

# Integrating early information communication and technology agreements and sustainability through project-based learning in architectural technology education

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**Abstract.** In the field of architectural technology studies, sustainability and digitalisation play a crucial role, leading to significant changes in current educational programmes. At KEA's Bachelor in Architectural Technology and Construction Management, the curriculum incorporates sustainability, advanced technology, and business expertise into building design, production and planning. This research focuses on early Information, Communication, and Technology (ICT) agreements using Project-Based Learning methodologies. The goal is to meet current and upcoming European regulations related to sustainability and digitalisation in building projects by proposing an ICT Process Manual Prototype as a new educational tool. The research involves revising lecturer plans, surveying industry practices, and designing an ICT Process Manual tailored to architectural technology programmes. Methodologically, the study uses qualitative data from deskwork, surveys from Danish industry stakeholders, and didactical reflections by the authors. Findings reveal the need to change the ICT Process Manual paradigm in school projects. Survey results show industry recognition of the importance of early ICT agreements in construction, while Project-Based Learning can facilitate developments in this regard, promoting sustainability and active student engagement. The study underscores the integration of early ICT agreements into education, enhancing the implementation of sustainability and digitalisation.

## 1 Introduction

KEA implements pedagogical principles based on innovative teaching methods to prepare competent and well-educated graduates for the labour market. Sustainability is a critical component of KEA's Bachelor in Architectural Technology and Construction Management (KEA BYG). The focus areas include training the students in methods and usage of materials that reduce the environmental impact, designing and constructing energy-efficient buildings, analysing the environmental impact of materials and structures throughout their lifetime, and planning and developing sustainable urban environments. Digitalisation is also an integral part of KEA BYG's teaching, which includes training in Building Information Modelling (BIM) tools and processes to improve the design, construction, and operation of buildings, innovative technology (Internet of Things), digital tools for project management (4D and 5D BIM dimensions) and collaboration in construction projects by using a Common Data Environment (CDE). There is a strong focus on sustainability and responsibility, both environmentally and socially, to shape students to take these aspects into account in their school projects and afterwards in any discipline or position they will take in the labour market. Additionally, students are provided with knowledge and skills related to the regulatory and legal framework, ensuring they are

well-prepared to navigate and comply with industry standards and regulations.

KEA BYG has started executing holistic procedures in different semesters, where the implementation of sustainable solutions and digitalisation has shown promising results. Still, it lacks better planning at upfront stages in school projects, which reflects the industry scope needs.

## 2 Context and problem statement

### 2.1 Regulative framework

The European Union (EU) has introduced various initiatives to translate sustainability principles into practical actions. Notably, the EU's Green Deal encompasses measures such as guidelines for financial operations outlined in the EU Taxonomy, the Corporate Social Reporting Directive (CSRD), and the forthcoming Corporate Social Due Diligence Directive (CSDDD). Starting in 2024, companies employing over 500 workers must gather and document data in compliance with EU directives and regulations concerning sustainability. These directives emphasise the comprehensive sustainability documentation across companies' Environmental, Social, and Managerial (ESG) dimensions [1]. The crucial point is the need for a

coordinated effort among different countries to address global concerns such as climate change. The EU's initiatives in response to the United Nations' Global Goals showcase its commitment to sustainability at a practical level, where educational institutions have a vital role in promoting thorough and well-connected interactions with all disciplines in the construction industry.

Industry standards such as ISO 19650-1 for digitalisation and ISO 15686-5 for planning buildings' operations have become mandatory for many public agencies and private developers. These standards provide a framework for green BIM projects. Denmark has a well-established framework for promoting sustainability in BIM practices within the construction industry. Various organisations and associations offer a range of standards, tools, and guidelines to support this effort. In Denmark, MOLIO is one of the largest non-profit organisations that assist the Architecture, Engineering, and Construction (AEC) industry with innumerable resources. These means aim to ensure that buildings are designed and constructed in an environmentally sustainable, economically viable, and socially responsible way. In Denmark, the 2013 Executive Orders 118 and 119 establish a legal framework for mandatory Information and Communication Technology (ICT) agreements in the public sector and social housing projects. These orders ensure that ICT is used effectively and efficiently to promote sustainability in the construction industry. In addition to the executive orders, Executive Order 2013 on Quality Assurance, Public and Private Partnership mandates preparing Life Cycle Cost (LCC) assessments. These assessments are essential for Green Building Certification applications and help to ensure that buildings have a low environmental impact and are cost-effective over their lifetime [2]. As of 1<sup>st</sup> of January of 2023, The Danish Building Regulations (BR) impose new climate demands that can be observed by Life Cycle Analysis (LCA) performance. New buildings projects under 1000m<sup>2</sup> floor area must submit an LCA upon completion notification, and projects over 1000m<sup>2</sup> must comply with the applicable CO<sub>2</sub> limit (12kg CO<sub>2</sub> equivalent/m<sup>2</sup>/year).

The merge of sustainability principles and digitalisation in construction projects presents a significant opportunity for the evolution of the AEC industry. Harmonising regulations and standards is essential to ensure their coherent and effective implementation by finding common ground, streamlining processes, enhancing efficiency, and amplifying the positive environmental impact of these actions. However, this endeavour requires a cooperative effort from educational programmes to equip future professionals with the knowledge, skills and competences needed to navigate this dynamic landscape.

## **2.2 Project-Based Learning and its significance in the context of sustainability and digitalisation**

The KEA BYG programme employs a didactic approach rooted in Problem-Based Learning facilitated by Project-Based Learning (PBL). Students collaborate in groups on real-life projects, aligning feasible solutions with

available resources to facilitate learning. Lecturers offer guidance and expose students to relevant construction project issues, initiating a learning cycle. Multidisciplinary feedback helps students integrate various learning outcomes throughout the semester, culminating in a fully developed project by the course's end [3]. This methodology effectively prepares students for immediate productivity in the labour market upon graduation. For successful PBL implementation, educators must possess substantial industry experience, skills, and competences acquired through active engagement in their respective fields. This approach bridges the gap between theory and practice, a crucial factor for the success of this teaching method.

In the architectural technology programme, students engage in projects from pre-design and design stages to construction, operation, and maintenance. Each semester, students tackle different building types, progressively increasing the complexity of their projects. Through lectures, consultancy, and feedback, students receive the support needed to understand projects holistically.

Integrating sustainability and digitalisation into school projects, particularly within a PBL framework, is immensely valuable and relevant. This approach equips students with the skills and knowledge necessary to address contemporary challenges in the construction industry. Students learn to develop environmentally responsible and resource-efficient solutions by incorporating sustainable practices. Meanwhile, digital tools and technologies enhance their ability to design, plan, and manage projects more effectively. Ultimately, the emphasis on sustainability and digitalisation complying with current and forthcoming regulations within a PBL setting cultivates well-rounded professionals capable of leading the way in sustainable development and intelligent construction practices.

## **2.3 Problem statement: ICT agreements and the need for early stages implementation of sustainability and digitalisation matters**

Early adoption of ICT agreements has been increasingly recognised as pivotal for successful project delivery. This approach involves the strategic implementation of LCA, digital tools, protocols, and a CDE set-up from the beginning of the project lifecycle. The objective is to define the project goals early on, allowing all parties to plan, mitigate risk, execute, and deliver the project within budget and time constraints. With current and upcoming strict regulations requiring more data on the buildings, such as LCA calculations, there is a significant need for the data to be defined early on. Another area where data development during project stages is not reaching the objectives is during handover and facilities management – recognised project lifecycle stages where most unsustainable practices appear.

KEA BYG adopted and implemented the 'Description of Services for Building and Landscape', prepared by The Danish Association of Consulting Engineers and The Danish Association of Architectural Firms in 2018 (DARK & FRI 2018). This document defines all stages of

building and landscaping projects, including the required documentation and processes for the ICT. The document requires the ICT Specification and the ICT Process Manual to be prepared early in the process, during the Initial Consultancy (equivalent to Assessment and Need and Invitation to Tender stages by ISO-10650) and Design Management (equivalent to Tender Response, Appointment, and Mobilization stages by ISO-19650). During semesters 1-5, the students prepare projects focusing on the design stages only – Outline Proposal, Project Proposal, Regulatory Project, and Tender Design (equivalent to Information Delivery and Collaborative Production by ISO-19650). During the design stages, the students comply with the ICT requirements used by the industry by preparing the ICT Specifications and ICT Process Manual, as well as a common BIM model. The common BIM model is created and used for various purposes in different subjects: common model built in Revit, visualisations and walkthroughs with Lumion, Enscape and Twin Motion, material take-off and cost calculations using Sigma Estimates, planning with Microsoft Project or Exigo Tactplan, clash detection using Navisworks, structural analysis using Autodesk Robot, Life Cycle Analysis using Real-Time LCA, documentation and information exchange using CDE Dalux Box and BIM360 and Facilities Management using Dalux FM.

Using PBL, stages defined in the DARK & FRI 2018, and the ICT documentation defined by MOLIO allows lecturers to create a learning environment that simulates a realistic project working environment. This learning environment facilitates optimal knowledge and practical skills acquisition, which translates into competences highly valued by the industry, enabling students to become proficient professionals ready to contribute effectively.

Most AEC industry actors and education programmes concentrate on the design stages, leaving the industry lacking understanding and knowledge about early decision-making during Initial Consultancy and Design Management. This can lead to inadequate comprehension of how the demands for projects are drafted, the actors involved and understanding the bigger image of the information exchange. Not understanding the full complexity of the issue often leads to underestimating the value of ICT enforcement and complete adoption.

### 3 Methodology

This study adopts a mixed-methods approach as a collaboration among this paper's three researchers and authors to investigate the challenges associated with implementing sustainability and digitalisation principles in construction projects. The research methodology combines qualitative data collection through online interviews with key industry actors and desk research techniques.

The investigation has been divided into four phases to accomplish the research objectives. The first three phases were designed to identify and characterise the barriers that face sustainability, BIM and ICT implementation at

upfront project stages through online interviews with AEC stakeholders in Denmark. The fourth phase was designed to investigate the approaches that would encourage the utilisation of improved BIM and ICT practices in school projects under PBL.

Detail of phases adopted for this research:

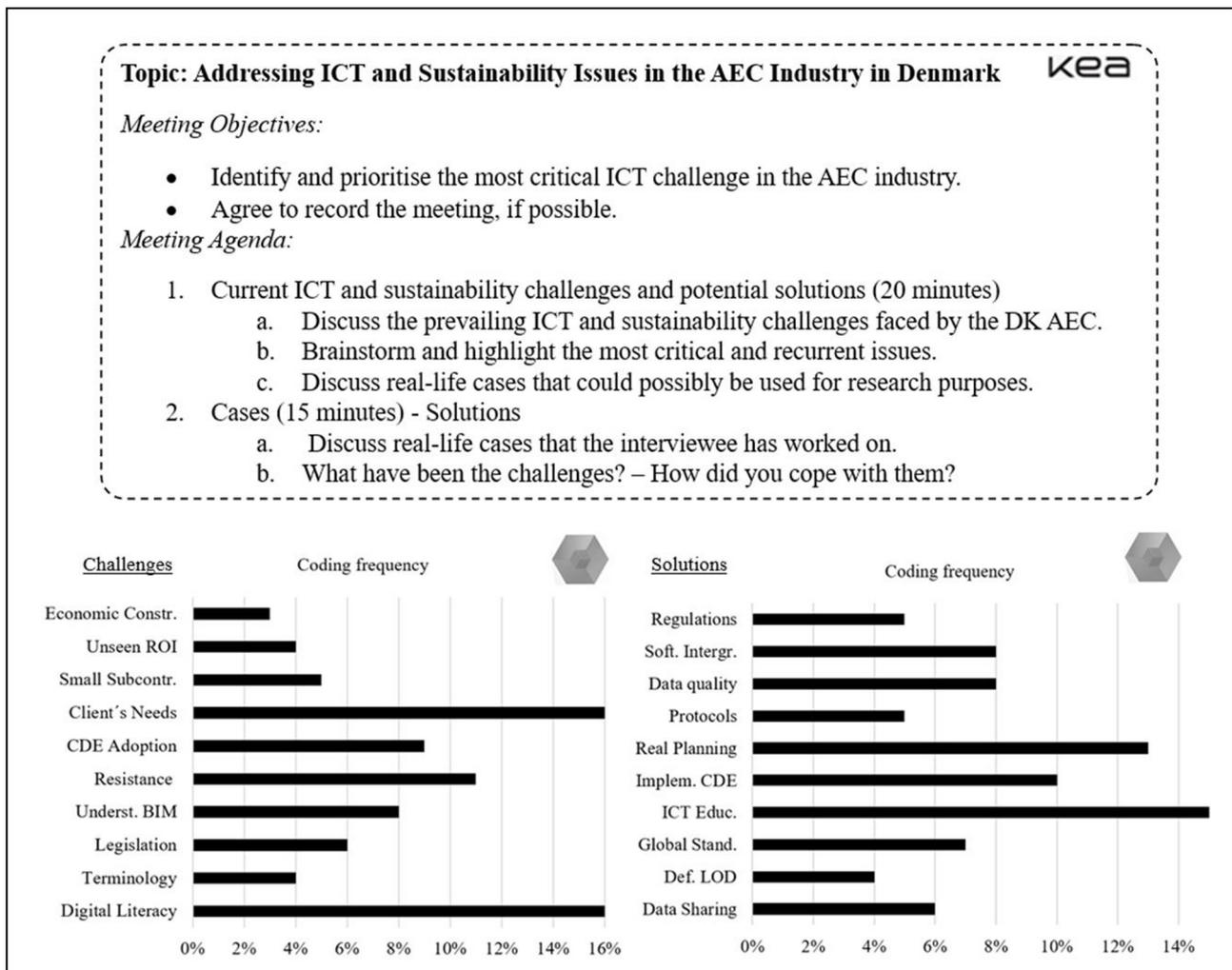
- Phase 1 [Questionnaire Design]: A standard questionnaire was designed based on specific questions to explore the challenges of implementing digitalisation, sustainability and ICT in construction projects. Phase 1 was a collaboration among the three researchers. The questionnaire is divided into two sections: A specification of research objectives and an agenda with questions indicating the expected time to be used per question. In Figure 1, the most salient questions from the survey are presented, offering a focused glimpse into the key areas of inquiry. This is an excerpt showcasing the critical questions that are central to the investigation. It is important to note that while Figure 1 highlights these pivotal questions, the complete dataset from the questionnaire has been comprehensively included and analysed as part of this research. This thorough inclusion ensures that all responses and nuances captured in the survey are duly considered in the study.

- Phase 2 [Online Interviews with Danish AEC stakeholders]: Ten participants were selected based on their expertise and involvement in digitalisation and sustainability initiatives within construction projects. The three researchers collaborated and found the participants via networking and direct calls to companies' headquarters. The survey targeted a relatively limited population, requiring careful selection to ensure comprehensive representation. To achieve this, respondents were chosen strategically to reflect the diversity and characteristics of the entire population as accurately as possible. The interviews were recorded and transcribed for analysis (collaboration among the three researchers). The average duration of the online interviews was approximately 45 minutes, where the three researchers posed the standard questions and took notes as appropriate.

- Phase 3 [Qualitative Data Analysis (QDA)]: Two researchers using QDA Miner analysed transcripts of the interviews. This involved identifying patterns emerging from the interviews. The QDA technique streamlined the process for systematically coding and categorising the qualitative data. Figure 1 (excerpt) reads the output of the QDA mining process for both the highest coding frequency and challenges/proposed solutions.

- Phase 4 [Desk Research]: In parallel with the interview process, the three researchers conducted a desk investigation to supplement the qualitative findings. This involved reviewing existing school lecture plans, reports, and scholarly articles on digitalisation and sustainability in construction projects. The desk research provided additional context and theoretical grounding for the study.

Patterns and themes emerging from the data will be visually represented in a Process Manual Prototype, highlighting the key challenges stakeholders face in integrating digitalisation and sustainability in construction projects and how PBL can support innovative solutions in the future.



**Figure 1.** Questionnaire Design and QDA output

## 4 Results and discussion

One of the aims of this research paper is to delve into the insights gained from interviews with AEC stakeholders in Denmark, focusing on the challenges and solutions associated with implementing sustainability and digitalisation during the early stages of construction projects. The intended outcomes of these interviews aim to identify key obstacles industry professionals face and explore innovative strategies to streamline sustainable practices and integrate digital tools. Furthermore, this paper extends the discussion to a pedagogical analysis of PBL, examining how industry insights can be effectively incorporated into a comprehensive process manual. This manual is designed not only for academic study purposes but also holds the potential for real-world application in future construction projects, thereby bridging the gap between theoretical knowledge and practical implementation.

### 4.1 AEC Industry input

The study's findings will be presented through a comprehensive analysis of the qualitative data collected from the online interviews, supplemented by insights

from desk research. Professionals shared up-to-date knowledge, helping shape relevant and innovative solutions. Their ability to identify hidden challenges and validate assumptions ensured the proposed solutions to be feasible and effective. Engaging with industry experts was crucial for developing tailored, actionable, theoretically sound and practically viable learning strategies.

#### 4.1.1 Identified challenges

- Limited digital literacy, ICT skills, and sustainability awareness: Newly graduated technologists and smaller contractors frequently lack proficiency in digital tools, ICT, and sustainability practices. This gap arises from insufficient emphasis on their education and limited resources, hindering their ability to effectively implement sustainable and digital solutions in projects.
- Confusing terminology, misunderstanding BIM, and overlooking sustainability: ICT is often misunderstood, and BIM is frequently misinterpreted as merely 3D geometry, neglecting the critical information aspect and its role in promoting sustainability. This confusion impedes the integration of digital tools and sustainable practices effectively in construction projects.
- Poor enforcement and adoption of ICT Standards: Weak enforcement of ICT and BIM legislation, resistance to

new standards and technologies, and inconsistent use of classifications and standards like ISO 19650 hinder effective implementation, complicating the integration of sustainable practices.

- Inadequate early-stage planning and requirement specification: early project stages often lack detailed planning, precise requirement specifications, and early involvement of ICT managers and facilities management teams. This results in inefficiencies, misaligned goals, and missed opportunities for sustainable development.
- Unclear client needs and engagement: clients often do not fully understand or engage with their ICT needs, leading to poorly defined requirements, resistance to new technologies, and insufficient consideration of sustainability goals.
- Loss and misalignment of information during design progression: Significant information loss occurs when models are started from scratch at each design stage, and different companies use varying parameters, standards, and revision practices. This hampers sustainable project continuity.
- Complexity and integration issues with digital tools: Contractors often rely on specialists for digital tools, leading to a disconnect with traditional workflows. Differences in software and tools teams use cause integration challenges, further complicating sustainable practices.
- Inconsistent data quality and management: Ensuring high-quality, consistent data in BIM models is challenging, and data is often managed in fragmented systems, leading to version control and information-sharing issues. This fragmentation undermines the sustainable management of building data.
- Inadequate documentation and communication: Poor documentation, lack of established ICT protocols, and communication issues between departments lead to inefficiencies, misaligned goals, and significant difficulties in project handover, adversely affecting sustainable outcomes.
- Unrealistic schedules and economic constraints: Clients often impose unrealistic schedules and budget constraints, leading to rushed decision-making, increased likelihood of errors, and reluctance to invest in thorough early-stage planning, which is crucial for sustainability.
- Inconsistent standards and practices across regions and projects: Variations in standards, such as Level of Development (LOD) requirements between countries and companies, lead to confusion and inefficiencies, particularly in international projects. This inconsistency poses challenges to maintaining sustainable practices.

#### 4.1.2 Proposed solutions

- Enhanced ICT and digital literacy education: Integrate comprehensive ICT and sustainability education into higher education curricula and provide ongoing training for all project stakeholders. This will improve digital literacy, ICT skills, and understanding of sustainable practices.
- Clear terminology and understanding of BIM: Promote a shift from "ICT" to "Information Management" in line

with ISO standards and ensure a comprehensive understanding of BIM that includes both geometry and information aspects, emphasising its role in sustainability.

- Consistent enforcement and adoption of standards: Promote consistent adoption and implementation of ICT standards, such as ISO 19650, across all projects. Encourage government reassessment and better enforcement of ICT legislation to support sustainable development.
- Detailed early-stage planning and requirement specification: Develop comprehensive, flexible requirement specifications and involve ICT and LCA managers and facilities management teams early in project planning. This alignment will ensure the efficient execution and integration of sustainable practices.
- Early and precise definition of client needs: Emphasize the importance of defining specific client requirements at the project's outset. Educate clients on the long-term benefits of proper ICT planning and engagement, highlighting sustainability benefits.
- Centralised and automated data management: Implement centralised data management systems and automated processes for converting and updating files. This will reduce manual efforts, ensure data quality, prevent information loss during design progression, and support sustainability by proper integration with LCA tools.
- Integrated digital and traditional workflows: Ensure digital tools and processes are integrated into conventional construction workflows, making them accessible and useful for all project participants. This integration improves overall efficiency and supports sustainable practices.
- Standardised documentation and communication protocols: Standardise documentation practices, revision numbering, and communication protocols to streamline updates, avoid misunderstandings, and facilitate efficient project handover, promoting sustainability.
- Realistic project planning and economic considerations: Establish realistic schedules and budget plans that allow for proper planning, error correction, adherence to ICT standards, and LCA output. Encourage early investment in thorough planning and data structuring.
- Unified standards and practices for international projects: Advocate for using unified standards across regions and projects, such as ISO and CDE. This consistency ensures improved data management, communication, and adherence to sustainability principles.

#### 4.2 Review of the didactical model

KEA BYG works actively to include sustainability and digitalisation in its lecture plans and teaching modules. Specific initiatives include workshops and seminars on the latest trends in sustainable construction and digitalisation, partnerships with companies to ensure that students gain practical insight and experience with sustainable and digital solutions and student projects and case studies focusing on sustainable and digital solutions in construction. The convergence of BIM, ICT and

sustainability matters within school projects centred on PBL presents a remarkable opportunity to elevate educational achievements and nurture inventive thinking. However, a notable deficiency in the existing school programmes lies in the early collaboration for crafting an ICT Process Manual that caters to client's needs and strives for sustainable solutions. This shortcoming undermines the comprehensive educational experience and fails to fully exploit the collaborative potential inherent in PBL.

The lack of early collaboration in shaping an ICT Process Manual means that students miss out on pivotal chances to engage with real-world client needs and sustainable design practices from the outset.

#### 4.2.1 Sustainability and digitalisation content

The early participation of all stakeholders, including clients, can guarantee that the ICT solutions developed are technically sound and tailored to the particular project requirements, cultivating a deeper understanding of client-oriented service provision among students. Additionally, this collaborative approach can underscore the significance of sustainability, guiding students to consider environmentally friendly practices and long-term impacts in their projects. Without this early involvement, the educational process becomes somewhat isolated, potentially leading to the development of technologically robust solutions disconnected from practical, client-specific needs and sustainable practices. Therefore, it is imperative to reconsider and restructure the ICT Process Manual preparation approach in school programmes to encompass early, sustained collaboration, thereby enhancing the relevance and impact of educational outcomes in the context of BIM, ICT, and digitalisation.

A clear example of how KEA BYG works in terms of its didactical model can be the school project that students have to develop in the 4<sup>th</sup> semester of the educational programme.

Students are presented with an open-ended, structured, and authentic real-world problem, working in teams to identify their learning needs and develop viable solutions. In this setting, instructors serve as facilitators rather than primary sources of information. This approach introduces relevant problems at the start of the instruction cycle, providing the context and motivation for subsequent learning. It is inherently active and typically collaborative, with students working together in small groups towards a common goal, or cooperative, involving structured group work where students pursue shared objectives while individually assessed [4]. Students generally begin the design process by interpreting architectural drawings, creating design documentation, and generating a federated 3D virtual model that includes three analytical models: architectural, structural, and mechanical ventilation. In groups, students upgrade the 3D models according to the specified LOD.

The BIM method facilitates environmentally conscious design choices by running a comparative analysis using data extracted from the 3D virtual model,

which serves as a comprehensive database. The primary parameters that students use as early indicators and assessment criteria for architectural system design include cost, sound performance, and environmental sustainability, specifically in terms of embodied CO<sub>2</sub>, thermal conductivity (U-value), and the Energy Frame. The pedagogical decision to develop engineered timber load-bearing elements aligns with adopting a teaching approach emphasising innovative, environmentally friendly building materials. As in a real-life sustainable project, students have to work with various massive timber products, including cross-laminated timber (CLT) walls and deck planks, laminated veneer lumber (LVL), and glue-laminated timber (GLT) [2].

While KEA is well-equipped with advanced technology and recognises the importance of integrating sustainability into school projects, there is a clear need for improvement in how these elements are incorporated into the curriculum. Despite the requirement for students to produce an ICT Process Manual, exam results indicate that understanding and application of sustainability and digitalisation are lacking. This suggests that these critical topics must be more thoroughly integrated at the early stages of the semester. To enhance student learning and performance, it is essential to embed sustainability (more precisely LCA) and digitalisation concepts more deeply into the initial phases of teaching, ensuring that students grasp these foundational principles from the outset.

#### 4.2.2 Implementation of new learning objectives

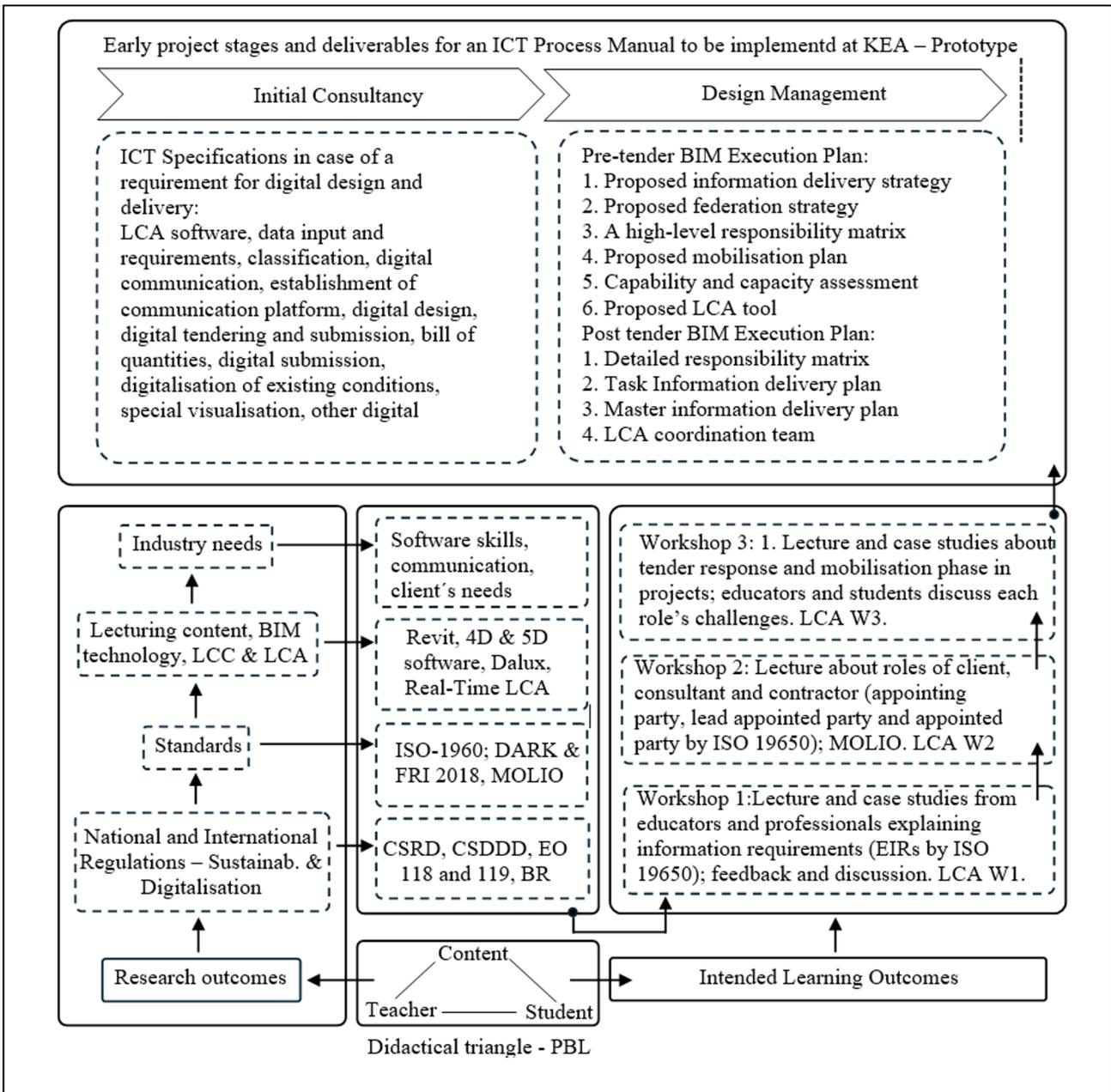
Comprehending the verb *understanding* can be challenging for lecturers as there are various levels of discernment. To address this issue, it is essential to specify the desired level of understanding when formulating an Intended Learning Objective (ILO) by choosing an appropriate verb [5]. Therefore, crafting an ILO necessitates a statement with a key verb. This statement should accurately represent the level of learning expected from the student. Learning objectives are categorised into three taxonomic levels: Knowledge, Skills, and Competences. When selecting and organising the specific content for a subject within a topic, it is crucial to align it with the ILO related to that topic. Bloom's Taxonomy, for example, can be utilised to effectively structure lecture plans, set aims and goals, and assess performances for different topics.

Considering the multidisciplinary nature of the ICT Process Manual Prototype shown in Figure 2 for study purposes, particularly in implementing sustainable solutions with the aid of digital tools in school projects, this research presents a set of learning outcomes to be included in the prototype. The new ILOs will be implemented in a series of workshops (W1, W2 and W3) where lecturers will play as facilitators to ensure that the students will be capable of:

- Understanding the principles and methodology of Life Cycle Analysis in construction projects.
- Learning about various digital tools and technologies used in construction for LCC and LCA.

- Developing the ability to integrate LCA considerations into the early design stages of construction projects.
- Utilising LCA software tools to assess environmental impacts during the early design phase.
- Critically evaluate the environmental impacts of different construction materials and processes.
- Analysing case studies of construction projects to identify best practices in LCA.
- Working effectively in teams to address LCA at upfront design stages and communicate the results to the client.
- Drafting information requirements.
- Evaluating the role and importance of information requirements.

- Evaluating the importance of early creation of information requirements.
- Explaining the actors and their roles as described by ISO 19650.
- Creating the necessary documentation for the tender process.
- Reflecting on the simulation and the importance of effective communication and documentation.
- Analysing the development of tender responses and the appointment process.
- Designing a comprehensive mobilisation plan and reflecting on the simulation and process.



**Figure 2.** ICT Process Manual Prototype

## 5 ICT Process Manual Prototype

The early implementation of ICT agreements in educational environments is pivotal in preparing students for the demands of the modern construction industry. Workshops, supported and organised by educators and industry professionals, can play a vital role in reinforcing theoretical knowledge, practical skills, and hands-on experience in preparing the ICT requirements and agreements. Such workshops would also connect the project lifecycle stages, allowing the students to better understand the information exchange and the project's longevity from the Initial Consultancy to the facilities management or operations stage. Another opportunity the workshops provide is facilitating a better understanding of the LCA requirements and the data necessary to calculate and validate.

The diagram in Figure 2 outlines a comprehensive workflow for creating an ICT Process Manual specifically tailored for school-building projects using a PBL approach. The didactical triangle illustrates the interaction between the teacher, the student, and the content. This framework guides the learning process, ensuring students are actively engaged with the material and the instructor, enhancing their understanding through practical application. The ICT Process Manual Prototype is a structured approach designed to integrate digitalisation and sustainability into the early design stages of construction projects. Through a series of workshops, students will learn to apply LCA, utilise BIM technologies, and adhere to industry standards based on the research outcomes.

There are critical components and benefits of proper ICT implementation in education, focusing on technology, teachers, students, and content. This approach highlights the necessity for adequate training and guidance for teachers to effectively use ICT tools for knowledge dissemination and blended learning [6]. In this regard, Phase 4 of this research involved an extensive investigation to identify cases or studies for comparison with the current research outcomes. Despite these efforts, it has not been feasible to establish direct parallels with the present study, thereby indicating that the ICT Process Manual Prototype represents a novel contribution to knowledge in this field.

Early integration of LCA and ICT requirements can facilitate the calculations and help streamline them. By defining standards for data formats, collection methods, and a CDE usage, the project participants can ensure that the data on climate impact can be consistently and accurately captured. Figure 2 shows the result of this research, namely an Early-Stage ICT Process Manual to be implemented in school projects under the PBL setting.

## 6 Conclusions

Integrating sustainability and digitalisation into the AEC education curriculum through PBL demonstrates significant potential to enhance the competences of future

professionals. This research underscores the importance of embedding these principles at the early stages of the educational process.

The qualitative data analysis from interviews with industry professionals reveals critical insights into the challenges and opportunities associated with implementing digitalisation and sustainability in construction projects. Key obstacles such as limited digital literacy, misunderstanding of BIM, and inadequate early-stage planning highlight the need for a comprehensive and systematic approach to education in these areas.

Findings suggest that the creation of a detailed ICT Process Manual designed to address specific client needs and sustainability goals can significantly improve the educational experience. This manual would be a crucial resource for students, providing clear guidelines and standards for sustainability, ICT and BIM practices.

Moreover, the early integration of ICT and sustainability principles into the curriculum can prepare students more effectively for the demands of the modern construction industry. By fostering a collaborative learning environment, PBL can bridge the gap between theoretical knowledge and practical application, ensuring graduates are well-equipped to contribute to sustainable and digitally advanced construction projects.

In conclusion, this study advocates for a strategic and early implementation of digitalisation and sustainability in educational programmes. The proposed ICT Process Manual Prototype represents a tangible step towards achieving this goal, promising to enhance student's learning outcomes and professional readiness. Future research should continue to explore innovative educational strategies and tools that can further align academic programmes with industry needs, ultimately fostering a more sustainable and technologically adept workforce.

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