

## Original Research

# Integrating Architecture, Engineering, and Construction Interdisciplinary Competencies for Mass Timber Construction Education: A DACUM-based Approach

Saiba, Mohammed Rayan<sup>1</sup>, Berghorn, George H.<sup>2</sup>, Syal, Matt.<sup>3</sup>, & Huberty, Sean<sup>4</sup>.

*Mass Timber Construction (MTC) requires effective interdisciplinary collaboration across Architecture, Engineering, Construction (AEC) disciplines. MTC competencies are the knowledge, technical skills, and process capabilities that require AEC professional collaboration for effective MTC project delivery. MT-related competencies, however, remain fragmented within many AEC curricula, emphasizing a need for collaboration across disciplines. An MTC competency framework was therefore proposed by this study, employing DACUM-based mixed-method approach to evaluate three discipline-specific MTC competency panels of architects, engineers, and CMs. 251 MTC-related duties and tasks were identified and thematically coded into 18 competency areas. Quantitative methodologies including frequency and Pareto analyses were employed to determine shared core and discipline-specific competencies. Qualitative expert inputs were then employed to synthesize insights from the quantitative results. The findings highlighted BIM-enabled coordination, Estimating and Planning, Design Codes and Standards, Technical Knowledge, and Sustainability core competencies across all disciplines. This informed, the proposal of an integrated curriculum framework consisting of shared core modules to support interdisciplinary collaboration, discipline-specific depth modules, and collaborative capstone experiences. The framework provides a practical roadmap for aligning AEC education with current MTC industry practice. This study promotes effective academia–industry collaboration in MTC delivery. It also provides an empirically grounded structure for integrating sustainable construction competencies into AEC curricula.*

**Keywords:** Mass Timber, DACUM, AEC Education, Interdisciplinary Collaboration, Curriculum Framework, BIM-enabled Coordination

## Introduction

Mass Timber Construction (MTC) systems including Glued-Laminated Timber (Glulam) and Cross-Laminated Timber (CLT) have been globally recognized for their beneficial sustainability characteristics such as carbon footprint reduction, carbon sequestration, and waste reduction potential (Liu et al., 2025). MTC offers faster construction delivery and better aesthetic appeal compared to steel and concrete (Abed et al., 2022). MTC projects, however, offers distinctive technical and organizational demands, including prefabrication tolerances, connection detailing, fire design, logistics planning, and digital coordination (Ahmed & Arocho, 2020; Rojas et al., 2025). Therefore, to ensure

MTC project success, these highlighted demands need to be addressed.

Existing research suggests that traditional, independent discipline educational models often fall short in preparing students for integrated MTC project delivery. Zaman et al. (2022) suggested that coordination among AEC industry is critical for overcoming challenges often associated with novel, innovative, and sustainable construction methods such as MTC. The limitation of discipline-specific models requires early collaboration in MTC training and education to facilitate the smooth transition of AEC students from academia to industry (Welcher et al., 2020). Wang et al. (2025) and Badawi and Abdullah (2021) further highlighted that robust interdisciplinary AEC collaboration can promote the understanding of integrated design processes. Despite the advantages of collaboration in MTC delivery, only a few studies elaborated an integrated educational roadmap for aligning curricula with current MTC demands across AEC disciplines (Kremer et al., 2025; Lehmann and Kremer, 2023; Chen and Carliner, 2021). Therefore, MTC curricula require realignment to meet the demands of rapidly growing MTC industry.

Mirando and Onsarigo (2025) posited that the prefabricated nature of MTC amplifies the consequences of coordination errors and necessitates early integration of design intent, fabrication constraints, and site logistics. Therefore, MTC requires more than material-specific technical knowledge but also demands process-oriented skills in digital coordination, estimating, sequencing, and regulatory compliance (Riggio et al., 2020). Durdyev et al.

## Contact

<sup>1</sup>Corresponding Author - PhD student, School of Planning, Design, and Construction, Michigan State University, East Lansing, MI 48824, USA. Email: saibamoh@msu.edu (Corresponding Author)

<sup>2</sup>Assistant Professor, Construction Management Program, Michigan State University, East Lansing, MI 48824, USA. Email: berghorn@msu.edu

<sup>3</sup>Professor, Construction Management Program, Michigan State University, East Lansing, MI 48824, USA. Email: syalm@msu.edu

<sup>4</sup>Teaching Specialist, Construction Management Program, Michigan State University, East Lansing, MI 48824, USA. Email: hubertys@msu.edu

Mass Timber Construction Journal Received 26th of November 2025, Accepted 10th of February 2026 - DOI: 10.55191/MTCJ.2026.7

(2020) emphasized that collaborative delivery environments can help eliminate coordination errors associated with MTC projects. Elghaish et al. (2020) further suggests that they can help enhance their sustainability outcomes, help projects stay on track, and have the potential to meet the collaboration and communication demands of MTC. While industry practice has increasingly leverage BIM for collaborative project delivery and integrated workflows, research is yet to fully elaborate how these collaborative requirements translate into interdisciplinary learning outcomes for AEC students.

Developing A Curriculum (DACUM) analysis has been widely acknowledged as a curriculum alignment approach in many industries including the construction sector (Yu et al., 2025; Telaga, 2022). In the MTC context, Kiesling et al. (2025) employed DACUM with engineering professionals to define technical competencies. Oliveira et al., (2022) and Muthumanickam et al., (2023) also emphasized the importance of interdisciplinary MTC education. Saiba et al. (2025) revealed that MTC curricula integration into AEC education requires effective expert collaboration. However, there is limited focus on shared across AEC expert panels for MTC project delivery.

Addressing these gaps can help to properly align AEC curricula with the growing MTC sector. To address the identified gap, this study (1) conducts a stratified analysis of discipline-specific DACUM panels of MTC professionals (2) synthesizes cross-panel competencies to support integrated curriculum development. By combining qualitative expert knowledge with quantitative synthesis, the study seeks to distinguish shared core competencies that enable collaboration from discipline-specific competencies that require targeted depth. MTC competencies in this study refer to the integrated knowledge, technical skills, process capabilities, and collaborative abilities required by AEC professionals to perform their roles effectively throughout MTC project delivery. These competencies encompass both material-specific capabilities, such as understanding timber behavior, connection detailing, fire performance, and dimensional tolerances, and process-oriented capabilities, including BIM-enabled coordination, estimating and planning, logistics, regulatory compliance, communication, and interdisciplinary decision-making. Competencies are therefore conceptualized not merely as isolated technical tasks but as the capabilities demonstrated through the duties and tasks identified by experienced AEC professionals during the DACUM workshops.

## 2. Background

MTC project success depends on effective collaboration among AEC professionals rather than on standalone discipline-specific tasks (Ahmed and El-Sayegh, 2020). MTC projects require early collaboration to tackle integrated processes including prefabrication, interface detailing, and tolerance setting for expected structural performance, and logical sequencing (Nouh et al., 2024; Santana-Sosa and Kovacic, 2022). MTC components are manufactured off-site, which increases the consequences of coordination errors and compresses opportunities for late design changes. These characteristics demand competencies that combine technical understanding with process-oriented skills in digital coordination, sequencing, and regulatory compliance

(Srivastava et al., 2021; Almuhammad and Ghareeb, 2024). Inadequate collaboration in MTC projects causes fragmentation, which consequently results in time and budget overruns (Smith et al., 2018).

Modern project environments increasingly rely on BIM-enabled coordination and collaborative workflows to manage these demands. Research evidenced that integral role of digital processes such as BIM-enabled coordination in minimizing rework while improving information exchange in MTC projects (Alinezhad et al., 2020; Babalola et al., 2024; Arar et al., 2025). Moreover, complexities associated with sustainable construction systems such as MTC can be minimized through effective collaboration (Assaf and Assaad, 2024). Furthermore, collaborative environments have been proven to foster design-construction workflow, resulting in faster project delivery and addressing the fragmentations associated with MTC projects through a robust collaboration among project teams and structures for successful project execution (Alameri and Esmaeili, 2023; Rashed and Mutis, 2023).

Effective MTC delivery therefore demands experts who can translate design intent into fabrication-ready information while conforming to schedules, logistics, and code pathways. The required skill set extends beyond discipline-specific knowledge to include interdisciplinary communication, planning logic, and shared decision making. However, existing MTC studies scarcely emphasize the key collaborative competencies required for effective MTC project delivery. Furthermore, research has emphasized that successful MTC project delivery depends effective MTC education and training including on-site assembly, structural detailing, and effective collaboration (Santana-Sosa and Kovacic, 2022; Tenório et al., 2024).

Despite growing recognition of collaborative MTC delivery, existing research provides limited empirical guidance on how professional responsibilities across AEC can be translated into an integrated educational competency structure. Therefore, detail clarity is required regarding which competencies should be learned across AEC disciplines and which require deeper discipline-specific development.

Accordingly, the aim of this study was to identify and synthesize shared and discipline-specific MTC competencies across AEC and translate these industry-derived competencies into an interdisciplinary curriculum framework. To achieve this aim, the study: (1) analyzed discipline-specific DACUM outputs from MTC professionals; (2) systematically coded the identified duties and tasks into competency themes; (3) compared competency emphasis within and across architecture, engineering, and construction management; and (4) translated the resulting shared and discipline-specific competency structure into recommendations for MTC curriculum integration.

## 3. Methodology

A mixed-design research approach (quantitative and qualitative) was adopted for this study. The mixed-method design was employed to draw qualitative insight from experts while enabling quantitative synthesis of competency emphasis across disciplines. The research focused on gaining insights from the qualitative inputs of experienced AEC industry professionals

through DACUM with quantitative analysis to identify potential integration competencies from three discipline-specific DACUM panels of architects, engineers, and construction managers (CMs) that will better align MTC education with industry expectations. DACUM workshops typically involve panels of professionals who define and prioritize job responsibilities and recommend approaches for improving existing educational models based on their industry experience (Norton, 1997). DACUM approach has been acknowledged as a framework for analyzing and aligning industry tasks and responsibilities. Three DACUM workshops were conducted with panels comprising architects, engineers, and CMs. A cross-panel synthesis was then conducted, which allowed for profound engagement with the AEC professionals to draw qualitative data reflecting their experience in MTC. Figure 1 outlines the DACUM-based mixed method roadmap for the study.

### 3.1 Panelist Selection and Expertise Criteria

Panelists were recruited through professional networks and industry-academic partnerships within AEC. Participants were considered MT experts based on meeting at least two of the following eligibility criteria: (1) a minimum of five years of professional experience in the AEC industry; (2) direct involvement in the design, engineering, estimating, coordination, or construction of at least two completed MT projects or one active project at the time of the workshop; (3) primary responsibility for MT-related tasks within a project team; or (4) demonstrated expertise through teaching, professional training, publications, or leadership roles related to MT delivery. Background information of the panelists was recorded regarding their discipline, experience level, and MT project involvement before their selection. Three

separate panels were convened for architecture, construction management, and structural engineering with nine, ten, and six prequalified industry experts, respectively. Table 1 describes the backgrounds of the DACUM panelists.

### 3.2 DACUM Workshop Procedure and Prompts

Each DACUM workshop panel followed a structured and facilitated process. A trained facilitator guided panelists through defining the scope of MT responsibilities for their respective discipline, followed by a brainstorming session to identify key duties and associated tasks. Key prompts included:

1. "What are the primary responsibilities of your role in MT projects?"
2. "What duties and tasks are expected of entry-level professionals in your discipline who are working on MT project delivery?"
3. "Which tasks require direct collaboration with other AEC disciplines?"
4. "What MT-specific competencies are essential for collaborative MT project delivery?"
5. "What tools do AEC professionals need to be knowledgeable of for MT projects?"
6. "What future trends do you believe will influence MT project delivery?"

Duties and tasks were collaboratively refined and consolidated by the panelists. Tasks were then clearly defined through group discussion to remove duplicates and ensure shared understanding. Furthermore, tasks were then organized

Table 1. DACUM Panelist

| Panelist ID | Panel                   | Job Title           | Licensure/<br>Certification | Location         | Experience |
|-------------|-------------------------|---------------------|-----------------------------|------------------|------------|
| Arch1       | Architecture            | Director            | AIA, LEED AP, NCARB         | Michigan         | 28 yrs     |
| Arch2       |                         | Associate           | AIA, LEED AP                | Oregon           | 9 yrs      |
| Arch3       |                         | Project Architect   | LEED AP BD+C                | Oregon           | 16 yrs     |
| Arch4       |                         | Creative Director   |                             | Kenya            | 18 yrs     |
| Arch5       |                         | Regional Director   | AIA, LEED AP BD+C, NCARB    | Michigan         | 28 yrs     |
| Arch6       |                         | Project Architect   |                             | California       | 17 yrs     |
| Arch7       |                         | Architect           | AIA, NCARB                  | Michigan         | 7 yrs      |
| Arch8       |                         | Principal           |                             | New York         | 14 yrs     |
| Arch9       |                         | Architect           | AIA                         | Illinois         | 10 yrs     |
| CM1         | Construction Management | Project Manager     | LEED AP                     | Oregon           | 15 yrs     |
| CM2         |                         | Sr. Project Manager |                             | Michigan         | 16 yrs     |
| CM3         |                         | Project Manager     |                             | Michigan         | 11 yrs     |
| CM4         |                         | Project Executive   |                             | Michigan         | 24 yrs     |
| CM5         |                         | VP Preconstruction  | LEED AP BD+C                | Ohio             | 32 yrs     |
| CM6         |                         | VP Construction     |                             | Minnesota        | 8 yrs      |
| CM7         |                         | Estimator           |                             | Michigan         | 3 yrs      |
| CM8         |                         | Project Manager     |                             | Michigan         | 13 yrs     |
| CM9         |                         | Director            |                             | Alaska           | 10 yrs     |
| CM10        |                         | Executive VP        | LEED AP                     | California       | 31 yrs     |
| Eng1        | Structural Engineering  | Associate           | PE, SE, LEED AP             | Oregon           | 17 yrs     |
| Eng2        |                         | VP Engineering      | PE                          | New York         | 18 yrs     |
| Eng3        |                         | Partner             | P.Eng., Dipl. Ing.          | British Columbia | 30 yrs     |
| Eng4        |                         | Principal           | SE                          | Illinois         | 10 yrs     |
| Eng5        |                         | Vice President      | None                        | Washington       | 18 yrs     |
| Eng6        |                         | Sr. Dir. of MT      | None                        | Wisconsin        | 8 yrs      |

according to typical project phases, including design, procurement, fabrication, installation, and closeout. Consensus-based validation was conducted during the workshop to confirm the accuracy and completeness of the identified duties and tasks. Following each workshop, the resulting DACUM charts were circulated to panelists for member checking and final validation.

### 3.3 Consensus-Based Validation

Resulting discipline-specific DACUM charts were reviewed by independent disciplinary panels to ensure external validity. Owing to the relative newness of MT in the United States and the small size of the expert DACUM panels, a consensus-based method was sought. The Delphi process was selected and empaneled three disciplinary panels of qualified MT experts to validate DACUM results. Experts were prequalified through the use of survey that assessed candidates' work experience, licensure, and educational background. Criteria were tailored specifically to the needs of this study and required, at minimum, prior experience on a mass timber project to ensure familiarity with MT design and construction. Seven, eight, and seven participants met all qualifications and were selected for the architecture, construction management, and structural engineering panels, respectively (Table 2). Although Delphi panel sizes vary widely, research indicates that expertise and representation are more important than sample size; therefore, these panel sizes comprised of highly

qualified professionals were deemed appropriate (Ameyaw et al., 2016; Naji, 2024).

The Delphi procedure was used to validate tasks, general knowledge and skills, and worker characteristics identified in the preliminary DACUM chart. The chart was converted into a digital survey in which experts rated whether newly graduated students in each discipline should be able to perform specific tasks within their first year. A five-point Likert scale was used to indicate agreement with identified duties and tasks. The measure of consensus was the median response score; items were determined as reaching consensus when at least 70% of the response values fell within one half bin of the median group response. To maintain engagement and reduce dropout risk, certain DACUM sections (such as software and future trends) were excluded from the Delphi rounds. Experts completed three rounds of surveys, with each round building on the previous one.

After each round, items reaching consensus were removed from subsequent surveys, and participant feedback was incorporated to improve clarity where needed. Summary reports provided median ratings, consensus percentages, and anonymized comments to encourage reflection and reconsideration of divergent opinions. In Round 2, individualized reports also compared each expert's responses to the group median, prompting further evaluation in the final round. All experts completed each survey round within the allotted timeframe, resulting in a validated and consensus-

Table 2. Delphi Panelist

| <b>Panelist ID</b> | <b>Panel</b>            | <b>Job Title</b>                                               | <b>Location</b> | <b>Experience</b> |
|--------------------|-------------------------|----------------------------------------------------------------|-----------------|-------------------|
| Arch9              | Architecture            | Senior Associate Architect at an architecture firm             | Michigan        | 30 yrs            |
| Arch10             |                         | Senior Project Manager at an engineering and architecture firm | Michigan        | 28 yrs            |
| Arch11             |                         | Architect at an architecture firm                              | Michigan        | 10 yrs            |
| Arch12             |                         | Architect at an architecture firm                              | Michigan        | 21 yrs            |
| Arch13             |                         | Sr Architect at an architecture firm                           | Wisconsin       | 9 yrs             |
| Arch14             |                         | Principal at an architecture firm                              | Michigan        | 26 yrs            |
| Arch15             |                         | Designer II at an architecture firm                            | Illinois        | 6 yrs             |
| CM11               | Construction Management | President of Commercial Construction at a general contractor   | Michigan        | 12 yrs            |
| CM12               |                         | Project Manager at a MT erector                                | California      | 4 yrs             |
| CM13               |                         | Director at a general contractor                               | Michigan        | 16 yrs            |
| CM14               |                         | Project Manager at a general contractor                        | Michigan        | 10 yrs            |
| CM15               |                         | Senior Project Manager at an engineering and architecture firm | Michigan        | 28 yrs            |
| CM16               |                         | Construction Project Manager at a MT manufacturer              | Illinois        | 8 yrs             |
| CM17               |                         | Contract Manager at a general contractor                       | Indiana         | 5 yrs             |
| CM18               |                         | Segment Leader at a general contractor                         | Michigan        | 30 yrs            |
| Eng7               | Structural Engineering  | Principal Lecturer at a public university                      | Maine           | 21 yrs            |
| Eng8               |                         | President of construction company                              | Michigan        | 23 yrs            |
| Eng9               |                         | President/CEO of engineering firm                              | Colorado        | 36 yrs            |
| Eng10              |                         | Vice President/COO of engineering firm                         | Arkansas        | 20 yrs            |
| Eng11              |                         | Principal and Director of Mass Timber                          | Oregon          | 15 yrs            |
| Eng12              |                         | Principal in fire protection engineering                       | Ontario         | 25 yrs            |
| Eng13              |                         | Associate Principal at engineering firm                        | California      | 10 yrs            |

based refinement of the DACUM findings.

### 3.4 Theme Development and Coding Process

An inductive–deductive thematic analysis was used to synthesize duties and tasks across the three discipline-specific DACUM panels. The thematic analysis process was informed by Braun and Clarke (2006), involving systematic familiarization with the data, initial coding, development and review of candidate themes, and definition of the resulting themes. The analysis combined inductive identification of recurring concepts within the DACUM outputs with deductive consideration of established MTC and AEC functional areas identified in the literature.

Three researchers independently reviewed an initial subset of the DACUM outputs to propose preliminary theme categories based on recurring concepts and functional similarities. These themes were then discussed and refined to produce a shared codebook with operational definitions and representative examples. Researchers then independently coded all identified tasks using the codebook. Coding issues were resolved through discussion to achieve consensus, and the codebook was iteratively refined throughout the process to ensure consistency, transparency, and analytical rigor in the identification of interdisciplinary and discipline-specific integration themes.

Using the agreed codebook, the identified duties and tasks

were independently assigned to competency themes. Coding disagreements or ambiguous tasks were reviewed collectively and resolved through researcher discussion and consensus. The codebook was iteratively refined where necessary to maintain consistent interpretation across the architecture, engineering, and CM datasets. The final coding structure contained 18 competency themes and formed the basis for the subsequent frequency, Pareto, heatmap, and cross-panel analyses.

### 3.5 Quantitative Analysis

Frequency analysis was adopted to assess and identify relative interdisciplinary and discipline-specific competency emphasis for each theme. Pareto analysis was applied to visualize cumulative distributions and identify dominant competency areas. Emphasized themes within each discipline were defined as contributing to approximately the first 80% of cumulative task frequency. This mixed qualitative–quantitative approach enabled both discipline-specific and cross-disciplinary interpretation of MT competency needs. This structured DACUM-based methodology provided a data-driven approach to transferring insights from expert knowledge to education framework development. This can allow the proposed curricula to reflect practical interdisciplinary collaboration within MT construction.

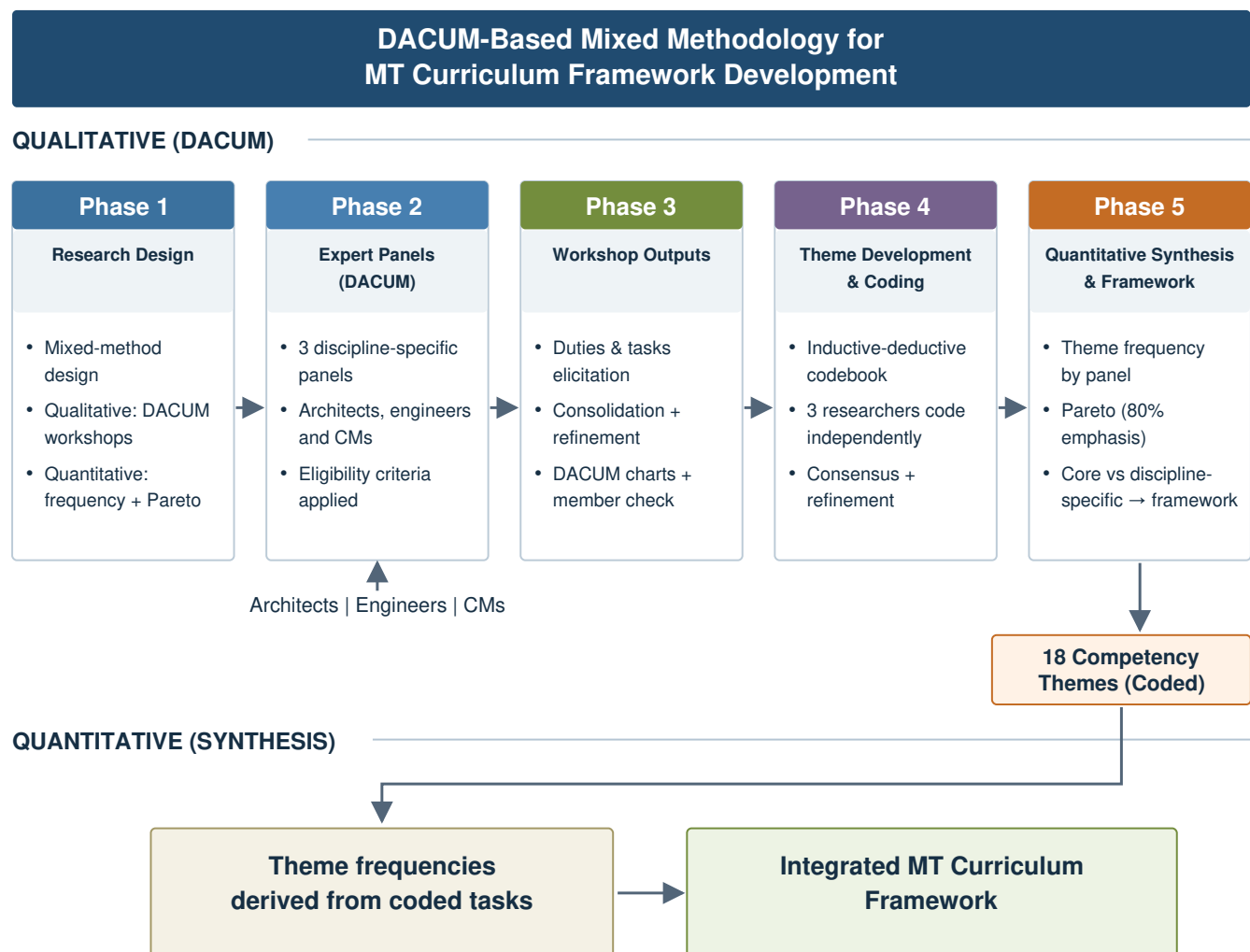


Figure 1. DACUM-based mixed-method research methodology for MTC curriculum framework development

## 4. Results

### 4.1 Definition of Identified Themes

To ensure clarity and analytical consistency, each integration theme was defined prior to quantitative synthesis. Technical Knowledge represents MTC-specific understanding required for informed decision making, including material characteristics, dimensional tolerances, connection detailing, and erection sequencing. Design Codes and Standards highlight regulatory and compliance activities such as interpretation of building

codes, fire and safety requirements, and inspection procedures. Estimating and Planning represent forecast activities, including quantity takeoffs, logistics planning, installation sequencing, crane studies, schedule development, and procurement lead-time analysis. Cost and Finance addresses financial management functions such as budget development, contingency allocation, change-order pricing, and cash-flow control. These operational definitions elaborated in Figure 2, guided thematic coding and cross-disciplinary comparison.

Table 3. Definitions of Identified Themes

| Theme                         | Definition                                                                           |
|-------------------------------|--------------------------------------------------------------------------------------|
| BIM-enabled Coordination      | Model integration, clash detection, information exchange, and workflow coordination. |
| Technical Knowledge           | MTC behaviour, constructability, tolerances, connections, and erection sequencing.   |
| Design Codes and Standards    | Building codes, fire requirements, life safety, and inspections.                     |
| Estimating and Planning       | Take-offs, sequencing, logistics, crane planning, scheduling, and lead times.        |
| Cost and Finance              | Budgets, contingencies, change pricing, and cash flow.                               |
| Connections and Assembly      | MTC connections, assembly logic, and interfaces with other systems.                  |
| Fire Performance              | Fire resistance, encapsulation, and testing requirements.                            |
| Sustainability and LCA        | Embodied carbon, life-cycle impacts, sourcing, and environmental performance.        |
| Documentation and Records     | Drawings, specifications, submittals, RFIs, and as-built records.                    |
| Logistics and Site Management | Site access, laydown, deliveries, and installation logistics.                        |
| Safety and Quality            | Safety planning, quality assurance, inspections, and compliance.                     |
| Stakeholder Coordination      | Coordination with owners, authorities, suppliers, fabricators, and contractors.      |
| Innovation and Research       | Emerging technologies, new construction methods, and applied research.               |
| Training and Outreach         | Education, workforce training, and MTC knowledge transfer.                           |
| Procurement and Bidding       | Vendor selection, bid review, scope definition, and procurement strategy.            |
| Risk and Compliance           | Technical, financial, contractual, and regulatory risk management.                   |
| Administration                | Scheduling, reporting, project administration, and internal management.              |
| Communication                 | Interdisciplinary communication, meetings, and information sharing.                  |

4.2 Cross-Panel Distribution of Competency Themes (Pareto Analysis)

Figure 2 presents the relative emphasis of competency themes identified by the three discipline-specific panels. While the specific ranking varies by discipline, BIM-enabled coordination, estimating and planning, design codes and standards, and technical knowledge consistently appear among the highest-frequency themes, indicating a shared foundation for interdisciplinary MTC practice. The Pareto analysis of the coded DACUM tasks highlights distinct yet overlapping competency emphases across the expert panels in accordance with the 80/20 principle. Emphasized themes were defined as those contributing to approximately the first 80% of cumulative task frequency within each discipline's Pareto distribution. As shown in Figures 2, the MTC competencies ranked in each panel highlight 5-7 major themes representing approximately 80% of the total competencies, indicating a concentrated set of competencies central to MTC project delivery.

4.2 Shared Core Themes Across Panels

Four competency areas were consistently emphasized across the three AEC expert panels (Table 4). These shared themes represent foundational competencies required for interdisciplinary MTC practice. The recurrence of these themes across all panels indicates that MTC education requires a common core that transcends individual disciplinary boundaries.

Table 3. Identified Shared Competencies and Applications in MTC

| Shared Competency          | MTC Task Example                             |
|----------------------------|----------------------------------------------|
| BIM-enabled Coordination   | CLT installation sequencing and clash review |
| Estimating and Planning    | Timber logistics quantities and scheduling   |
| Design Codes and Standards | Fire-resistance detailing and compliance     |
| Technical Knowledge        | Panel tolerances and connection detailing    |

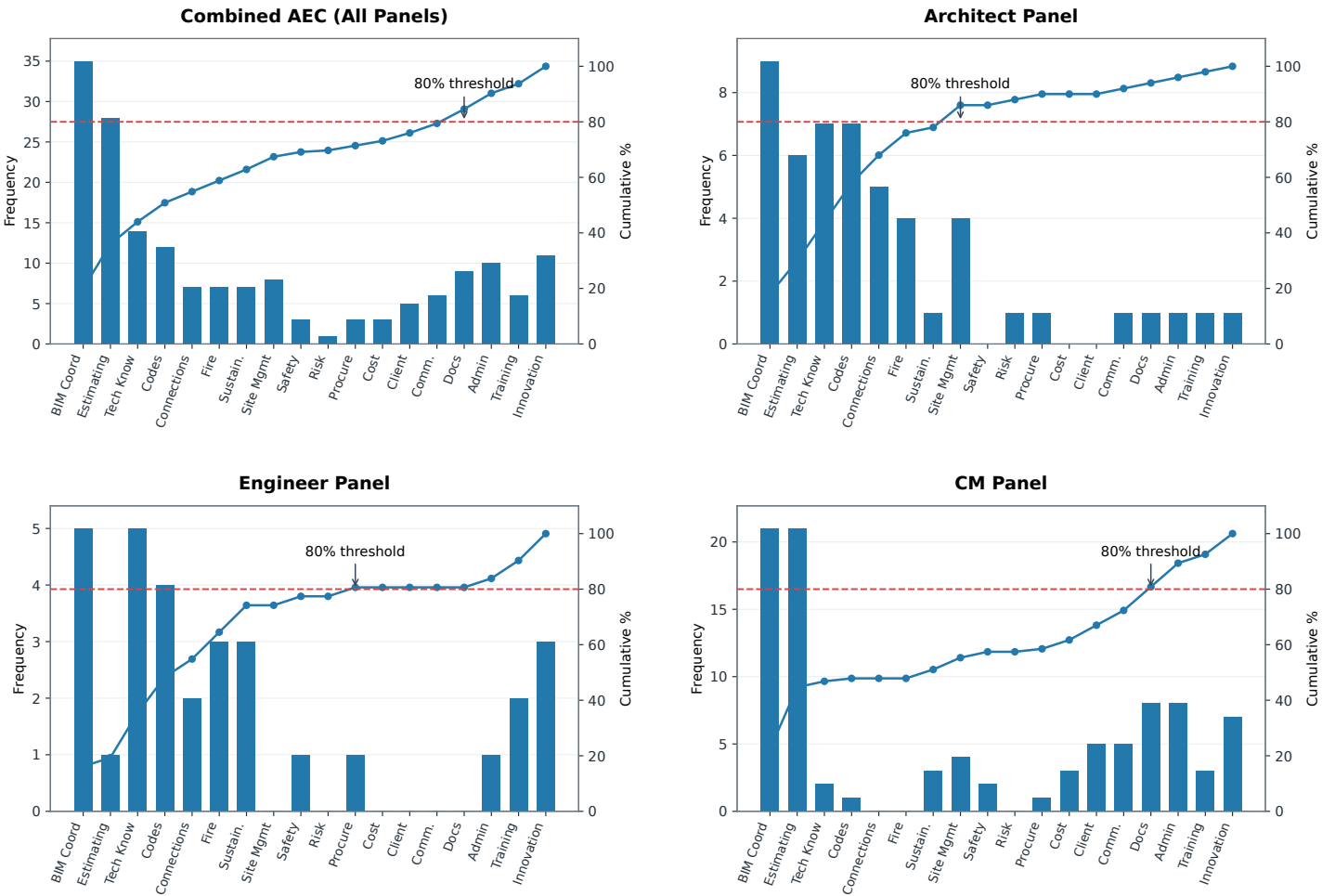


Figure 2: Distribution of MTC competency themes across AEC panels derived from DACUM tasks. Emphasized themes represent those contributing to approximately 80% of cumulative task frequency within each discipline, indicating the core capabilities required for interdisciplinary MTC delivery.

### 4.3 Discipline-Specific Themes

While core themes were shared, each panel demonstrated distinctive priorities. Architects most frequently emphasized connection and assembly (5 tasks) and fire safety (4 tasks), reflecting responsibilities for detailing and regulatory integration. The main concentration of CMs is on documentation and records (8 tasks) and stakeholder or client (5 tasks), aligning with their lead responsibility in project controls and stakeholder management. Furthermore, the strongest emphasis of engineers is on fire and sustainability, consistent with their analytical design obligations. These differences highlight the need for discipline-specific depth alongside shared competencies.

### 4.4 Thematic Emphasis by Discipline

Figure 3 revealed the intensity of the task's occurrences across the identified major theme categories for each expert group. The darker the color, the higher the intensity of occurrence, indicating the level of emphasis placed on the theme. It highlights the discipline-specific focus trends and shared competency areas across the three AEC panels.

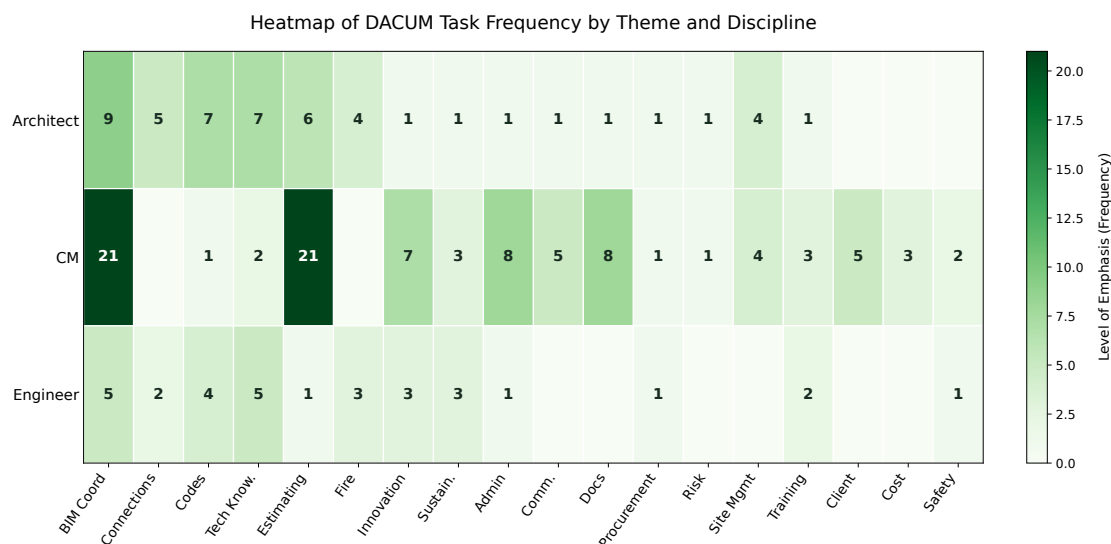


Figure 3, Heatmap of interdisciplinary competency emphasis illustrating overlaps and specializations.

CMs appeared with the most emphasized tasks across the panels, concentrating strongly on BIM-enabled coordination and estimating and planning respectively. Thus, reflecting their interest in workflow planning, scheduling, and controls. Architects demonstrated elevated emphasis on design codes and standards and technical knowledge, highlighting their primary focus on compliance, and conceptual detailing. Engineers also strongly emphasized technical knowledge and design codes and standards. This aligns with their core interest in structural performance. BIM-enabled coordination was significant across all panels reflecting the need for digital collaboration among all AEC professionals. Sustainability and LCA also appeared moderately across the panels, reflecting the continuous traction of sustainability with the AEC setting.

Overall, Figure 3 displays a visual overlap and distinctions across the AEC panel competencies. Areas that require

integration for MTC were highlighted, emphasizing panel-specific modules and offering insights for the development of an interdisciplinary curriculum framework.

### 4.5 Synthesis of Overlapping and Unique Competencies

Figure 4 conceptually synthesizes the relationships between competencies. Only high-frequency and strongly shared themes were included. All three panels intersected centrally with themes including BIM-enabled Coordination, design codes and standards, estimating and planning, sustainability and LCA, technical knowledge and innovation and research. It indicates that these competencies are universally relevant and therefore should form the core of an interdisciplinary MTC curriculum. There also exists an overlap between architects and engineers (connection and assembly and fire detailing), projecting the importance of joint technical training modules.

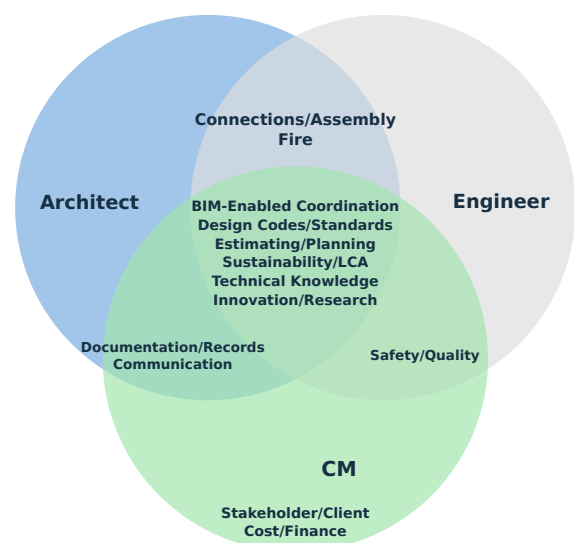


Figure 4, A Venn diagram showing overlapping and unique thematic competencies among Architect, Engineer, and CM DACUM panels. Shared zones represent integration opportunities for interdisciplinary mass-timber education.

Engineer-CM overlap (safety and quality) was also highlighted, supporting their shared responsibility in maintaining safety protocols and quality assurance on site. Stakeholder or client coordination and cost and finance appeared unique to CMs, thus, emphasizing their leadership role in stakeholder management and project cost control. Absence of competencies unique solely to architect and engineer highlights a collaboration gap, reinforcing the need for integrated curriculum for MTC education and effective project delivery.

## 5. Discussion

The study aimed to identify and synthesize shared and discipline-specific MTC competencies across AEC and to translate these industry-derived competencies into an interdisciplinary curriculum framework. The cross-panel DACUM analysis demonstrates that effective MTC practice requires a combination of common collaborative capabilities and profession-specific technical depth. The findings therefore address the central educational gap identified in the study, which is the absence of a clearly structured approach for translating interdisciplinary MTC project-delivery requirements into shared and discipline-specific learning priorities for AEC education.

The results demonstrate that competencies support effective MTC delivery better than isolated technical knowledge. The significant emphasis of BIM-enabled coordination across all panels confirms that digital integration is critical for aligning design, fabrication, and site execution. This finding suggests that MTC education should prioritize process-oriented collaboration skills alongside material-specific content. Furthermore, discipline-specific competencies also appear significant, with architects prioritizing connections, assembly and fire detailing, confirming their interest in integrating structural and regulatory requirements. Engineers focus on technical performance and sustainability, emphasizing their responsibility in analyzing obligations. CMs also focus on planning and documentation, reflecting accountability for constructability and project controls. These variations in priorities emphasized the need for interdisciplinary MTC education for a balanced learning experience.

Furthermore, BIM-enabled coordination and estimating and planning were the most highlighted competencies. This positions them as the major theme areas that requires the strongest collaboration for MTC projects. Notwithstanding, the study revealed variations in theme emphasis in each panel, such as significant emphasis on design codes and standards and technical knowledge by architects and engineers and estimating and planning by CMs. These variations indicate that each panel contributes unique technical and managerial expertise for project integration. Moreover, strong emphasis on BIM-enabled coordination for CMs reveals their high interest in collaboration, while emphasis on estimating and planning reflects the need for collaborative project planning, scheduling, and control. Engineers appeared across all theme categories, confirming their bridging role between conceptual design and project execution.

The study confirms that shared competencies and discipline-specific tasks are both critical for effective MTC education and project delivery. The DACUM approach offers a roadmap for MTC academic-industry competency alignment. This program

can provide AEC students with the readiness to collaborate for successful MTC project execution.

### 5.1 Implications for AEC Education

The findings highlight a paradigm shift from the conventional isolated (stand-alone) education approach within the AEC. The identified competency structure has direct implications for curriculum design. Shared competencies offer the basis for interdisciplinary core modules for AEC students, centered on BIM coordination, effective planning and estimation, and code integration. Discipline-specific competencies inform specialized modules addressing detailing, performance analysis, or project controls. The architect-engineer competency overlaps in connection and fire performance supports joint technical studios, while the engineer-CM overlap on safety and quality encourage integrated construction laboratories.

Notwithstanding, the findings suggest that MTC education should be organized around project workflows rather than isolated courses. Competencies such as sequencing, logistics, and coordination are inherently integrative and cannot be fully developed within single-discipline classrooms. Collaborative capstones and studio environments therefore represent critical venues for applying the shared core.

### 5.2 Curriculum Integration Framework

This study proposes a curriculum integration framework (see Figure 5) for aligning shared and discipline-specific competencies with MTC education based on insights from the DACUM analyses and findings from the cross-panel comparisons of architects, engineers, and CMs. The framework organizes learning around a shared core of collaboration-oriented capabilities while preserving discipline-specific depth required for professional roles. The framework consists of:

- **Shared Core Modules:** Based on shared competencies across the three DACUM panels. This will encourage interdisciplinary collaboration and system thinking.
- **Discipline-Specific Modules:** Based on tasks unique to each panel. This reflects the competencies that were strongly emphasized by the individual panels.
- **Collaborative Capstone Experiences:** Bringing panels together through MTC workshops, seminars, and interdisciplinary research collaborations.

The framework emphasizes that MTC delivery leverages BIM-enabled coordination for integrated workflows rather than independent technical instruction. The framework can be implemented by systematically embedding short MTC units within existing BIM, estimating, structures, and codes courses, offering elective MTC certificates, or adopting interdisciplinary studios. These approaches help overcome challenges associated with accreditation while fostering integrated learning.

### 5.3 Implementation Strategy

Given the limited flexibility within accredited AEC degree programs, the proposed MTC curriculum framework is designed for scalable implementation through multiple pathways.

## CURRICULUM INTEGRATION FRAMEWORK FOR MT EDUCATION

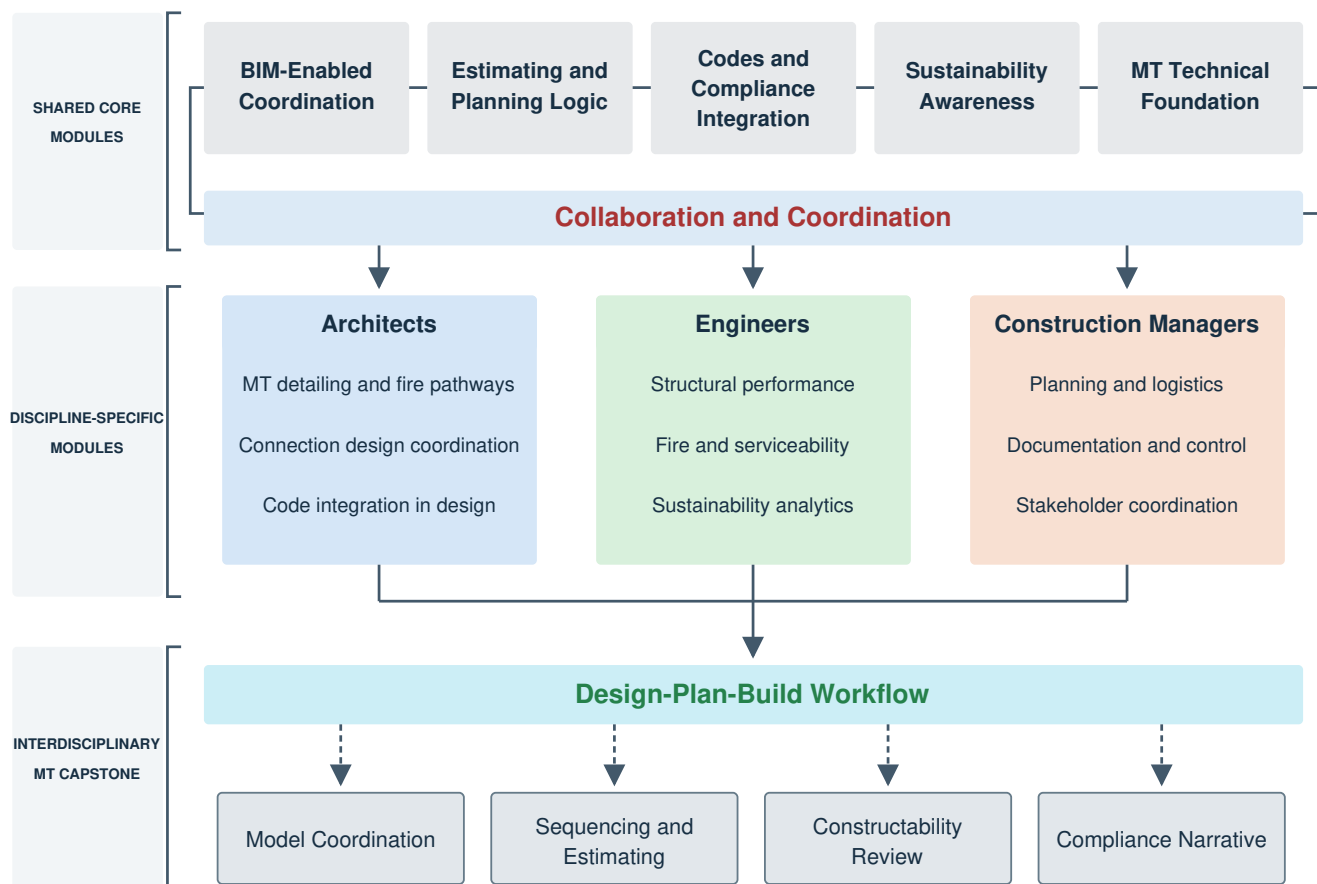


Figure 5. Educational framework translating DACUM-derived competencies into three instructional layers: (1) shared core modules that develop interdisciplinary collaboration and digital coordination; (2) discipline-specific modules that provide role-based depth; and (3) collaborative capstone experiences that integrate design, engineering, and construction workflows in mass timber projects.

First, modular integration adoption ensures shared-core MTC competencies to be embedded within existing courses, such as structures, construction methods, BIM, estimating, and building codes, through short instructional modules or focused learning units. Furthermore, a certification or credential approach allows students to pursue interdisciplinary MTC training as an elective sequence that complements required degree coursework. Moreover, an interdisciplinary capstone or studio model provides a high-impact implementation option in which AEC students collaborate on an MTC project exercise comprising design coordination, estimating, scheduling, constructability review, and code compliance. Collectively, these strategies offer flexible adoption options that align with institutional constraints while supporting interdisciplinary competency development.

#### 5.4 Comparison with Existing Industry Training and Resources

The competencies identified through the DACUM panels align with several emphasis areas found in existing industry-focused MTC training resources, particularly those addressing connection detailing, constructability, and installation logic. Industry programs for instance often prioritize practical understanding of connections and erection logic and flow. This aligns with the strong emphasis on technical and coordination-related tasks prominent across all three disciplinary panels.

However, many industry resources are oriented toward individual roles or specific phases of construction. This study therefore emphasizes the cross-disciplinary perspective, distinguishing between shared-core competencies required across AEC and discipline-specific competencies that require targeted depth. By aligning industry-informed competencies with academic curricula through the proposed curriculum framework, this study complements existing MTC training resources and addresses the gaps in interdisciplinary integration within AEC education.

#### 5.5 Limitations and Future Studies

This study focused on framework development based on expert knowledge synthesis rather than empirical evaluation of student outcomes. Panel composition reflects experienced practitioners but does not capture all organizational and regional context. Future research should pilot the framework in AEC academic environment to assess the learning impacts and compare outcomes across different implementation approaches. Longitudinal academic-industry partnerships would further refine competency priorities as MTC practice evolves.

#### 5.6 Summary and Conclusion

By synthesizing expert knowledge across AEC panels, this study identifies the competency structure underlying interdisciplinary

MTC delivery. The evidence supports an educational model centered on BIM-enabled coordination, planning, codes, and technical knowledge, complemented by discipline-specific depth. The resulting framework provides a practical mechanism for aligning AEC curricula with sustainable contemporary construction practice and preparing graduates for collaborative MTC project environments.

## References

- Abed, J., Rayburg, S., Rodwell, J., & Neave, M. (2022). A review of the performance and benefits of mass timber as an alternative to concrete and steel for improving the sustainability of structures. *Sustainability*, 14(9), 5570. <https://doi.org/10.3390/su14095570>
- Ahmed, S., & Arocho, I. (2020). Mass timber building material in the U.S. construction industry: Determining the existing awareness level, construction-related challenges, and recommendations to increase its current acceptance level. *Cleaner Engineering and Technology*, 1, 100007. <https://doi.org/10.1016/j.clet.2020.100007>
- Ahmed, S., & El-Sayegh, S. (2020). Critical review of the evolution of project delivery methods in the construction industry. *Buildings*, 10(11), 11. <https://doi.org/10.3390/buildings10010011>
- Alameri, R., & Esmaeili, B. (2023). Progressive design-build delivery method: Assessment of project performance. *International Journal of Construction Education and Research*, 19(1), 22–41. <https://doi.org/10.1080/15578771.2021.1961931>
- Alinezhad, M., Saghatforoush, E., Kahvandi, Z., & Preece, C. (2020). Analysis of the benefits of implementation of IPD for construction project stakeholders. *Civil Engineering Journal*, 6(8), 1609–1621. <https://doi.org/10.28991/cej-2020-03091563>
- Almaz, F. (2022). A new way of doing business during the COVID-19 pandemic: An example of the DACUM analysis. *Management – Journal of Contemporary Management Issues*, 27(1), 337–359. <https://doi.org/10.7595/management.fon.2022.0018>
- Almuhannadi, M. A., & Ghareeb, A. S. (2024). Enhancing design-bid-build project delivery: A comprehensive review and framework for contractor selection and project optimisation in the construction industry. *Organization, Technology & Management in Construction*, 16(1), 63–80. <https://doi.org/10.2478/otmcj-2024-0006>
- Ameyaw, E. E., Hu, Y., Shan, M., Chan, A. P. C., & Le, Y. (2016). Application of Delphi method in construction engineering and management research: A quantitative perspective. *Journal of Civil Engineering & Management*, 22(8), 991–1000. <https://doi.org.proxy2.cl.msu.edu/10.3846/13923730.2014.945953>
- Arar, A. J., Poirier, E., & Staub-French, S. (2025). A research and development framework for integrated project delivery. *Construction Management and Economics*, 43(2), 85–112. <https://doi.org/10.1080/01446193.2024.2359710>
- Assaf, G., & Assaad, R. H. (2024). A decision-support system for choosing between traditional and alternative project delivery methods for bundled projects. *Engineering, Construction and Architectural Management*. Advance online publication. <https://doi.org/10.1108/ECAM-09-2023-0773>
- Babalola, O. G., Alam Bhuiyan, M. M., & Hammad, A. (2024). Literature review on collaborative project delivery for sustainable construction: Bibliometric analysis. *Sustainability*, 16(17), 7707. <https://doi.org/10.3390/su16177707>
- Badawi, A. M., & Abdullah, M. R. (2021). Interdisciplinary design education: Development of an elective course in architecture and engineering departments. *Journal of Engineering and Applied Science*, 68(1), 10. <https://doi.org/10.1186/s44147-021-00003-8>
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, 3(2), 77–101. <https://www.tandfonline.com/doi/pdf/10.1191/1478088706qp0630a>
- Chen, Y., & Carliner, S. (2021). A special SME: An integrative literature review of the relationship between instructional designers and faculty in the design of online courses for higher education. *Performance Improvement Quarterly*, 33(4), 471–495. <https://doi.org/10.1002/piq.21332>
- Durdyev, S., Hosseini, M. R., Martek, I., Ismail, S., & Arashpour, M. (2020). Barriers to the use of integrated project delivery (IPD): a quantified model for Malaysia. *Engineering, Construction and Architectural Management*, 27(1), 186–204. <https://doi.org/10.1108/ECAM-07-2018-0279>
- Elghaish, F., Hosseini, M. R., Talebi, S., Abrishami, S., Martek, I., & Kagioglou, M. (2020). Factors driving success of cost management practices in integrated project delivery (IPD). *Sustainability*, 12(22), 9539. <https://doi.org/10.3390/su12229539>
- Kiesling, C., Person, C., Cetin, K., & Berghorn, G. (2025). Mass Timber Curriculum Development for Engineering Students Using Dacum and Delphi Methodologies. *Journal of Civil Engineering Education*, 151(4), 04025015. [https://doi.org/10.1061/\(ASCE\)EI.2643-9115.0000023](https://doi.org/10.1061/(ASCE)EI.2643-9115.0000023)
- Kremer, P. D., Abbasnejad, B., Ahankoob, A., & Wakefield, R. (2025). Advancing Global Mass Timber Construction-A Decade of Progress, Challenges, and Future Directions: A Systematic Literature Review. *Building and Environment*, 113458. <https://www.sciencedirect.com/science/article/pii/S036013232500931X>
- Lehmann, S., & Kremer, P. D. (2023). Filling the Knowledge Gaps in Mass Timber Construction.: Where are the Missing Pieces, What are the Research Needs?. *Mass Timber Construction Journal*, 6(1), 1–10. <https://www.journalmtc.com/index.php/mtcj/article/download/34/13>
- Liu, R., Yao, L., Gong, Y., & Wang, Z. (2025). Life Cycle Assessment with Carbon Footprint Analysis in Glulam Buildings: A Review. *Buildings*, 15(12), 2127. <https://doi.org/10.3390/buildings15122127>
- Mirando, A. M., & Onarigo, L. (2025). Managing Mass Timber: A Guide to Delivering Large-Scale Mass Timber Construction Projects. Taylor & Francis. <https://doi.org/10.4324/9781003437243>
- Muthumanickam, N. K., Brown, N., Duarte, J. P., & Simpson, T. W. (2023). Multidisciplinary design optimization in Architecture, Engineering, and Construction: a detailed review and call for collaboration. *Structural and Multidisciplinary Optimization*, 66(11), 239. <https://doi.org/10.1007/s00158-023-03638-3>
- Naji, K. K., Gunduz, M., Alhenzab, F., Al-Hababi, H., & Al-Qahtani, A. (2024). Assessing the Digital Transformation Readiness of the Construction Industry Utilizing the Delphi Method. *Buildings*,

- 14(3), 601. <https://doi.org/10.3390/buildings14030601>
- Norton, R. E. (1997). DACUM Handbook. Leadership Training Series No. 67.
- Nouh, A., Elkasaby, E., & Wageh, O. (2024). Dynamic approach for investigating delivery system effects on infrastructure project performance. *Engineering, Construction and Architectural Management*, 31(12), 4791-4808. <https://doi.org/10.1108/ECAM-03-2023-0265>
- Oliveira, S., Olsen, L., Malki-Epshtein, L., Mumovic, D., & D'Ayala, D. (2022). Transcending disciplines in architecture, structural and building services engineering: a new multidisciplinary educational approach. *International Journal of Technology and Design Education*, 32(2), 1247-1265. <https://doi.org/10.1007/s10798-020-09651-2>
- Rashed, A., & Mutis, I. (2023). Trends of integrated project delivery implementations viewed from an emerging innovation framework. *Engineering, construction and architectural management*, 30(3), 989-1014. <https://doi.org/10.1108/ECAM-07-2021-0611>
- Riggio, M., Alhariri, N., & Hansen, E. (2020). Paths of innovation and knowledge management in timber construction in North America: a focus on water control design strategies in CLT building enclosures. *Architectural Engineering and Design Management*, 16(1), 58-83. <https://doi.org/10.1080/17452007.2019.1671633>
- Rojas, C., Mourgues, C., Rosa, P. D. L., Mesa, H., Ruz, F., & Guindos, P. (2025). Impact of Using an Exchange Model (EM) to Support the Early Assessment Process of Industrialized Timber Projects. *Buildings*, 15(11), 1835. <https://doi.org/10.3390/buildings15111835>
- Saiba, M. R., Berghorn, G. H., Nubani, L., Cetin, K., & Syal, M. M. (2025). Transforming AEC Education: A Systematic Review of VR/AR in Mass Timber Curriculum. *Buildings*, 15(16), 2938. <https://doi.org/10.3390/buildings15162938>
- Santana-Sosa, A., & Kovacic, I. (2022). Barriers, opportunities and recommendations to enhance the adoption of timber within multi-storey buildings in Austria. *Buildings*, 12(9), 1416. <https://doi.org/10.3390/buildings12091416>
- Smith, R. E., Griffin, G., Rice, T., & Hagehofer-Daniell, B. (2018). Mass Timber: evaluating construction performance. *Architectural Engineering and Design Management*, 14(1-2), 127-138. <https://doi.org/10.1080/17452007.2017.1400556>
- Srivastava, Y. C., Srivastava, A., & Canning, D. (2021, December). Strategies for Successful Project Execution—A Transformation in Project Delivery without Disruption. In Abu Dhabi International Petroleum Exhibition and Conference (p. D011S011R004). SPE. <https://doi.org/10.2118/D011S011R004>
- Telaga, A. S. (2022). A lesson learned from the integration of BIM in construction engineering education in an Indonesian Polytechnic. *Jurnal Pendidikan Vokasi*, 12(2), 130-140. <https://doi.org/10.21831/jpv.v12i2.43711>
- Tenório, M., Ferreira, R., Belafonte, V., Sousa, F., Meireis, C., Fontes, M., ... & Branco, J. M. (2024). Contemporary strategies for the structural design of multi-story modular timber buildings: A comprehensive review. *Applied Sciences*, 14(8), 3194. <https://doi.org/10.3390/app14083194>
- Wang, Z., Leicht, R., & Solnosky, R. (2025). Importance of Interdisciplinary Learning in Achieving AEC Industry Success. *Journal of Civil Engineering Education*, 151(1), 04024004. [https://doi.org/10.1061/\(ASCE\)EI.2643-9115.0000021](https://doi.org/10.1061/(ASCE)EI.2643-9115.0000021)
- Welcher, R., Carpenter, A., Pijanowski, J., Messadi, T., Jacobus, F., Furlong, K., & Berhardt-Barry, M. L. (2020). Advancing sustainable wood design and technologies through interdisciplinary collaboration. *Proceedings of the 56th International Conference of the Architectural Science Association*. Retrieved from <https://anzasca.net/paper/>
- Yu, Y. U., Lee, C. H., & Ahn, Y. J. (2025). Developing a Competency-Based Transition Education Framework for Marine Superintendents: A DACUM-Integrated Approach in the Context of Eco-Digital Maritime Transformation. *Sustainability*, 17(14), 6455. <https://doi.org/10.3390/su17146455>
- Zaman, A., Chan, Y. Q., Jonescu, E., & Stewart, I. (2022). Critical challenges and potential for widespread adoption of mass timber construction in Australia—An analysis of industry perceptions. *Buildings*, 12(9), 1405. <https://doi.org/10.3390/buildings12091405>