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INTERDISCIPLINARY DIGITAL CONSTRUCTION: FRAMING THE DEVELOPMENT OF A NEW UNIVERSITY STUDY PROGRAM

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Abstract

This study frames the development of a new Interdisciplinary Digital Construction (IDC) program. A review of 15 and detailed analysis of five selected programs revealed a strong emphasis on Building Information Modelling (BIM), simulation, and computational design, while topics such as robotics, additive manufacturing, and construction management receive limited attention. The proposed IDC concept and principles suggest combining domain engineering principles, computational thinking, information and communication technology (ICT) management, and production theory to foster physical–digital–human integration. The alignment of technology implementation with process management can yield graduates prepared to lead the digital transformation of the AEC industry.

Introduction

The AEC industry is going through a digital transformation, driven by growing complexity, and productivity and sustainability expectations (European Commission, 2023). Since the 1960s, the integration of computing in AEC has given rise to the interdisciplinary field of construction informatics (CI), which emphasizes planning, designing, developing and managing computing systems specific to construction processes (Pauwels and McGlinn, 2022). CI should be seen as a domain engineering approach (Bjørner, 2021), reflecting the need for deeper alignment of digital tools with underlying construction processes. ICT adoption without proper changes in the underlying processes alone does not guarantee returns (Oludapo et al., 2024; Smits et al., 2017).

Realizing the full benefits of ICT implementation requires re-engineering processes and a conceptual grounding in theories on construction production and management (Koskela and Kazi, 2003; Sacks et al., 2020b, 2020a). That is, educational institutions should adopt targeted and mission-oriented strategy to plan, design, and develop new Interdisciplinary Digital Construction (IDC) study programs, balancing ICT implementation with production and construction management principles. However, existing digital construction programs center on (computational) design topics, such as visual scripting, programming, and BIM, and tend to overlook broader production or management aspects. This means there is a gap in the current scope of digital construction programs and how they can integrate these elements.

The main aim of this research is to frame the development of a new IDC study program, describing key concepts, trends, and challenges; evaluating existing offerings; and proposing main principles for the development of a new study program. Within that, our main objectives are:

- **O1:** Identify the current landscape of existing digital construction programs.
- **O2:** Uncover patterns and gaps in program content, particularly in relation to foreseen industry needs.
- **O3:** Reinterpret limitations and opportunities to reframe the development of a new IDC program.

This paper is divided into four sections. First, the research background explains why a construction-specific domain engineering perspective is important, also highlighting relevant trends, challenges and requirements for IDC programs. Second, the research method section describes how existing programs were identified and analyzed. The third section presents the thematic and in-depth analyses of selected programs. Finally, a general concept is proposed and principles are listed for the development of a new IDC program together with conclusions regarding future directions for digital construction education.

Research background and problem statement

Construction Informatics and Domain Engineering

Computational thinking (CT) has emerged as an important 21st century skill (Wing, 2008). CT is a problem-solving approach, utilizing decomposition, abstraction, algorithmic design, iteration, and generalization (Shute et al., 2017). While CT originated in computer science, it extends beyond computer science and programming to disciplines such as AEC (Grajdura and Niemeier, 2023; Lane and Hawkins, 2024).

In AEC, the integration of computing since the 1960s led to the interdisciplinary field now known as construction informatics (CI), which addresses how to process, represent, and communicate construction information

(Bucher et al., 2024; Pauwels and McGlinn, 2022). CI merges computational, cognitive, and social perspectives, focusing on computational design, interoperability, intelligent construction sites, collaboration support, and ICT management (Isikdag et al., 2009; Sacks et al., 2020b).

From a domain engineering perspective, CI can be understood as a construction-specific approach to planning, designing, and engineering of computing systems (Bjørner, 2021): *Before software can be designed we must know its requirements. Before requirements can be expressed we must understand the domain. So it follows, […] we must first establish precise descriptions [models] of domains; then, from such descriptions, "derive" at least domain and interface requirements; and from those and machine requirements design the software, or, more generally, the computing systems.*

Viewed this way, CI aligns digital solutions with practical construction needs and processes (El-Diraby, 2013), for instance, through ontology engineering to promote software reuse and interoperability (Pauwels and McGlinn, 2022). Another well-recognized example of CT in AEC is computational design (CD), which employs algorithms, parametric modeling, and generative methods to iteratively create and evaluate novel solutions (Caetano et al., 2020).

Construction Informatics and Production Management

Digital transformation in the AEC industry is driven by growing complexity and expectations for increased productivity and sustainability (Bolpagni et al., 2022; Sacks et al., 2020b). Integrating digital solutions can facilitate collaboration, waste reduction, and data-driven decisions (Sacks et al., 2020b). However, the AEC sector still lags behind other industries, struggling with skill gaps, fragmented processes, and minimal training (European Commission, 2023; Sacks et al., 2020b).

Research shows that ICT adoption alone does not guarantee returns (Oludapo et al., 2024; Smits et al., 2017). Koskela and Kazi (2003) emphasized the need to redesign construction processes in light of its peculiarities to achieve the ICT benefits. For example, combining lean construction principles with BIM has shown to produce more impactful outcomes than either approach alone (Sacks et al., 2018, 2010). That is, maximizing ICT benefits depends on underlying process changes, along with ICT and lean management principles rooted in a conceptual understanding of construction production (Koskela and Kazi, 2003; Sacks et al., 2020b, 2020a).

This means that construction domain engineering of computing systems should be informed by theories of construction production and management, blending social and technical aspects (Ballard, 2000). Hence, it is important to teach construction ICT implementation strategically in conjunction with construction management principles. Strategic ICT management needs to support addressing industry fragmentation and foster lean practices, sustainability, and lifecycle assessment (Bucher et al., 2024; Dave et al., 2014; Koskela and Kazi, 2003; Patacas et al., 2020; Succar and Poirier, 2020).

AEC Education State of the Art

Ongoing construction ICT advancements, extending from CI, CD, BIM, digital twins to Industry 4.0 technologies such as IoT, AI, and robotics, are already shaping the AEC practices and education (Bolpagni et al., 2022; Sacks et al., 2020b), stimulating new directions in curriculum design and teaching strategies. Furthermore, Web3 technologies, blockchain, and decentralized data protocols (Bucher et al., 2024) enable more secure, transparent, and collaborative practices, minimizing data silos and enhancing lifecycle integration (Pauwels and McGlinn, 2022). While BIM remains a cornerstone for construction information (Sacks et al., 2020b), computational approaches expand digitalization opportunities (Caetano et al., 2020; McCord et al., 2024; Wing, 2006).

Novel AEC ICT study programs need to emphasize interdisciplinary collaboration, hands-on experience with emerging software and hardware tools, and a holistic curriculum integrating technical, managerial, and sustainability objectives. The implementation of these technologies requires AEC education to adopt a more student-centered and experiential learning, requiring properly balancing and integrating challenge-, design-, project- and problem-based teaching (Christiansson, 2012; Grajdura and Niemeier, 2023; Menzel et al., 2006). Through interdisciplinary team projects, mirroring real-world complexities, students can have firsthand experience in ICT management and technologies. For example, some new courses already integrate several topics, including BIM, lean, and integrated project delivery (IPD), developing graduates capable of navigating micro-level technical challenges (e.g., parametric modeling) and macro-level strategic needs (e.g., digital transformation) (Patching et al., 2024; Pikas et al., 2024). However, the program development should be an ongoing activity as new technologies, production methods and management approaches continually emerge.

Challenges and Future Directions

The fragmentation of AEC curricula is still a major challenge, for example, failing to holistically integrate BIM, computational thinking, and sustainability into a coherent framework (Grajdura and Niemeier, 2023; McCord et al., 2024; Pikas et al., 2024). This is compounded by limited faculty expertise, adoption barriers related to cost and inadequate infrastructure, and insufficient emphasis on sustainability, resulting in graduates lacking critical digital competencies (Bolpagni et al., 2022; McCord et al., 2024). Further, inequal access to technology, combined with minimal lifelong learning opportunities, exacerbates the digital divide and hinders continuous upskilling (Menzel et al., 2006; Sacks et al., 2020b; Too et al., 2002).

Educational institutions need to adopt targeted, mission-oriented strategies to develop interdisciplinary curricula merging construction informatics, computation, construction and ICT management and sustainability (Brosque and Fischer, 2022; Lane and Hawkins, 2024; Patching et al., 2024). Furthermore, faculty development programs and industry partnerships should be established to help educators to be current with evolving technologies, and technology hubs, subsidized resources, and open-access platforms could lower barriers to innovation and access to technologies (Too et al., 2002).

Synthesizing Requirements for IDC Development

In summary, when developing new IDC study programs, it is important to integrate core construction management principles with computational thinking, ICT management, and AEC-specific digital technologies to prepare students for the AEC domain. These programs should address existing gaps in AEC education, such as curriculum fragmentation and insufficient computational training, by adopting balanced learning strategies, fostering interdisciplinary collaboration, and incorporating cutting-edge digital solutions. Specifically, this requires:

- **Interdisciplinary Approach:** Merging technical, managerial, and sustainability objectives to enable graduates tackle both micro-level technical tasks (e.g., parametric modeling) and macro-level strategic issues (e.g., digital transformation).
- **Domain-Centric ICT Engineering:** Incorporating domain engineering principles to ensure digital solutions are rooted in well-informed understanding of production theory and construction-specific needs and requirements.
- **Experiential Learning:** Balancing experiential and traditional teaching methods to foster problem-solving and collaboration skills.
- **Continuous Curriculum Development:** Staying updated with rapid technological changes, incorporating ongoing faculty training, and establishing links with industry to maintain relevance and to enhance employability.

When focusing on these requirements, educational institutions can prepare future AEC professionals who are not only knowledgeable in the latest digital solutions but also capable of integrating them strategically within the broader framework of construction ecosystems.

Research Methods

For fulfilling the research aim, we first identified various digital construction-oriented master's programs from renowned institutions to evaluate current offering and its gaps. In the first step, we searched the web for relevant master's programs using key words, such as digital construction, digital architecture, computational design, parametric modelling, BIM, digital twins, and construction informatics. We focused on identifying programs from universities in geographically different places, known for well-established research in the digital construction field.

In several cases, the programs analyzed were selected based on the availability of detailed program descriptions and syllabuses given in English. Finally, the list was narrowed down to 15 digital programs offered by different universities (**Table 1**). While not conclusive, it is representative of a diverse range of institutions from different locations with focus on different AEC sub-domains to ensure a global perspective into digital construction education.

In the second step, we reviewed the program descriptions and identified key themes mentioned across the curricula. Based on the initial reading, and to ensure a systematic approach to thematic analysis, we expanded the list of identified themes by including synonyms and related terms for each key area. The list of synonyms within each theme is given in **Table 2**. Using this expanded list, we analyzed the content of the selected programs to identify which themes were explicitly mentioned.

In the third step, we chose five out of fifteen programs to do a more in-depth evaluation. The same criteria applied as in the first step. Here the focus was on ensuring that the list fairly represented engineering-oriented digital construction study programs, but to be more inclusive, we added a program from architecture and geodesy.

Results

Thematic Analysis of Existing Programs

The thematic analysis of 15 study programs revealed varied emphasis across institutions (Figure 1). Building Information Modeling (BIM) is notably widespread (9 out of 15), underscoring the industry's reliance on BIM-based collaboration. Simulation tools and performance (9 out of 15) analysis is also present in same number of programs, highlighting the AEC industry's growing reliance on modelling and predictive analytics. Around half of the programs (7 and 8 out of 15) address AI and machine learning (ML), digital architecture and design, computer scripting and programming, data management and interoperability, and parametric and computational modelling, representing the increasing integration of automation and data-driven methods in the AEC education. However, among those featuring AI/ML, only a few explicitly include data management and interoperability, suggesting a missed opportunity to optimize broader workflows through AI/ML.

In contrast, certain topics receive comparatively little attention. Robotics, for instance, appears in five programs, and 3D printing/additive manufacturing in four. Construction planning, the management of construction information and physical flows and operations, is featured in three programs. Also, teaching of mixed reality and visualization, both rapidly evolving fields, is not that widespread (2 out of 15 programs).

Discipline-specific trends reveal that architecture-oriented programs tend to focus on virtual aspects (e.g., computational design, AI/ML) and may incorporate robotics or digital fabrication, while engineering- and construction-oriented programs prioritize BIM, data management, and simulation, often with limited coverage of AI/ML. Hybrid programs bridge architecture and engineering, emphasizing both technical skills and digital solutions in the design.

Detailed Analysis of Selected Programs

Five digital construction programs (**Table 3**) were analyzed in depth, including programs 3, 6, 12, 14 and 15 in **Table 1.** TU Delft's Geomatics is program on geoinformation science for AEC, encompassing data acquisition, modeling, and utilization (GIS, 3D modeling, remote sensing). Courses and topics cover remote sensing (LiDAR, GNSS), digital terrain modeling, photogrammetry, GIS/cartography, geodata governance, and 3D city models. As such, the emphasis is on spatial data handling for mapping, planning, and infrastructure.

At the University of Pennsylvania (Penn), Environmental Building Design program merges architecture and building performance assessment in a studio-centric setting. Courses cover building performance (energy, daylight, HVAC), bioclimatic design, history/theory, specialized electives, and research methods in research version of the program (MSD-EBD). General IT or coding skills are minimally addressed.

The Integrative Technologies and Architectural Design Research program at the University of Stuttgart focuses on computational design and advanced fabrication (e.g., robotics), with an architectural research lens on new materials. Courses and topics covered include architectural biomimetics, computational design, advanced fabrication, engineering materials, and specialized colloquia. The program does not have a wide coverage of typical BIM workflows and standard industry practices.

Table 1: List of analyzed programs

#	Program name	Program Focus	University	Country	Details
1	Building Technology Program	Sustainable Building Design and Engineering	Massachusetts Institute of Technology (MIT)	United States	Master of Science in Building Technology; 2 years; Credit Points: Not specified
2	Geographical Information Management and Applications	Geographic Information and Spatial Analysis	TU Delft	Netherlands	Master of Science (MSc); 2 years (full-time); 4 years (part-time); Credit Points: 120
3	Geomatics	Geographic Information and Spatial Analysis of Built Environment	TU Delft	Netherlands	Master of Science (MSc); 2 years; Credit Points: 120
4	Architecture, Urbanism and Building Sciences – Building Technology Track	Sustainable Design and Engineering	TU Delft	Netherlands	Master of Science (MSc); 2 years; Credit Points: 120
5	Robotics and Autonomous Systems	Architecture Technology	University of Pennsylvania	United States	Master of Science in Design (MSD); 1 year; Credit Points: 10 course units
6	Environmental Building Design	Sustainable Building Design and Engineering	University of Pennsylvania	United States	Master of Environmental Building Design (MEBD); Master of Science in Design (MSD-EBD); 1 year (MEBD); 2 years (MSD-EBD); Credit Points: 9-10 course units
7	Digital Architecture and Emergent Futures	Computational Architecture	Lund University	Sweden	Master of Fine Arts (MFA); 2 years; Credit Points: 120
8	Computational Methods in Architecture	Computational Architecture	Cardiff University	United Kingdom	Master of Science (MSc); 1 year; Credit Points: 180
9	Advanced Computation for Architecture and Design	Computational Architecture	Institute for Advanced Architecture of Catalonia (IAAC)	Spain	Master in Advanced Computation for Architecture and Design; 1 year; Credit Points: 75
10	Artificial Intelligence for Architecture and Built Environment	AI and Computational Architecture	Institute for Advanced Architecture of Catalonia (IAAC)	Spain	Master in Artificial Intelligence for Architecture and Built Environment; 1 year; Credit Points: 75
11	Robotics and Advanced Construction	Robotics and Construction Technology	Institute for Advanced Architecture of Catalonia (IAAC)	Spain	Master in Robotics and Advanced Construction; 1 year; Credit Points: 75
12	Integrative Technologies and Architectural Design Research	Computational Architecture	University of Stuttgart	Germany	Master of Science (M.Sc.); 4 semesters; Credit Points: 120
13	Computing in Construction	Construction ICT	Metropolia University of Applied Sciences	Finland	Master of Engineering (MEng); 2 years; Credit Points: 60
14	Computational Engineering	Computational Engineering Science	Ruhr University Bochum	Germany	Master of Science (M.Sc.); 4 semesters; Credit Points: 120
15	Information Technologies for the Built Environment	Interdisciplinary, covering ICT related to architecture, civil engineering, and geodesy	Technical University of Munich (TUM)	Germany	Master of Science (M.Sc.); 4 semesters; Credit Points: 120

Table 2: List of main themes and synonyms

#	Theme	Synonyms
1	Digital Architecture and Design	Digital Architecture, Computational Architecture\Design, Digital Design, Innovative Design
2	Artificial Intelligence	Artificial Intelligence, AI, Machine Learning, Intelligent Systems
3	Mixed Reality and Visualization	Mixed Reality, Virtual Reality (VR), Augmented Reality (AR)
4	3D Printing and Additive Manufacturing	3D Printing, Additive Manufacturing, Rapid Prototyping
5	Building Information Modelling (BIM) and Digital Twin	Building Information Modelling (BIM), BIM Processes, BIM Platforms, Collaborative BIM, Digital Twin
6	Parametric and Computational Modelling	Parametric Modelling, Computational Design, Algorithmic Modelling
7	Computer Scripting and Programming	Computer Scripting, Programming, Python for Design, Computational Programming
8	Physical Computing and Prototyping	Physical Computing, Interactive Prototyping, Arduino, Embedded Systems
9	Building Performance and Human Comfort	Building Performance, Thermal Performance, Energy Efficiency, Comfort
10	Simulations	Simulation Tools, Digital Simulations
11	Construction Management	Cost Analysis, Quantity Takeoff, Budget Planning, Construction Planning, Scheduling, Project Management
12	Robotics	Robotics, Autonomous Systems
13	Data Management and Interoperability	Data extraction and processing, Data Sharing, Data Integration

Ruhr University Bochum's (RUB) Computational Engineering program focuses on simulation and computation for civil and mechanical engineering, and emphasizes numerical methods, simulation, and programming. Courses cover differential calculation, mechanical modeling, FEM, fluid dynamics, numerical methods, ML, and advanced simulation, but lacks AEC-specific modules on BIM integration, project workflows, and cross-disciplinary collaboration.

Technical University of Munich's Information Technologies for the Built Environment program focus on interdisciplinary digital technology in AEC (architecture, civil, and geodesy), across different scales. Courses and topics covered include geospatial information, BIM, photogrammetry, software engineering, semantic modeling, ML, structural analysis, and project management. While it offers a broad overview of digital methods in design and infrastructure and has a course on project management, it has limited focus on construction management and business processes.

Several general observations can be made based on these selected programs. One common theme is whether program is either broad or specialized: TU Delft and TUM present broader overviews, while RUB, Penn, and Stuttgart have a more specific focus. All emphasize varying degrees of computational skills, whether design-, simulation-, or GIS-centric. Construction management and business process content appears only occasionally (e.g., TUM and RUB). Furthermore, programs typically have either research or an industry orientation, with RUB and Stuttgart leaning toward research and design innovation, while TUM adopting more practical

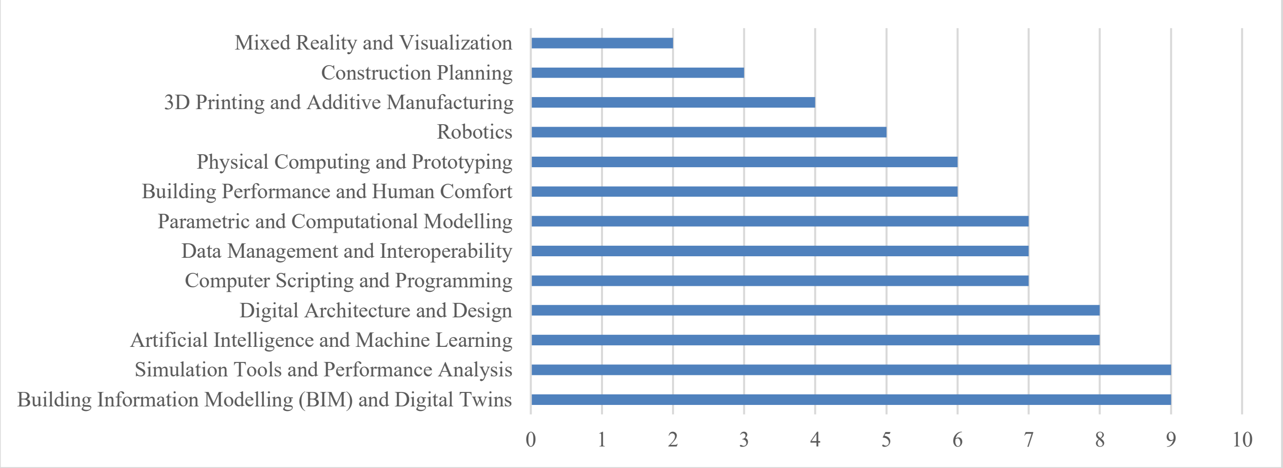

Figure 1: Results of thematic analysis, keyword count

engineering-centered perspectives. TU Delft stands out for its specialized geospatial data management focus.

Common strengths include a strong grounding in computational design or simulation and some formal programming courses. Yet managerial and collaborative dimensions, such as construction management or business processes, remain limited. This gap suggests an opportunity for a new Interdisciplinary Digital Construction (IDC) curriculum that combines computational rigor with data-centric strategies and practical process management to better prepare graduates for leadership and management roles in an evolving digital AEC environment.

Discussion

Existing programs have advanced digital construction education but there are gaps. To borrow from Sacks et al. (2020a), their conceptualization of digital twin information systems' ontological categorization of virtual and physical spaces, the focus in current offerings is on virtual aspects of digital construction, not on the management and control of construction production systems, productive assets (e.g., 3D printing, machinery), and built assets (e.g., maintenance) in the physical space. Factors contributing to this probably include limited faculty expertise, high implementation costs for emerging technologies, and insufficient coverage of construction management and business processes. These challenges underscore the need for a new IDC program that merges construction informatics, computing, ICT management, and production theory, while also fostering physical–digital–human integration (McCord et al., 2024) to ensure that technological innovations align with both human collaboration and physical construction workflows.

A distinguishing feature of such an IDC program should be the implementation of theme-specific progressive upskilling paths: fundamentals → specialization → integration. Instead of isolating computer science or engineering from construction and project management, the program would begin with essential computational, AEC ICT, and construction concepts, then advance to specialized digital technologies, culminating in holistic, real-world project workflows. This structure can allow students to gain both technical competencies (e.g., AI, robotics, automation) and strategic management skills, empowering them to succeed in a data-intensive and cross-disciplinary industry.

However, implementing such an IDC curriculum can face challenges. Balancing theory with hands-on learning in rapidly evolving digital contexts, maintaining faculty proficiency in emerging technologies, and continuously updating content can be difficult. Furthermore, many engineering programs continue to segment subject areas (Menzel et al., 2006). Overcoming these challenges requires adopting a holistic approach to study program development, balancing pedagogical methods, and establishing strong industry-academic partnerships (Too et al., 2002).

Table 3: Overview of five selected programs

#	Program, University	Focus and Orientation	Intended Learning Outcomes	Curriculum Outline	Key Courses and Topics
3	Geomatics (Built Environment), TU Delft	Geo-information science for AEC. Focus on data acquisition, modeling, and utilization (GIS, 3D modeling, remote sensing). Applications in mapping, planning, infrastructure	Apply remote sensing and positioning, design spatial databases (SQL/UML), advanced 3D modeling, handle spatial data governance & decision-making	~10 core courses in sensing, 3D modeling, geo-databases, cartography, visualization; advanced electives in second year, research thesis project	Remote sensing (lidar, GNSS), digital terrain modeling, photogrammetry, GIS/cartography, geodata governance, 3D city models
6	Environmental Building Design, University of Pennsylvania	Architectural design with performance simulation (sustainable, bioclimatic). Post-professional for architects, integrating climate, energy modeling, advanced systems	Understand environmental design, apply simulation, integrate performance, create bioclimatic solutions	One-year (MEBD) or two-year (MSD-EBD) program with required performance studios, seminars, and a culminating design studio. The two-year version adds research/prototyping and a design-based thesis	Building performance (energy, daylight, HVAC), bioclimatic design, history/theory, specialized electives, research methods in MSD-EBD
12	Integrative Technologies and Architectural Design Research, University of Stuttgart	Computational design/fabrication in architecture. Interdisciplinary research bridging architecture and structural/material engineering. Innovations in robotics, new materials	Analyze and apply biomimetic principles, design and fabricate prototypes, master computational design, research structural and material systems	Two large research studios in consecutive semesters, thesis prep module, Master' s thesis. Seminar-based instruction (computational design, simulation, biomimetics)	Architectural biomimetics, computational design, advanced fabrication, engineering materials, specialized colloquia
14	Computational Engineering, Ruhr University Bochum (RUB)	Simulation and computation for civil and mechanical engineering. Emphasis on numerical methods, structural/fluid mechanics, software development and similar.	Master computational methods (FEM, CFD), apply math and programming, use advanced data-driven techniques (ML)	~7 core math/mechanics/FEM/CFD courses + >15 specialized electives (e.g. HPC, ML); thesis in final semester	Differential equations, mechanical modeling, FEM, fluid dynamics, numerical methods, HPC, ML, advanced simulation
15	Information Technologies for the Built Environment, Technical University of Munich (TUM)	Interdisciplinary digital technology in AEC (architecture, civil, geodesy). Emphasis on BIM, GIS, remote sensing, AI, etc. across all scales	Develop Information Technologies and database skills, interdisciplinary knowledge	9 core modules + ~36 ECTS electives; interdisciplinary project (Fusion Lab) in 3rd semester; final thesis in 4th sem.	Geospatial info, BIM, photogrammetry, software engineering, semantic modeling, ML, structural analysis, project management

Several tactics can aid in developing a successful IDC program (Too et al., 2002):

- Holistic and modular program design enables a systematic progression from foundational to specialized skills, which is suitable for both full-time students and working professionals.
- Faculty development programs and adequate resource investments to ensure that educators remain current with digital transformations.
- Close collaboration with industry through internships, cooperative research, and expert guest lectures to keep learning outcomes aligned to AEC industry needs.
- Continuous feedback loops with alumni and employers to refine and recalibrate program content in response to new technologies and shifting market demands.

By adopting a progressive upskilling approach and emphasizing physical–digital–human integration alongside technical innovation and process-management, an IDC program can support developing graduates prepared to lead digital transformation in the built environment. The unification of computational thinking, operational excellence, and strategic leadership supports aligning academic training with the industry's rapidly evolving landscape.

Conclusions

This research highlights the importance of bridging the gap between digital virtual aspects and the physical construction processes in the AEC education. A review of 15 and detailed analysis of five selected programs (**O1 objective**) revealed that many existing programs excel at teaching BIM, simulation, and computational design, but they often underemphasize managerial and operational aspects such as construction planning, production workflows, and business process management (**O2 objective**). The proposed concept and principles for IDC address these gaps by advocating for (**O3 objective**):

- **Progressive Upskilling:** A program structure that starts with core computational and AEC fundamentals, progressing to advanced digital AEC technologies and ultimately integrating these skills in realistic, holistic construction scenarios.
- **Domain-Centric ICT Engineering:** Grounding digital applications in thorough knowledge of construction processes and production theory to ensure alignment of solutions with industry-specific needs.
- **Physical–Digital–Human Integration:** Emphasizing the interplay between digital systems, practical construction workflows, and human collaboration to reflect the realities of modern construction project operations.
- **Continuous Improvement:** Incorporating industry partnerships, active faculty development, and feedback loops to keep the program relevant in response to technological evolutions.

By utilizing these principles, academic institutions can produce a new generation of AEC professionals proficient in computational innovation and strategic process management. The results of this study contribute to ongoing efforts to refine digital construction pedagogy, suggesting that combining technical depth with robust managerial and operational training is needed to unlock the full benefits of AEC digitalization.

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