress Report:**

**Project Description:**

1. Research Plan - Statement of Problem

Precast concrete systems (PCS) have been widely used by the US State Department of Transportation (DOT) agencies as a promising alternative to cast-in-place concrete systems. High-quality PCS provides several benefits including shorter lane closures and reduced traffic congestion attributed to accelerated construction with shorter project duration, and increased road user and worker safety when such systems are utilized correctly [1]. However, quality deficiencies during any PCS lifecycle phases (i.e., design, manufacturing, transporting, lifting and installation, and operation and maintenance (O&M)) can easily offset the expected benefits, leading to premature failures and excessive repair costs.

Current practice in quality management (QM) of PCS (PCS QM) heavily relies on manual approaches and remains isolated within each lifecycle stage. For instance, quality control (QC) during the precast-at-plant stage is done using labor-intensive performance audits and sporadic inspections with the potential to miss important problems and thus violate specifications at precast facilities [2]. Resulting quality deficiencies can impact the transportation of precast elements, their installation and connections with other components at transportation projects and their life-cycle performance and maintenance. Using checklists for pre-shipping and onsite acceptance can help capture certain quality deficiencies such as dimensions and locations of dowel bars. However, such actions are often reactive and offset benefits such as reduced project duration and shortened lane closures in transportation projects.

To address the mentioned problems, this research project aims to develop, validate, and test a holistic quality management framework/model for precast construction of transportation infrastructure. The framework collects, measures, and evaluates data of the precast process across its life cycle, from design to production, transport, installation/construction, commissioning, O&M, and decommission/reuse. By integrating BIM, laser scanning, GPR, vision sensing, and extended reality (XR) along with advanced computational tools, the framework creates a digital twin as the ‘seamless’ method of information management and sharing that can be used for quality control and management of the precast systems from the life-cycle perspective. This framework is a step towards ensuring that the following key attributes of successful PCS projects can be achieved: constructability, concrete durability, load transfer at joints, panel support, and performance efficiency [3].

1. Research Plan - Summary of Project Activities (Tasks)

***Task 1:*** *Design a system-level framework for lifecycle data/information/knowledge acquisition and data exchange in PCS.*

This task focuses on framework design and workflow and process modeling. It consists of three steps: (a) compiling knowledge of field practice of PCS QM, (b) assessing the state-of-the-art BIM practice in PCS QM, and (c) designing a BIM-based digital twin system.

***Task 2:*** *Design an expandable BIM approach to meet the data and information needs of lifecycle PCS QM.*

This task includes (1) design of templates for expandable BIM, using IFC as the open standard, (2) identification of data needs in precast production, transporting, installation, and operation and maintenance, and (3) implementation to accommodate data needs in precast production and generate data to meet the transporting and installation needs.

***Task 3:*** *Validation and case study – the precast-at-plant stage.*

This task targets quality control considering different operations in precast manufacturing at plants. The task evaluates the newly designed BIM framework by comparing it with the current QM practice in terms of utilization of resources, time and labor savings, capture of deficiencies in quality, and the completeness of the BIM model.

***Task 4:*** *Presentation/panel discussion at 2024 Purdue Road School.*

A presentation/panel discussion will be held at the 2024 Purdue Road School to share project findings and to engage with/learn from experienced researchers and practitioners in the field of precast concrete in transportation projects.

**Project Progress:**

1. Progress for each research task

**Task 1 progress [100% completed]**

*Subtask 1.1 - Compiling knowledge of field practice of PCS QM [100% completed]*

The first subtask in Task 1 is the assessment of the current field practice related to quality management throughout the life cycle of PCS. Since different PCSs have many QC/QA tasks in common, Jointed Precast Concrete Pavement (JPrCP) System and MSE wall system were studied as example PCSs for this task. For each PCS QC/QA task in different lifecycle phases (except for the design stage), we determined its checklists, timing, responsible parties, methods and tools by examining existing manuals and specifications that guide the implementation of precast concrete pavement projects [4,5]. A breakdown structure of QC/QA field practice was followed to compile the knowledge, as shown in Figure 1. Driven by the idea of object-oriented modeling in BIM, specific check items were identified and organized in the format of “object-attribute”. These results were used for the design of expandable BIM templates in Task 2.

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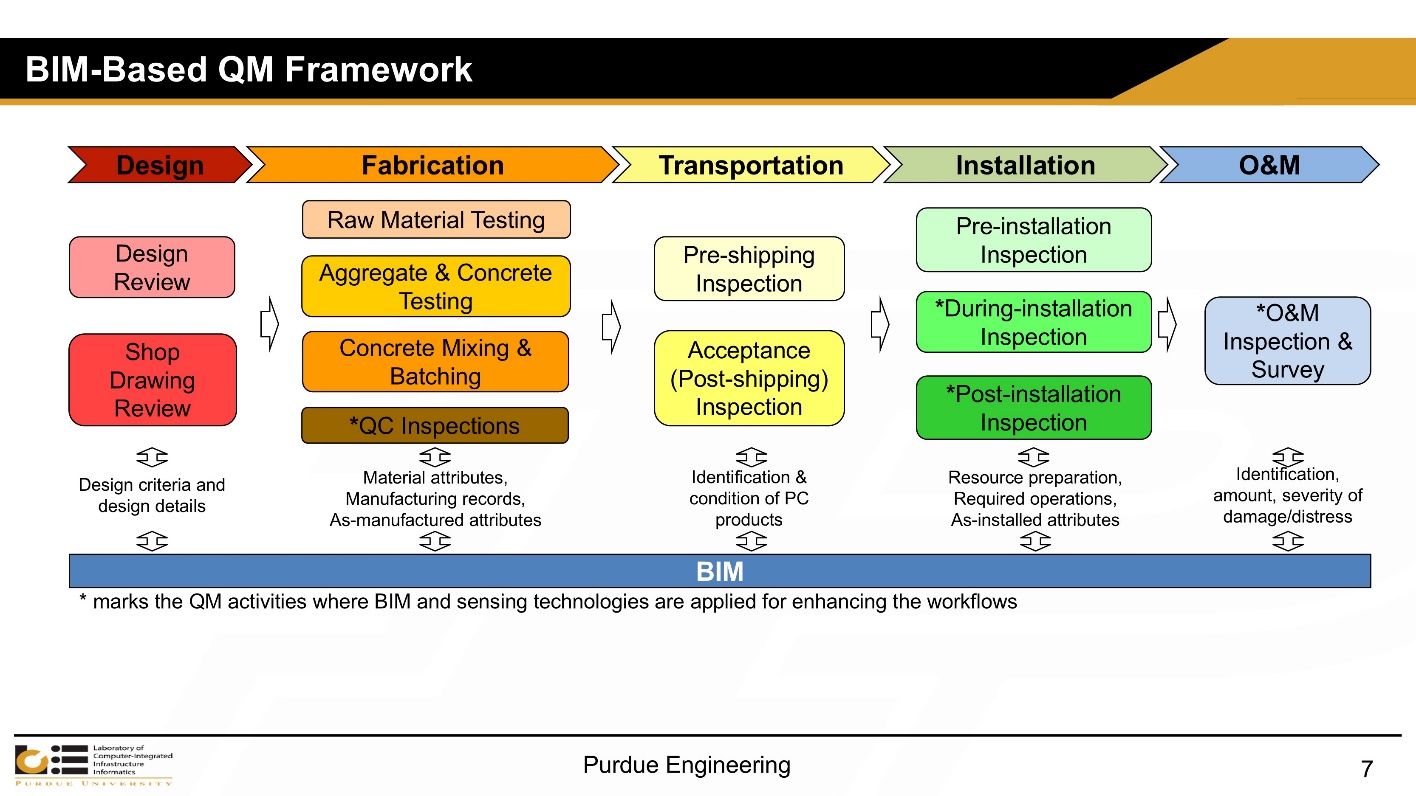
**Figure 1 Breakdown structure of QC/QA field practice**

*Subtask 1.2 - Assessing the state-of-the-art BIM practice in PCS QM [100% completed]*

The current status of BIM practice in PCS QM was investigated by reviewing the related research literature. Three research themes regarding PCS QM were identified from existing literature: 1) advanced sensing technologies for automated inspection of PC components in fabrication and installation stages, 2) advanced sensing technologies that can automate the checking and assessment of PC components in the O&M stage, and 3) BIM and IFC based data representation, storage and delivery. The sensing technologies were carefully evaluated by comparing their technical specifications, including the methods, tools, performance, working conditions, and limitations. Besides, different IFC-based data modeling approaches were reviewed by analyzing how the physical PC components can be digitally modeled by IFC entities.

*Subtask 1.3 - Designing a BIM-based digital twin system [95% completed]*

The framework of the BIM-based digital twin system was designed based on the compiled knowledge and findings from the previous two subtasks. Figure 2 shows the designed BIM-based framework for PCS QM throughout all lifecycle cycle stages. Critical QM activities for each project stage were identified and their interactions with BIM were illustrated. Each QM activity inspects and/or records a set of quality-related attributes. Relevant attributes of MSE walls are demonstrated in Figure 3 as examples. Besides, the QM activities that can be applied with BIM and sensing technologies were identified and marked in Figure 2. Among the activities, the QC inspections during in-plant fabrication were examined and their BIM-based workflow was established (shown in Figure 4). The framework was designed with an executable demo in Task 2; and assessed, validated, and improved in Task 3.



**Figure 2 BIM-based overall framework for PCS QM throughout all life cycle stages**

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**Figure 3 Quality attributes of MSE walls inspected at different stages [4, 5, 6, 7]**

A diagram of a workflow

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**Figure 4 BIM-based workflow of QC inspections during in-plant fabrication**

**Task 2 progress [100% completed]**

*Subtask 2.1 - Design of templates for expandable BIM, using IFC as the open standard [100% completed]*

First, the entity list of the up-to-date IFC data schema (IFC 4.3 ADD2 [8]) was examined to identify the IFC entities suitable to represent the quality inspection data of PCS components. The examination demonstrates that the extension of the current IFC data schema is required to accommodate our needs of quality data representation. To achieve the extension goal with a minimum impact on IFC interoperability, we opted for adding customized object property sets instead of creating new IFC entities. We designed an IFC data structure for expandable BIM templates. Figure 5 shows the data structure of the templates for various precast concrete elements. The left substructure covers QC activities such as raw material testing, aggregate testing, concrete testing, and concrete batching. The right substructure models pre-pour and post-pour inspections of PC elements. Both substructures are task-centered, which allows for the accumulation of quality information/knowledge with the collected data in each inspection task.

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**Figure 5 Task-centered IFC data structure for description of QC activities and associated data needs: a) substructure for testing/batching activities (left), and b) structure for QC inspections (right)**

*Subtask 2.2 - Identification of data needs in precast production, transporting, installation, and operation and maintenance [100% completed]*

In this subtask, we assessed the data/information/knowledge needs and exchange in the BIM model and the levels of development (LOD) and accuracy. For example, as shown in Figure 5, the data need for pre-pour and post-pour inspections during manufacturing includes actual measurements, deviations, compliance, and corrections. Any design-to-actual changes of critical quality attributes, such as weight, dimensions, and strength of as-manufactured PC products, are captured and stored in BIM. The data can provide guidance for planning the loading/unloading operations and transporting trajectories in the subsequent transportation stage.

*Subtask 2.3 - Implementation to accommodate data needs in precast production and generate data to meet the transporting and installation needs [95% completed]*

An IFC toolkit named IfcOpenShell was utilized to create the templates designed in Subtask 1. LOD400 IFC models from Autodesk Revit were used as the base models to create the templates. We generated synthetic data to simulate the quality data collected in precast production and test if the designed template can meet the data representation needs. The synthetic data is created based on the quality data samples and tolerance from existing inspection checklists and manuals [9]. Figure 6 shows the template for MSE wall panels as an example. Figure 7 demonstrates the representations of synthetic quality data enabled by the designed template. Following the idea, we created BIM templates for MSE wall panels, bridge deck panels, bridge beams, and pavement slabs. We will finalize the BIM templates in the upcoming quarter.

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**Figure 6 BIM template of MSE wall panels**

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**Figure 7 Representations of synthetic quality data**

**Task 3 progress [100% completed]**

We made a plant visit to Norwalk Concrete Industries (NCI) located in Norwalk, OH 44857. NCI is an experienced regional PC producer founded in 1906, providing service to over 8 mid-west states [10]. Their products cover a variety of types, including building products, storm & sanitary, precast walls, heavy & highway, etc. To enhance our understanding of the QC practice at the plant, we 1) watched different operations of precast manufacturing, such as reinforcement cage fabrication, formwork, concrete pouring, etc., 2) observed different QC activities, such as concrete testing, pre-pour and post-pour inspections of MSE wall panels, and 3) a round table discussion with the company owner, general superintendent, and QC personnels to learn the current QC practice and key challenges.

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**Figure 8 Plant Visit to Norwalk Concrete Industries**

We assessed our BIM template design using the actual design data and QC data of MSE walls obtained during the visit. Figure 9 shows the design model of the inspected MSE wall panel and Figure 10 demonstrates the QC data documented on an inspection form. Figure 11 shows the relevant properties and property values stored in the created template. It proves that the template can represent relevant quality attributes and store the data by comparing Figure 10 and Figure 11.

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**Figure 9 BIM design model of MSE wall panel annotated with dimensional properties and property values**

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**Figure 10 QC data of MSE wall panel documented on the inspection form**

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**Figure 11 IFC template created using real inspection data (top) and QC properties visualized in IFC tool (bottom)**

**Task 4 progress [100% completed]**

A group of men sitting on a stage

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**Figure 12 Panel discussion at Purdue Road School 2024**

We held a panel discussion at the Purdue Road School 2024 (Figure 12). We invited four keynote speakers: Tommy Nantung (Research Manager) and Andrew Pangallo (Construction Digital Lead Engineer) from INDOT, Jeff Brechbill (President and part owner) from First Group Engineering, and John Lendrum (President) from Norwalk Concrete Walk Concrete Industries to give presentations on 1) the growth of PCS, 2) common types of structure, 3) common challenges, 4) specific perspectives on QM, 5) Stakeholders and involved parties, and 6) Inspection, identification, and correction of defects. A Q&A session followed the presentations for the project team to ask key questions to the panelists and exchange ideas. The Purdue team also had a follow-up conversation with Tommy and John after the panel discussion.

1. Percent of research project completed

The total project is 90% completed in this quarter ending on Sept. 30, 2024.

1. Expected progress for next quarter

* We will finalize all the BIM templates to conclude *Subtask 2.3* in Task 2 and Subtask 1.3 in Task 1.
* We will file a technology disclosure.
* We will finish and submit the journal paper under preparation (see Section 8).
* We will develop a course module on BIM for lifecycle quality management of precast concrete in infrastructure construction for CE 52200 Computer Applications in Construction.
* We will also prepare the final technical report.

1. Educational outreach and workforce development

We plan to develop a course module on BIM for lifecycle quality management of precast concrete in infrastructure construction for CE 52200 Computer Applications in Construction. The first delivery will be Spring 2025.

We plan to make a presentation to Purdue Road School 2025, which will be held on Purdue campus on March 18 and 19 in 2025.

1. Technology Transfer

We plan to file a technology disclosure on the BIM-based templates for lifecycle quality management of precast concrete infrastructure.

**Research Contribution:**

1. Papers that include TRANS-IPIC UTC in the acknowledgments section:

Hong, Z., Hong, Y., Cai, H., Abraham, D.M., Zhang, J., Dunston, P.S. (2024). *BIM-based framework for in-plant quality control of precast concrete manufacturing – a case study* [Under Preparation].

1. Presentations and Posters of TRANS-IPIC funded research:

Hong, Z., Hong, Y., Cai, H., Abraham, D.M., Zhang, J., Dunston, P.S. (2024, Feb. 19). *Holistic Quality Management of Precast Concrete Construction for Transportation Infrastructure* [Webinar presentation]. TRANS-IPIC Monthly Research Webinar.

Hong, Z., Hong, Y., Cai, H., Abraham, D.M., Zhang, J., Dunston, P.S. (2024, Feb. 22). *Holistic Quality Management of Precast Concrete Construction for Transportation Infrastructure* [Poster presentation]. JTRP Poster Session. Indianapolis, IN, United States.

Hong, Z., Hong, Y., Cai, H., Abraham, D.M., Zhang, J., Dunston, P.S. (2024, Mar. 12). *Holistic Quality Management of Precast Concrete Construction for Transportation Infrastructure* [Poster presentation]. Purdue Road School 2024. West Lafayette, IN, United States.

Cai, H., Abraham, D.M., Zhang, J., Dunston, P.S., Hong, Z., Hong, Y. (2024, Mar. 12). *Holistic Quality Management of Precast Concrete Construction for Transportation Infrastructure* [Panel discussion]. Purdue Road School 2024. West Lafayette, IN, United States.

Hong, Z., Hong, Y., Cai, H., Abraham, D.M., Zhang, J., Dunston, P.S. (2024, April. 22). *Holistic Quality Management of Precast Concrete Construction for Transportation Infrastructure* [Keynote address]. TRANS-IPIC Annual Workshop 2024. Rosemont, IL, United States.

Hong, Y., Cai, H., Abraham, D.M. (2024, July 28). *Coupling Mobile Laser Scanning and BIM for Dimensional Quality Control of Precast Concrete Elements* [Poster presentation]. ASCE International Conference on Computing in Civil Engineering (i3CE 2024). Pittsburgh, PA, United States.

1. Please list any other events or activities that highlights the work of TRANS-IPIC occurring at your university (please include any pictures or figures you may have). Similarly, please list any references to TRANS-IPIC in the news or interviews from your research.

*NA*

**References:**

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