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A Seven-Step BIM Collaboration Model for AEC Education: Bridging Disciplinary Silos Through BIM Maturity Level 3 Implementation †

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Abstract

The growing implementation of Building Information Modelling (BIM) within the architecture, engineering, and construction (AEC) industries has placed increased pressure on higher education institutions to prepare graduates for interdisciplinary digital collaboration. In many emerging higher education environments, such as South Africa, structured pedagogical frameworks for BIM Level 3 collaboration are less well established. This paper addresses this gap by introducing and evaluating a seven-step BIM collaboration framework in an interdisciplinary final year undergraduate project. A comparative cohort case study design was adopted, analysing two cohorts: the 2022 cohort operating within a traditional siloed design model, and the 2023 cohort applying the proposed framework. Grounded in Habermas's theory of communicative action, student design projects and self-reflection narratives from both the traditional siloed design process and the BIM-enabled framework were analysed deductively according to communication frequency, content, and quality as key categories. Communication quality was evaluated through intrinsic, contextual, representational, and accessibility information dimensions. Findings show that the BIM group had higher levels of established collaboration, better-quality contextually available information, more accessible structured data, and more effective communication. The findings indicate that structured BIM-based collaboration enhances a transformation from mere data exchange to constructive participation and comprehensive information development among students. Rather than functioning solely as a technical tool, BIM served as a structured communication environment that supported critical engagement and interdisciplinary workflows. This study offers a transferable pedagogical model for interdisciplinary BIM education and provides evidence supporting communication-oriented approaches to digital collaboration within built environment curricula.

Keywords: AEC education; BIM educational framework; collaborative learning digital construction; project-based learning

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1. Introduction

Construction projects are becoming more complex due to technological advancements, new materials, and integrated project delivery requirements. These changes require built environment specialists to work collectively across disciplinary boundaries [1]. However,

despite the collaborative demands of practice, higher education in many contexts continues to train architecture, construction management, and quantity surveying students within disciplinary silos, often with limited structured interdisciplinary engagement prior to graduation [2]. Today's graduates need skills in problem-solving, critical thinking, collaboration, communication, and information technology to become global citizens [3,4].

Sharing Computer-Aided Design (CAD) drawings among professionals remains a slow, error-prone process. As a result, using new technologies to improve collaboration is more important than ever for delivering complex construction projects [5]. Building Information Modelling (BIM) is leading this digital transformation by addressing information-sharing challenges and helping teams manage shared knowledge production across project stakeholders [6]. BIM Level 3, which stipulates full integration of various professionals in a collaborative environment, requires not just technical skills, but high-level communication skills. Programmes in the built environment have already begun implementing BIM at the postgraduate level by undertaking research, offering short courses, or incorporating BIM elements into existing modules [7]. These existing BIM educational frameworks predominantly focus on competency mapping, software integration, or curriculum alignment. While these frameworks support skill development, few studies empirically assess the impact of BIM Maturity Level 3 environments on the quality of interdisciplinary communication and collaborative learning at the undergraduate level. There are two main challenges in implementing BIM in higher education. The first is academic resistance and a shortage of trained BIM lecturers, while the second is an already overcrowded curriculum [8].

Communication plays an important role in the success of interdisciplinary collaboration. This study draws on Habermas's theory of communicative action and, therefore, conceptualises collaboration not as a shared task to complete but as a communicative process through which meaning, validity claims, and coordinated action are negotiated [9]. It is through this theoretical lens that communication frequency, content, and quality become measurable dimensions for evaluating pedagogical effectiveness. In a BIM-enabled environment, communication is more than just verbal; it includes model-based information exchange, visual coordination, and digital production.

This article builds on prior exploratory work presented at the ICCCBE 2024 conference, where initial findings on virtual reality and digital environment collaboration and communication patterns were reported [10,11]. The present study extends that work by refining the pedagogical framework into a structured seven-step model and by providing a comparative cohort analysis to evaluate its communication effectiveness in an undergraduate implementation at BIM Maturity Level 3.

Despite increasing adoption of BIM curricula, no study has empirically tested replicable pedagogical models for BIM Maturity Level 3 implemented at the undergraduate level. This study is situated within a developing higher education context and explicitly operationalises and evaluates communication as a measurable mechanism for interdisciplinary collaboration, rather than assuming it will emerge automatically through project participation or software usage. Existing models seldom provide empirical evidence on how BIM-enabled teamwork changes communication frequency, content, and quality, thereby influencing collaborative learning outcomes.

The research question driving this study is: How does a BIM Maturity Level 3 collaboration framework affect interdisciplinary collaboration and communication quality among final-year undergraduate AEC students? The study aims to develop and evaluate a communication-oriented pedagogical model for interdisciplinary BIM Level 3 education by implementing a structured seven-step collaboration framework in an undergraduate setting. The objectives include:

- Develop a seven-step BIM Level 3 collaboration framework that can be implemented in interdisciplinary undergraduate AEC education;
- Implement the framework within a real project context involving architecture, construction management, and quantity surveying;
- Compare a traditional siloed cohort with the BIM-framework cohort to examine differences in communication frequency and communication content;
- Evaluate communication quality;
- Generate evidence-based guidance on how communication can be scaffolded and assessed as a core pedagogical mechanism within interdisciplinary BIM curricula.

Section 2 reviews the literature on collaborative learning, BIM maturity levels, existing BIM education frameworks, and the role of communication in interdisciplinary collaboration. Section 3 introduces the theoretical lens by framing communication as a mechanism for interdisciplinary collaboration, using Habermas's communicative action theory. Section 4 outlines the research design, context, data sources, and deductive analytic approach. Section 5 presents the proposed seven-step pedagogical framework, and Section 6 presents the comparative results across both cohorts, while Section 7 discusses the findings through the lens of communicative action. Section 8 concludes by summarising the contribution, while Section 9 outlines future research opportunities.

2. Literature Review

The literature review examines (1) collaborative learning traditions in AEC education, (2) BIM maturity levels and existing BIM education frameworks, and (3) communication as a measurable component of interdisciplinary teamwork. The literature review identifies the conceptual and empirical gaps that inform the development of the proposed seven-step framework.

2.1. Collaborative Learning and AEC Education

Collaboration is key to professional practice in the AEC industry, where project outcomes depend on coordinated action across multiple specialist disciplines. During collaborative learning, higher-order thinking skills are practised through inquiry and discussion with peers in small groups. Collaborative pedagogy is built on discovery learning, grounded in the theories of John Dewey, Jean Piaget, and Lev Vygotsky, who described learning as active, process-based, and collaborative. Accordingly, knowledge is constructed through active exploration and problem-solving. It is student-centred and student-driven and promotes the integration of new knowledge into students' existing knowledge [12]. Therefore, collaborative pedagogy is more process-driven than fact-driven, with active learner participation, and feedback is vital to developing and promoting deeper learning, higher-order thinking, and deeper conceptual understanding. Although the benefits outweigh the challenges, three prominent challenges exist. The first is team experience; if a team member is slow to respond or grasp the task at hand, it decreases the experience. The second is in terms of assessment, assessing individual performance is difficult. Lastly, because dialogue is collaborative, if students do not communicate or interact with their peers, which cannot be forced on them, the collaboration activities fail [13].

Prominent learning styles in collaborative pedagogy include team-based, problem-based, project-based, case-based, and inquiry-based learning. Project-based and problem-based learning are dominant in AEC education, reflecting the profession's reliance on real-world project simulation. Therefore, teamwork is dynamic and multidimensional, requiring strong communication and collaboration skills [14]. During problem-based learning, the students face a problem that is followed by a systematic, student-centred enquiry process. Therefore, problem-based learning teaches both an approach and an attitude

towards problem-solving. Problem-based learning can be described as "a collaborative, constructivist and contextualised learning and teaching approach that uses real-life problems to initiate, motivate and focus knowledge construction [15]." Project-based learning is a model that centralises learning around a project [16]. Although these learning models simulate professional practice, they often assume that collaboration will emerge naturally from shared tasks. However, the literature rarely interrogates how communication within such models is structured, scaffolded or assessed.

The built environment professions are no strangers to collaboration, as even the smallest design implementation requires the knowledge and skills of individual specialists, each with distinct expertise, using various communication methods such as drawings, design specifications, critiques, and other disciplinary outputs to convey ideas. The contemporary approach to architecture education in the 21st century still follows the basic principles of the Beaux-Arts (the studio) and the Bauhaus (curriculum); therefore, the focus is on design education in the design studio, with supporting modules separate from it [17]. The studio's success lies in open, transparent communication that promotes a collaborative, problem-based environment conducive to the free exchange of ideas. Accordingly, the studio adopts project-based and problem-based learning strategies. The literature indicates that the current training method for construction managers is inadequate in preparing graduates for professional roles in the built environment. Quantity surveying education falls under the traditional teaching model, where systematic instruction in the form of lectures, assignments, and tests constitutes the primary component. Graduates continue with informal training once employed through continuing professional development by attending activities offered by the professional bodies. This structural separation reinforces disciplinary silos, despite the integrative demands of professional BIM-enabled practice. Students need to engage in more practical activities, thereby providing them with opportunities to encounter diverse conditions and situations [18]. Although collaboration is fundamental to the built environment, its pedagogical support—particularly through digitally integrated workflows such as BIM Level 3—remains inconsistently implemented and insufficiently evaluated.

2.2. BIM, the Four Levels of BIM Maturity, and Current BIM Educational Frameworks

The technology driving the AEC industry's transformation towards a culture of collaboration and information sharing is BIM [6]. BIM maturity has been classified into four levels, reflecting increasing degrees of collaboration.

Levels 0 and 1 focus on the digitalisation of drawings and partial 3D modelling, while Levels 2 and 3 introduce structured collaboration. BIM Level 3 is classified as the highest level of collaboration, where a shared environment, usually cloud-based, enables all disciplines to work on a single federated model. The demands for Level 3 include real-time coordination, shared responsibility, and continuous interdisciplinary negotiation [6].

Although BIM maturity levels are well established in industry literature, their pedagogical implications have not been thoroughly examined. Specifically, BIM Level 3 environments demand not only technical proficiency but also advanced communication skills, conflict resolution abilities, and coordinated decision-making. Limited educational research has investigated how undergraduate students address these communicative and collaborative challenges in fully integrated BIM contexts. Therefore, although maturity levels are often described in technical terms, their educational operationalisation, particularly at Level 3, remains insufficiently theorised.

The literature divides frameworks into three categories: educational, industry, and hybrid (combining educational and industry approaches). Only holistic academic frameworks were investigated because the study focuses on higher education interdisciplinary collabo-

ration and not on industry implementation. The prominent frameworks were developed internationally, primarily in Australia, the United Kingdom and New Zealand [19–22].

The following four frameworks are analysed:

- The BAF Initiation Framework developed by the BIM Academic Forum;
- The IMAC Framework created by Jennifer Macdonald and CodeBIM;
- New Zealand's National Draft Framework;
- The Collaborative BIM-EDU Framework from the BIM Education Working Group (EWG).

Although these frameworks are structured differently, they share three common emphases, namely, competency development, alignment with learning outcomes, and structural implementation strategies.

The BAF Initiation Framework was developed by the BIM Academic Forum (BAF) in the UK to support the deployment of BIM. The framework offers a structured pathway for maintaining a long-term vision of BIM integration into discipline-specific undergraduate and postgraduate education. The framework aims to identify specific competencies at various levels 4, 5, 6 (undergraduate), and 7 (postgraduate) of BIM Level 2 programmes in the UK. The framework outlines potential learning outcomes at each level, including knowledge and comprehension, transferable skills, and practical abilities.

With funding from the Australian Learning and Teaching Council, Jennifer Macdonald created the IMAC Framework to aid in addressing the growing demand for collaboration within the AEC sector. The framework is structured around four progressive achievement stages. According to MacDonald and Granroth [20], these are the Illustration, Manipulation, Application, and Collaboration stages. The proposed IMAC framework's stages are mapped to Bloom's taxonomy of learning. IMAC's technical (IT and discipline-specific) and interpersonal (collaboration and teamwork) skill sets are explicitly defined and integrated across the stages.

The University of Auckland in New Zealand began collaborating with industry to develop an educational framework for integrating BIM into the curriculum. Disciplines were initially structured according to the New Zealand Qualifications Framework. The three knowledge domains are enterprise and management, software and technology, and business, architecture, engineering, and construction. The framework was not created to outline a specific programme but rather to focus on intended goals and learning outcomes using three types of education: degree programmes (undergraduate and postgraduate professional degrees), research (postgraduate research degrees), and vocational training/continuing professional development [21].

The Collaborative BIM-EDU Framework has emphasised collaboration since its establishment in 2011. The Australian Institute of Architects (AIA) and Consult Australia (CA), two industry organisations in Australia, oversee the framework. Six parts make up the framework. The first three sections detail the development and classification of BIM learning modules and the identification and recognition of BIM competencies. The establishment of academic and industry frameworks for professional development is examined in sections four and five. The final section advocates the establishment of a BIM institute [22].

Comparing the frameworks mentioned above reveals three principles, each comprising three key elements. Table 1 lists the three principles, together with the pertinent concepts, indicating their presence ("yes") within each framework.

Table 1. Comparison among the BAF, IMAC, New Zealand National Draft, and BIM-Edu Frameworks.

	Skills			Teaching Approach			Implementation Strategy		
	Link to Competencies or Goals	**Link to Learning Outcomes**	**Link to Learning Strategies**	**Link to BIM Maturity Levels**	**Process-Driven Approach**	**Collaborative-Driven Approach**	**Link to Different Types of Education**	**Link to HEQF Levels**	**Applies**
BAF Framework		yes		yes	yes			yes	yes
IMAC Framework			yes		yes				yes
New Zealand National Draft Framework	yes				yes		yes	yes	
BIM-EDU Framework	yes					Yes			

2.2.1. Skills Development

Skills development can be examined in relation to structure and scope. Structurally, two principal approaches can be identified. The IMAC Framework uses a principled, four-stage method based on Bloom's taxonomy. Institutions can apply these stages with flexibility according to their curricular context. These stages are not tied to specific HEQF (Higher Education Qualifications Framework) levels or predefined learning outcomes, making the approach flexible for different academic disciplines. However, because it is grounded in Bloom's taxonomy, learning outcomes can be developed for different levels of education.

The BAF, New Zealand National Draft Framework, and BIM-EDU Framework adopt a different approach. They employ predefined learning objectives, divided into knowledge, practical skills, and transferable abilities. These frameworks are more formalised and closely aligned with the HEQF levels. The New Zealand National Draft and BIM-EDU frameworks emphasise broader goals or competencies, whereas the BAF Framework provides clear outcomes for different educational levels.

The scope of skills may similarly be categorised from two perspectives. The IMAC Framework divides skill scope into technical skills—particularly in information technology (IT)—and interpersonal skills, such as collaboration and teamwork. Technical skills are introduced during the initial two stages (illustration and manipulation), while interpersonal skills are emphasised during the latter two stages (application and collaboration). These stages may be implemented within a single academic year or distributed across different HEQF levels. The BAF Framework, on the other hand, has a more defined strategy and identifies specific abilities for each level of study. Interpersonal skills are only required here at the third-year level, with technology-related abilities being introduced at the first-year level.

The BIM-EDU Framework suggests that BIM competencies and learning outcomes should be identified and developed prior to full framework implementation. These learning outcomes are intended to be part of an online learning hub where students can learn about BIM before diving into technology and using their interpersonal skills. Notably, the framework allows for establishing specific competencies and learning outcomes in line with standards set by various institutions or entities, based on peer-reviewed literature reviews.

The selection of a particular framework inevitably influences both teaching approaches and implementation strategies. Direct cross-referencing of the frameworks is challenging due to structural differences. In conclusion, triangulating the three approaches may facilitate the development of a more robust framework, wherein the strengths of one approach compensate for the limitations of another.

While several frameworks acknowledge the importance of both technical and interpersonal skills, these are typically prescribed as learning outcomes rather than evaluated as dynamic,

measurable processes within interdisciplinary collaboration. This study responds by examining how communication quality (as a skill) manifests in authentic BIM-enabled teamwork.

Only the BAF framework, which employs a BIM Maturity Level 2 approach and fully integrates collaboration up to the 6D stage (costing), combines BIM maturity levels among the frameworks under examination. The other frameworks do not explicitly reference global BIM maturity levels.

2.2.2. Teaching Strategies

The teaching approach within these frameworks can be categorised into two primary approaches: a process-driven approach within the educational context and a collaborative process involving both industry and academia. Among these frameworks, only the BIM-EDU framework proposes a link between academia and industry during framework development. In contrast, the remaining frameworks are primarily based in academia and employ a process-driven approach. The IMAC and BAF frameworks, which fall within the process-driven category, incorporate interdisciplinary student collaboration; BAF includes it at the postgraduate level, while IMAC introduces it at the collaboration stage. Conversely, the New Zealand National Draft Framework does not include collaboration.

Although some frameworks introduce collaborative elements at the curriculum level, they often assume that collaboration automatically leads to learning without interrogating how students coordinate and communicate in practice. This study addresses this gap by investigating the internal dynamics of BIM collaboration as a pedagogical strategy, rather than just a delivery format.

2.2.3. Implementation Models

The New Zealand National Draft Framework uniquely establishes connections across diverse forms of education, including vocational training, continuing professional development, degree programmes (both undergraduate and postgraduate), and research degrees; the New Zealand National Draft Framework stands apart. While leaving the interpretation more open for degree and research programmes without guidelines, this framework emphasises content development for continuing education and professional development programmes.

The BAF and the New Zealand National Draft Framework link various skills to different levels of the HEQF. However, the New Zealand National Draft Framework adopts a more thorough approach by outlining outcomes particular to different levels of education and HEQF. While the BAF Framework includes guidance for research, professional development, and vocational programmes, it only outlines a set of outcomes based on knowledge, practical abilities, and transferable skills for bachelor's (three-year) and honours (one-year) degrees.

Of the four proposed frameworks, only the IMAC and BAF Frameworks have been implemented. In contrast, the New Zealand National Draft Framework and the BIM-EDU Framework remain in the conceptual stage.

Despite their positive contributions, several limitations remain evident:

- Most frameworks emphasise technical skills development and curriculum alignment, with limited investigation into the practical dynamics of interdisciplinary collaboration;
- Levels higher than BIM Level 2 are seldom implemented in undergraduate education, and
- Interpersonal skills are recognised; however, communication is generally regarded as a learning outcome rather than as a quantifiable process that directly influences the quality of collaboration.

This study addresses this gap by proposing and evaluating a structured seven-step BIM Level 3 pedagogical framework that explicitly operationalises communication as a measurable mechanism for interdisciplinary collaboration.

2.3. Communication in Interdisciplinary BIM Collaboration

Communication is central to successful collaboration, particularly in interdisciplinary learning environments where meaning must be constructed across disciplinary boundaries. Effective communication requires the ability to articulate ideas verbally and nonverbally while listening attentively to ensure mutual understanding [23,24]. In collaborative design environments, communication extends beyond verbal exchange and includes drawings, models, specifications, and digital coordination. In BIM-enabled environments, communication is inherently multimodal and occurs through face-to-face dialogue, digital messaging platforms, model coordination, and visual representations, all within a shared environment. These communicative interactions are not just a mechanism for transferring information, but a process in which shared interpretations, assumptions, and coordinated actions are developed.

The literature identifies three dimensions for the systematic analysis of communication. Communication frequency encompasses the regularity, intensity, and timing of interactions among team members. Communication frequency varies across project phases and typically increases during periods of uncertainty or heightened coordination complexity. Previous research indicates that unfamiliar teams often exhibit elevated initial communication frequency as members negotiate roles and establish shared understanding [25]. Communication content refers to the substantive focus of interactions among team members. Within interdisciplinary teams, content may be task-oriented, such as technical problem-solving, coordination decisions, or design adjustments, or relational, including trust-building, role clarification, and peer support. Both types of content influence the depth of collaboration and the formation of shared mental models. Communication quality relates to the clarity, coherence, relevance, and reliability of exchanged information. In BIM environments, the quality of communication is intrinsically linked to the information quality present in models and drawings. According to Mai [26], information quality can be categorised into four dimensions: intrinsic (accuracy and credibility), contextual (relevance and completeness within a specific stage), representational (clarity and consistency of presentation), and accessibility (ease of retrieval and interpretability). These dimensions provide a structured framework for assessing communication outputs within collaborative BIM environments.

Although collaborative learning literature acknowledges communication as central to effective teamwork, numerous BIM education frameworks prioritise competencies or technical integration while neglecting empirical investigation of communication as a measurable mechanism within interdisciplinary collaboration. Few studies explicitly operationalise communication frequency, content, and information quality as evaluative constructs for determining pedagogical impact. The present study addresses this gap by conceptualising communication not only as a competency outcome but also as an observable and assessable process embedded within BIM-enabled interdisciplinary teamwork.

3. Theoretical Framework

This study is based on Jürgen Habermas's theory of communicative action, which views communication as a social action that enables individuals to achieve mutual understanding and coordinate action, rather than merely exchange information [9]. Within this framework, participants engage in dialogue to negotiate meaning, assess the validity of claims and reach a shared understanding. Communication is viewed as a rational process in which people explain and support their claims about truth, appropriateness, sincerity, and clarity, rather than simply exchanging information.

In interdisciplinary built environment education, effective collaboration extends beyond the coordination of technical tasks. Students need to explain their design ideas, support their decisions, question assumptions, and respond thoughtfully to feedback.

These practices demonstrate communicative rationality, in which ideas are critically examined through conversation rather than imposed by authority. Because of this, how often people communicate, what they talk about, and how well they communicate are seen as key parts of communicative action.

This study also draws on the concept of criticality from Davies and Barnett [27], who argue that critical engagement includes critical reasoning, self-reflection, and action. Communicative action provides the mechanism through which criticality emerges in collaborative contexts. When students engage in structured discussion, question assumptions, and make collective decisions within a BIM-enabled environment, they transition from isolated problem-solving to reflective and collaborative practice.

By integrating communicative action theory with theories of frequency, content, and quality of communication, this study develops a framework for examining how BIM Level 3 environments influence interdisciplinary teamwork. Within this framework, communication is seen both as a teaching method and as an evaluative measure of collaborative effectiveness.

4. Materials and Methods

4.1. Research Design

This study used a qualitative comparative cohort case study design to evaluate the pedagogical impact of a structured seven-step BIM Level 3 collaboration framework in undergraduate AEC education. The research compares two consecutive exit-level undergraduate cohorts within the same institutional context between 2022 and 2023. The 2022 cohort continued to use the traditional, discipline-specific design process, while the 2023 cohort implemented the seven-step BIM Framework. All other contextual variables were intentionally kept consistent. Both cohorts were supervised by the same lecturer; the architectural design brief remained consistent in size, scope, spatial requirements, budget and time parameters; the assessment rubrics were identical, and the cohort sizes were comparable, with fourteen architecture students in each cohort.

Although the architectural design task was consistent in both years, the pedagogical structure differed. In 2022, the architecture students received design critiques only from the design lecturer, resulting in decision-making informed solely by architectural feedback. By contrast, while the 2023 cohort used the same design brief, students received structured interdisciplinary design input from architectural lecturers, construction management and quantity surveying students. The diversity of voices influenced the design through material selection, constructability, and cost within a BIM Level 3 environment. The independent variable that distinguishes the cohort was therefore the formal integration of structured interdisciplinary communication aligned with BIM Level 3, rather than task complexity.

The study is situated within a design-based research paradigm, investigating and evaluating a pedagogical intervention implemented in an authentic education setting. Design-based research allows theoretical constructs to be tested, evaluated and refined through iterative implementation. In this study, the seven-step BIM Framework is a structured pedagogical intervention designed to scaffold interdisciplinary collaboration and communication in undergraduate AEC education.

A deductive, theory-informed analytical approach was employed, utilising Habermas's theory of communicative action to operationalise communication through three analytical dimensions: communication frequency, communication content, and communication quality. These dimensions served as predefined categories for comparing observable interaction patterns in the student design projects and student self-reflection narratives between the BIM framework and the siloed design process.

4.2. Context and Participants

The study was conducted at Nelson Mandela University in Gqeberha, South Africa. It focused on final-year undergraduate students from the departments of architecture, construction management, and quantity surveying, disciplines central to AEC collaboration. Architecture is housed within the School of Architecture, while construction management and quantity surveying form part of the School of the Built Environment and Civil Engineering. Both schools are located within the Faculty of Engineering, the Built Environment and Technology.

Two consecutive cohorts were examined. In 2022, fourteen exit-level undergraduate architecture students participated in the study, completing the design project using a traditional, discipline-specific studio structure. No structured interdisciplinary collaboration was introduced during this year. The 2023 cohort also consisted of fourteen exit-level undergraduate architecture students. In addition, nine construction management students and eight quantity surveying exit-level undergraduate students participated in the study. Fourteen project teams were formed based on the fourteen architecture students. Some construction management and quantity surveying students participated in up to two teams to accommodate enrollment imbalances.

The architectural cohort size remained consistent across both years (n = 14), ensuring comparability in design outputs and assessment. The construction management and quantity surveying students' feedback was not included in the present analysis due to an imbalance in team sizes and participation. Consequently, the primary distinction between the two architectural cohorts lies in the structured interdisciplinary collaboration facilitated by the seven-step BIM Level 3 Framework.

4.3. Data Collection

Data were collected from two cohorts of students (2022 and 2023), both of whom received the same design project brief. Students were required to design a small living unit with a footprint of 5000 mm $\times$ 8500 mm $\times$ 7500 mm. The project budget was set at 1 million South African rands, with a construction time frame of 6 weeks. The 2022 cohort followed the traditional, siloed discipline-specific approach. In contrast, the 2023 cohort implemented the proposed seven-step BIM pedagogical framework (see Section 5). While design constraints remained constant, the 2023 cohort engaged in interdisciplinary feedback rather than discipline-specific feedback when making design decisions. This seven-step model aims to scaffold BIM Maturity Level 3 collaboration by aligning learning outcomes, competencies, and, critically, communication processes. Both cohorts followed the same academic timeline, and submissions were structured according to SACAP professional work stages to ensure comparability.

Two primary data sources were collected from both cohorts. The first consisted of the final design submissions, including—but not limited to—conceptual and developmental drawings, design presentations, construction drawings, costing documentation, construction schedules, and BIM models. The second data source comprised student self-reflection narratives produced by the architecture students. Each cohort was asked to reflect on their collaboration process and experiences, communication methods, challenges encountered, and project developmental decisions. Communication was not observed through recorded meetings or digital chat logs. Instead, it was observed through the narratives, evidence embedded within project submissions and indicators of digital coordination visible within the BIM models.

4.4. Data Analysis

Data analysis followed a structured, deductive comparative approach, examining both the design projects and the student self-reflection narratives. The analysis followed three sequential stages.

Firstly, each design project was evaluated using two structured assessment frameworks. The SACAP professional work stages were used to ensure compliance with standard documentation requirements at each work stage [28]. The deliverables outlined for each work stage served as a guideline for student submissions, as summarised in Table 2.

Table 2. Requirements at Work Stages 1, 2, and 3. Adapted and summarised from SACAP [28].

Work Stage 1 Inception	Work Stage 2 Concept and Viability	Work Stage 3 Design Development	Work Stage 4 Construction Documentation
Establishment of the project brief outlining the client's requirements. Appointment and confirmation of the required consultants.	Presentation of the design concept through preliminary graphical representations of the proposed building. Preliminary costing documentation. Input and reports from relevant professional consultants. Time schedule. Confirmation of fees.	Further development and refinement of the design, including: • The form of the building; • The structure of the building; • The standard of finishes; • The performance of the building. (operational and energy efficiency); • Elemental cost analysis; • Updated project programme.	The preparation of: • Local authority submission drawings; • Specifications; • Service coordination; • Working drawings.

Wei and Yupen's [29] grading rubric was used, providing performance indicators across five dimensions for informative and summative assessments, including professional documentation, content accuracy and formatting. A fifth criterion, namely collaboration, was incorporated into the rubric for this research. Table 3 presents the adapted rubric used to assess the projects during the second stage of analysis. The rubric provided measurable indicators of information completeness, information integration and evidence of coordinated outputs. The rubric was applied to both cohorts under the supervision of the same lecturer, ensuring consistency in evaluation procedures.

During the second stage, the student design project submissions and self-reflection narratives were analysed deductively using a coding framework derived from Habermas's theory of communicative action. Communication was analysed through three predefined dimensions. The first is communication frequency, where interaction timing, communication around milestones, and evidence of sustained or sporadic exchange were measured. Secondly, communication content looked at task-oriented (problem-solving) versus relational communication (trust-building). Lastly, communication quality was evaluated using Mai's [26] four information dimensions of intrinsic quality (accuracy and credibility), contextual quality (relevance, completeness), representational quality (clarity, consistency, visual logic), and accessibility quality (retrievability, cross-referencing, integration). The coding categories were established prior to the analysis to ensure deductive consistency.

The focus was not on the number of words, but rather on the presence of structured communication behaviours.

Table 3. Adapted marking guide [29].

Grading Criteria	Poor	Below Expectation	Meet Expectation	Confident	Advanced
Score	0	1	2	3	4
Professional documentation	Documentation is poorly prepared; no evident effort made toward professional documentation	Some effort made toward professional documentation	Satisfactory compliance with professional documentation	Good professional documentation	Excellent professional documentation
Contents—Completion	Submission contains 50% or less of required project deliverables	Submission contains 51–69% of required project deliverables	Submission includes 70–79% of necessary project deliverables	Submission has 80–89% of needed project deliverables	Submission includes 90–100% of required project deliverables
Content—Accuracy	Minimal information is provided in the deliverables with poor accuracy	Limited information is provided in the deliverables with low levels of accuracy	Adequate information is provided in the deliverables with acceptable accuracy	Comprehensive information is presented in the deliverables with full accuracy	Excellent coverage of information in the deliverables with impeccable accuracy
Formatting	No evident compliance with formatting requirements	Limited compliance with formatting requirements	Acceptable formatting, despite a few mistakes and inconsistencies	Good and consistent formatting, minor mistakes	Excellent formatting, almost impeccable consistency
Collaboration	No group collaboration	Little evidence of group collaboration	Satisfactory group collaboration	Good and apparent group collaboration	Excellent and consistent group collaboration

After stages one and two, the final stage involved a structured comparison between the siloed model (cohort 2022) and the seven-step BIM Framework (2023). The comparison examined the differences in communication timing and clustering, differences in communication content, observable information integration and rubric-based scores. As the contextual variables (lecturer, brief, assessment criteria and cohort size) were held constant, observed differences were interpreted in relation to the structured implementation of the seven-step framework. The purpose of the analysis was not to evaluate BIM software proficiency, but to evaluate whether the structured pedagogical framework altered communication patterns and information quality within an interdisciplinary environment.

4.5. Ethics Approval

The participation of both the 2022 and 2023 cohorts was voluntary. The project was not part of any summative academic assessment. The project was presented as a design competition through the research assistant, who is impartial and not involved in any design studio, thereby eliminating any power relationship between the researcher and the students. Students were made aware that they could withdraw from the competition at any point. Furthermore, the design project was delivered and supervised by the same design lecturer, thus minimising potential bias arising from shared lecturer responsibilities. Ethical

clearance was received prior to the start of the data collection for the study from Nelson Mandela University for conducting research involving students. Ethical clearance number: H22-ENG-CMA-013. Students were approached by the research assistant, who was not a lecturing staff member, to present the research study to the students, upon which they signed an informed consent form to participate.

4.6. Threats to Validity

This study compares two naturally occurring cohorts rather than randomly assigned groups, so the possibility of cohort non-equivalence cannot be entirely dismissed. Participation by all students (architecture, construction management, and quantity surveying) was voluntary, which introduces the potential for self-selection bias. In certain cases, these students (construction management and quantity surveying) contributed to multiple architectural teams, potentially compromising group independence. The research was conducted within a single institutional context in South Africa; therefore, the findings should be regarded as contextually specific rather than universally generalisable.

5. A Seven-Step Pedagogical Framework for Collaborative BIM Education

Drawing on the literature and the pedagogical need to link communication quality to interdisciplinary collaboration, this study proposes a seven-step BIM Maturity Level 3 collaboration framework. Linking instructional content to the framework and applying it in practice, this framework serves as a pedagogical model. The steps are sequential and cumulative, where each stage scaffolds the communicative and collaborative conditions required for full BIM Level 3 integration. It was tested in this study with the 2023 cohort and evaluated against the communication quality metrics. Table 4 provides an overview of the seven-step pedagogical framework for BIM Maturity Level 3 education.

Table 4. Seven-step pedagogical framework.

Step	Description
1	BIM Maturity Level.
2	Define the role players in the model, including a clearly defined job description.
3	Based on the aim of the BIM level, determine the competencies required to satisfy the chosen BIM Maturity Level for each discipline.
4	Select learning strategies to guide planning, outcomes, and assessment for effective learning.
5	Develop learning outcomes aligned to the required competencies and relevant HEQF levels that the local department defines. Some learning outcomes may repeat across levels but increase in complexity.
6	Develop the implementation approach to satisfy the learning outcomes, e.g., embedding into a module, capstone project or workshop.
7	Develop the content, including theoretical material, practical material and assessment methods.

In the next section, the framework will be described, explaining the purpose of each step, its application in the 2023 cohort, and its link to communication quality.

5.1. Step 1: BIM Maturity Level

BIM Level 3 offers a full collaboration experience by sharing information on a centralised database, enabling integrated co-authorship and design thinking within interdis-

ciplinary teams. Thus, necessitating continuous negotiation, validation of assumptions, and real-time conflict resolution. In the final year, exit-level architecture, construction management, and quantity surveying students were required to work together on a shared model to simulate a BIM Maturity Level 3 workflow.

By selecting BIM Maturity Level 3, the framework intentionally requires students to demonstrate a high level of communication, handle complex conflict situations, navigate real-time coordination, and interpret verbal and non-verbal information. Therefore, the context provides an opportunity to assess communication frequency, information content, and information quality.

5.2. Step 2: Defining the Role Players and Their Responsibilities

In step two, the role players must be identified, and their responsibilities clearly articulated within the interdisciplinary team. The roles include discipline-specific and collaborative project responsibilities.

Without clear roles and responsibilities, communication is compromised, which can lead to duplication of work and undermine meaningful teamwork, which is the core premise of BIM Maturity Level 3. From an educational perspective, it is important that students not only understand their specific discipline but also how their role intersects with other professionals on the team in the shared environment.

In the 2023 cohort, each group consisted of one architecture, one construction management, and one quantity surveying student, with each profession's role clearly defined at the outset. The architecture students were responsible for the spatial and conceptual design, while the quantity surveying students ensured the design stayed on budget throughout the design phases. Lastly, the construction management students were responsible for programming, sequencing, and building. The role configuration was intentionally designed to produce epistemic interdependence, thereby necessitating communicative negotiation rather than isolated decision-making.

Determining the role and responsibilities at the outset helps improve communication and reduce ambiguity. Each discipline can clearly communicate its needs, which promotes more purposeful collaboration and helps researchers measure the quality of communication.

5.3. Step 3: Disciplinary Competencies for Role Players

This step identifies the disciplinary competencies each role player must demonstrate to achieve BIM Maturity Level 3, aligned with a fully integrated BIM environment. For BIM Level 3 to be successful, it must demonstrate a fully integrated, collaborative mode of working. Therefore, each discipline must possess not only technical competencies but also interpersonal, reflective, and workflow-related competencies. By determining the competencies and understanding what students must know and do, learning outcomes can be established.

For the 2023 cohort, competencies for all three disciplines reflected BIM Maturity Level 3 expectations. Architecture students received spatial and conceptual modelling training, quantity surveying students received cost management training, and construction management students received training in sequencing and scheduling. Students were expected to apply their knowledge collaboratively and communicate contributions clearly. Four competencies were identified: (1) BIM technology development; (2) BIM application in a cloud-based environment; (3) Building process management; (4) Performance analysis.

5.4. Step 4: Selecting the Learning Strategies

Step four focuses on selecting learning strategies to shape planning, outcomes, and assessment for achieving the relevant BIM Maturity Level. Strategy plays an important role in anchoring the implementation model in education theory. This, in turn, ensures

that the application is not just technical but pedagogically sound, which influences student engagement, promotes reflective practice, and collaboration.

The 2023 cohort applied a constructivist PPR-based (project-, problem-, and role-play-based) learning strategy. A real-world problem was presented to interdisciplinary groups, solved through a design project that simulates real collaboration. This strategy was selected to position communication not as a tool, but as a collaborative competency. It allowed the research to assess communication frequency, content and quality. The PPR strategy was selected because it situates communication as the primary mechanism for negotiating problem interpretation, disciplinary positioning, and design justification.

5.5. Step 5: Developing Learning Outcomes Aligned to Competencies

In step five, measurable outcomes are developed and aligned to the competencies stated in step three. Learning outcomes are important because they indicate what students should know, do, and value upon completing a project/assignment or task.

Learning outcomes establish the alignment between interdisciplinary collaboration and BIM Maturity Level 3 competencies, providing a reliable evaluation. Outcomes can be divided into three broad areas: disciplinary knowledge and application, collaborative problem-solving, and communication and information quality. Table 5 provides detailed learning objectives and outcomes for each competency. Unlike traditional BIM frameworks, where collaboration is embedded as a discrete outcome, communication objectives were horizontally integrated across all competencies, positioning communicative clarity, validation, and coordination as performance indicators across the learning outcomes rather than as a separate outcome.

Table 5. Learning objective and outcome (step 5) outline for each competency (step 3).

Competency 1: Development of BIM Technologies		
Discipline	Learning Objective	Learning Outcome
Architecture	Review the basic BIM theoretical concepts.	Formulate the theoretical and practical characteristics of non-BIM and BIM models.
	Apply BIM practical skills.	Create and construct 3D models.
Construction Management Quantity Surveying	Review the basic BIM theoretical concepts.	Formulate the theoretical and practical characteristics of non-BIM and BIM models.
	Apply BIM practical skills.	Operate BIM tools.
Competency 2: BIM Application in a Cloud-Based Collaborative Environment		
Discipline	Learning Objective	Learning Outcome
Architecture Construction Management Quantity Surveying	Develop collaboration with other built environment professionals.	Formulate appropriate communication in interdisciplinary teams. Develop interactive and cooperative skills within a team. Validate the roles and responsibilities of participants in a BIM-based project.
	Design, construct and develop using a virtual environment.	Evaluate and critique BIM-based models using cloud-based collaborative environments.
Competency 3: Management of the Building Process		
Discipline	Learning Objective	Learning Outcome
Architecture Construction Management Quantity Surveying	Identification of BIM tools in terms of the design process.	Develop, visualise, amend, evaluate, process and manage data associated with BIM models.

Table 5. *Cont.*

Competency 4: Performance Analysis		
Discipline	Learning Objective	Learning Outcome
Architecture	Compose, argue and critique BIM analysis (implicit versus explicit solutions).	Design, plan, assemble and validate a design option.
Construction Management	Compose, argue and critique BIM analysis (implicit versus explicit solutions).	Design, plan, assemble and validate a site logistics schedule.
Quantity Surveying	Compose, argue and critique BIM analysis (implicit versus explicit solutions).	Design, plan, assemble and validate the cost of a design option.

5.6. Step 6: Designing the Implementation Strategy

In step six, the BIM pedagogical framework examines how it will be implemented in practice, such as embedding it into an existing capstone project, a stand-alone module, or a competition, ensuring interdisciplinary BIM Level 3 alignment. The success of a framework is based on the mode of delivery.

The implementation strategy employed an interdisciplinary co-curricular design competition, given the ethical criteria for research studies involving students. The selection offers flexibility beyond departmental and module timetables, enabling interdisciplinary participation. The design brief aligns with SACAP's work stages one to four, simulating a real-world interdisciplinary engagement. Project milestones are set throughout the project. The inclusion of submission milestones (a submission after each work stage) makes communication an integral part of the learning journey, rather than incidental; therefore, the milestone structure functioned as a pedagogical scaffold for communicative reflection. This also allows the opportunity to observe and assess how information is shared, represented, and negotiated.

5.7. Step 7: Developing the Content and Assessment

Step seven aligns the learning content and assessment tools to the learning outcomes, implementation model, and interdisciplinary collaboration goals. It is only at this step that the framework becomes a functioning pedagogical model, ready for application.

- The content development for the BIM cohort included:
- BIM software, which includes Autodesk Revit® 2023 and Navisworks Manager® 2023 training. File sharing and collaborative processes (using the Nelson Mandela University's internal network), and BIM Level 3 training.
- Design a competition brief that challenges students by framing a real-world project using SACAP work stages 1 to 4.

The assessment is guided by Wei and Upen's [26] rubric, which includes professional documentation, content accuracy and completeness, formatting and standardisation, and team collaboration.

Communication is incorporated as both a skill and an assessment objective within the content. Students produce both co-created artefacts in the form of drawings and models, and student self-reflection, which assesses the depth, frequency and clarity of these interactions. Communication is therefore not seen as a soft outcome, but rather a measurable and central component to the model's effectiveness, allowing comparison of interaction frequency, content depth, and information quality across cohorts.

What sets this framework apart from other frameworks that focus on competency mapping, curriculum alignment or staged skill progression is threefold. Firstly, is specifically developed for BIM Maturity Level 3 at the undergraduate level. Secondly, it positions communication as a measurable, observable mechanism for interdisciplinary collabora-

tion rather than as an implicit outcome of teamwork. Lastly, the model was tested using a comparative cohort design, which enables evaluation of communicative patterns and information quality. The framework is conceptually grounded in communicative action theory, which positions interdisciplinary coordination as a validity-seeking process rather than mere information exchange.

In the results section, a comparative analysis is based on the previously identified linguistic act themes. Communication frequency and content were evaluated through direct observation and artefact review. Data from both cohorts, collected across SACAP-aligned project stages, formed the main dataset for examining how collaborative behaviours and information quality changed across siloed and BIM-enabled educational models.

6. Results

This section presents the results of a comparative analysis of the 2022 (Student 1, 2, etc.) and 2023 (Student A, B, etc.) exit-level undergraduate architecture student cohorts. The 2022 cohort followed a traditional, sequential, discipline-specific design process, whereas the 2023 cohort implemented the seven-step BIM Level 3 collaboration framework within an interdisciplinary setting. All contextual variables were kept constant, including the same design lecturer, base design brief, assessment rubric and cohort size (fourteen students), thereby leaving the BIM framework as the only pedagogical variable.

The analysis was deductive and theory-informed, drawing on Habermas's theory of communicative action to examine communication as a mechanism for interdisciplinary collaboration. Data sources included project artefacts (design and construction drawings, physical models, and digital models) and student self-reflection narratives. The data were examined across three predefined dimensions derived from the literature.

In this study:

- Communication frequency refers to how often team members interact, including both formal and informal exchanges, and whether these were sustained, clustered, or sporadic over time [25].
- Communication content refers to the substance of team interactions, including task-related topics like coordination, problem-solving, and clarifications, as well as relational topics like emotional support and social bonding [30].
- Communication quality is grounded in Mai's [26] framework, which defines information quality in four categories: intrinsic (accuracy, credibility), contextual (relevance, completeness), representational (clarity, visual structure), and accessibility (ease of access, availability).

The following three subsections compare the two cohorts across the three dimensions to evaluate how the proposed BIM Level 3 Framework influenced interdisciplinary communication patterns and information development.

6.1. Communication Frequency

The student self-reflection narratives were used to deductively analyse communication frequency indicators. The students were not asked to keep a detailed schedule of every meeting or communication interaction, nor to submit meeting minutes or communication logs. This methodological choice was aimed at avoiding the imposition of an artificial structure on communication behaviour and allowing interaction patterns to emerge organically within both cohorts. Therefore, the reflection provides an authentic account of communication frequencies.

The 2022 cohort met in person weekly throughout the project, relying exclusively on face-to-face meetings as shown in the narrative of Student 5.

> "*All of these conversations with my friends can be seen as informal crits. It was very impromptu and fun. It was nice to help others and be helped by your peers learning from them and their way of thinking. We could book a crit with our lecturers on the days we had design which was usually Mondays to Wednesdays and talk to them about our designs.*" (Student 5)

In contrast, the 2023 cohort, utilising the BIM methodology, primarily communicated at the project's outset and immediately prior to deadlines, employing both in-person and digital platforms, as shown in the narratives of Students C, G, and I. Additionally, members of the 2022 cohort were already acquainted, whereas the 2023 cohort consisted of individuals who had not previously met.

> "*Communication was mainly two to three days before submission, but there was communication throughout the project. Few planned meetings, but a good mixture between problem identification and solution development and check-ups to see how the members are doing and experiencing the project.*" (Student C)

> "*We spoke often at the beginning of the project when we discussed the building. However, near the end we just spoke before submissions or whenever problems arose and discussed what we had to do next. We also confirmed what everyone's jobs would be and when each task needed to be completed. We also bumped into each other a lot in the labs or after joint classes (KESV) and spoke of our progress so far, and how busy we were with other classes.*" (Student G)

> "*Communicating with my QS group members was mainly over WhatsApp. However, communication with my CM group members was fairly often in person when we were both in the computer labs and via WhatsApp text messages when needed.*" (Student I)

Each cohort adopted distinct communication methods. The 2022 cohort primarily relied on verbal communication, while the 2023 cohort supplemented verbal exchanges with WhatsApp and other text-based messaging platforms, as indicated in the narratives of Student I. The 2022 cohort experienced delays of up to one week in receiving critical updates, whereas the 2023 cohort reported faster access to interdisciplinary information updates through shared digital platforms. The shift reflects a change in communication structure. The frequency pattern moved from a regular weekly discipline-based interaction (2022) to a milestone-driven interaction (2023), suggesting that BIM structured communication around coordination requirements rather than the studio routine. These differences suggest that BIM did not increase the volume of communication but altered its distribution and platform use.

6.2. Communication Content

The student self-reflection narratives were again used to analyse the content of their communication during their interactions, whether discipline-specific or interdisciplinary in nature. The 2023 cohort employed a dual communication strategy, integrating both relational (social communication) and task-oriented (project-driven communication) exchanges, facilitated by BIM. Face-to-face interactions in the 2023 cohort frequently included relational discussions that extended beyond immediate project tasks, whereas WhatsApp messaging remained predominantly task-focused. Students described relational exchanges extending beyond immediate project tasks, indicating a broader interactional scope than the primarily critique-driven communication reported in 2022. Early recognition of the importance of both oral and written communication proved essential for effective collaboration. These initial discussions established the foundational knowledge required for cohesive group work.

> "*In the beginning, we spoke in person more often, but as varsity became more hectic, we spoke via WhatsApp more, especially near the end. There is one discussion about the budget and the materials used that I remember took place only via WhatsApp.*" (Student G)

> "*We only met on campus twice as a group to discuss the project. We did bump into one another in the studio, and we chatted about the project as well as classes, hobbies, etc.*" (Student D)

In contrast, the 2022 cohort primarily engaged in task-oriented communication, focusing on project directives and objectives. Additionally, the traditional design methodology of the 2022 cohort was more static and insular, lacking the collaborative content sharing facilitated by the BIM process in the 2023 cohort.

> "*Throughout the design process, you started by creating a general design. You often end up with the most generic Design when going into your first crit! But lecturers helped and guided you away from that. They helped you create a more tailored and unique design and bring your ideas to life.*" (Student 9)

> "*I enjoyed crits with my design lecturer because I felt like the design was mine and I was receiving direction on how to steer it right.*" (Student 6)

> "*I often spoke to my lecturer to ask him questions about the brief and site and different queries I had throughout the design process.*" (Student 5)

Importantly, the two cohorts described the two communication platforms differently based on communicative functions. WhatsApp was more task-driven, whereas face-to-face interactions led to broader discussion and perspective sharing communication for the 2023 cohort, compared to the task-driven face-to-face communication seen in the 2022 cohort. The integration of relational and task-driven content in 2023 reflects a broader communicative function beyond direct instruction.

6.3. Communication Quality

Communication quality was evaluated using the four dimensions as defined by Mai [26], namely intrinsic, contextual, representational, and accessibility.

In the 2022 cohort, each individual drawing (including plans, sections, and elevations) was treated as an isolated task containing self-contained information relevant only to that specific drawing, rather than as part of a holistic building representation (Figure 1). The intrinsic information within these drawings was accurate, objective, credible, complete, and trustworthy, consistent with the concept of intrinsic information as specific and contextually independent.

Figure 2 illustrates the lack of contextual information quality when the drawings are removed from the sequence in which the student presented them and grouped according to design presentation and technical submission drawings.

The presented work omits background elements such as the synthesis of the brief, project requirements, and design development. Contextual information is essential for interpreting specific details; however, the project lacks sufficient contextual information, including design concepts and strategies. Students used Autodesk Revit® 2022 to enhance representational information, effectively communicating the architectural exterior.

Table 6 indicates the extent to which students meet information quality criteria adapted from Mai [26] in terms of mean scores (MSs) ranging between 1.00 and 5.00, based on the percentage response across a scale of poor to advanced performance. It is notable that three out of four (75.0%) of the mean scores are above the midpoint score of 3.00, indicating that, overall, the students meet the expected threshold concerning the quality of information. However, 'content completion' is below the midpoint of 3.00 at 2.64; therefore, students do not meet the expected information quality threshold for completion. It is further noteworthy that two out of four (50%) of the mean scores are $>3.40 \leq 4.20$; thus, the extent of meeting the information quality criteria can be deemed to fall between meeting expectations and

confident performance. 'Formatting' predominates with a mean score of 4.43, followed by 'content accuracy', 'professional documentation', and 'content completion'.



Figure 1. Presentation of the final project presented by Student 4, 2022 cohort.



Figure 2. Student 4's drawings have been reordered according to the two stages: presentation drawings and technical drawings.

Table 6. Summary of drawing communication quality based on the projects submitted by the 2022 cohort.

Information Quality	Response (%)					Mean Scores	Rank
	Poor				Advanced		
	1	2	3	4	5		
Formatting (Representational)	0.0	0.0	21.4	14.3	64.3	4.43	1
Content accuracy (Intrinsic)	7.1	0.0	21.4	42.9	28.6	3.86	2
Professional documentation (Accessible)	0.0	14.3	28.6	21.4	35.7	3.79	3
Content completion (contextual)	14.3	21.4	50.0	14.3	0.0	2.64	4

Unlike the isolated approach of the 2022 cohort, the BIM methodology adopted by the 2023 cohort supported a more holistic approach to project development. Information quality was assessed across the intrinsic, contextual, representational, and accessible dimensions. The information generated in both the holistic project and individual drawings was accurate, objective, credible, complete, and trustworthy. Consequently, information quality was transparent, comprehensive, coherent, and timely, supported by continuous team dialogue [26]. Students progressed through each project stage, producing information aligned with the intrinsic, contextual, representational, and accessible dimensions of information quality. Each stage provided contextual information for subsequent phases, as depicted in Figure 3.

Table 7 indicates the extent to which students meet the information quality criteria adapted from Mai [26] in terms of mean scores (MSs) ranging between 1.00 and 5.00 based on the percentage responses to a scale of "poor" to "advanced". It is notable that all five (5/5; 100.0%) mean scores are above the midpoint score of 3.00, which indicates that, in general, the students meet the expected threshold concerning the quality of information. However, it is also notable that all five (5/5; 100%) mean scores fall within the range > 4.20 $\leq$ 5.00, and thus the extent of meeting the information quality can be deemed to range from "confident" to "advanced". 'Formatting' predominates with a mean score of 5.00, followed by 'collaboration', 'professional documentation' and 'content completion'.

Table 7. Summary of drawing communication quality based on the projects submitted by the 2023 cohort.

Information Quality	Response (%)					Mean Score	Rank
	Poor				Advanced		
	1	2	3	4	5		
Formatting (Representation)	0.0	0.0	0.0	0.0	100.0	5.00	1
Collaboration	0.0	0.0	0.0	0.0	100.0	5.00	2
Professional documentation (Accessible)	0.0	0.0	0.0	42.9	57.1	4.57	3
Content accuracy (Intrinsic)	0.0	0.0	7.1	35.7	57.1	4.50	4
Content completion (contextual)	0.0	0.0	0.0	21.4	71.4	4.43	5

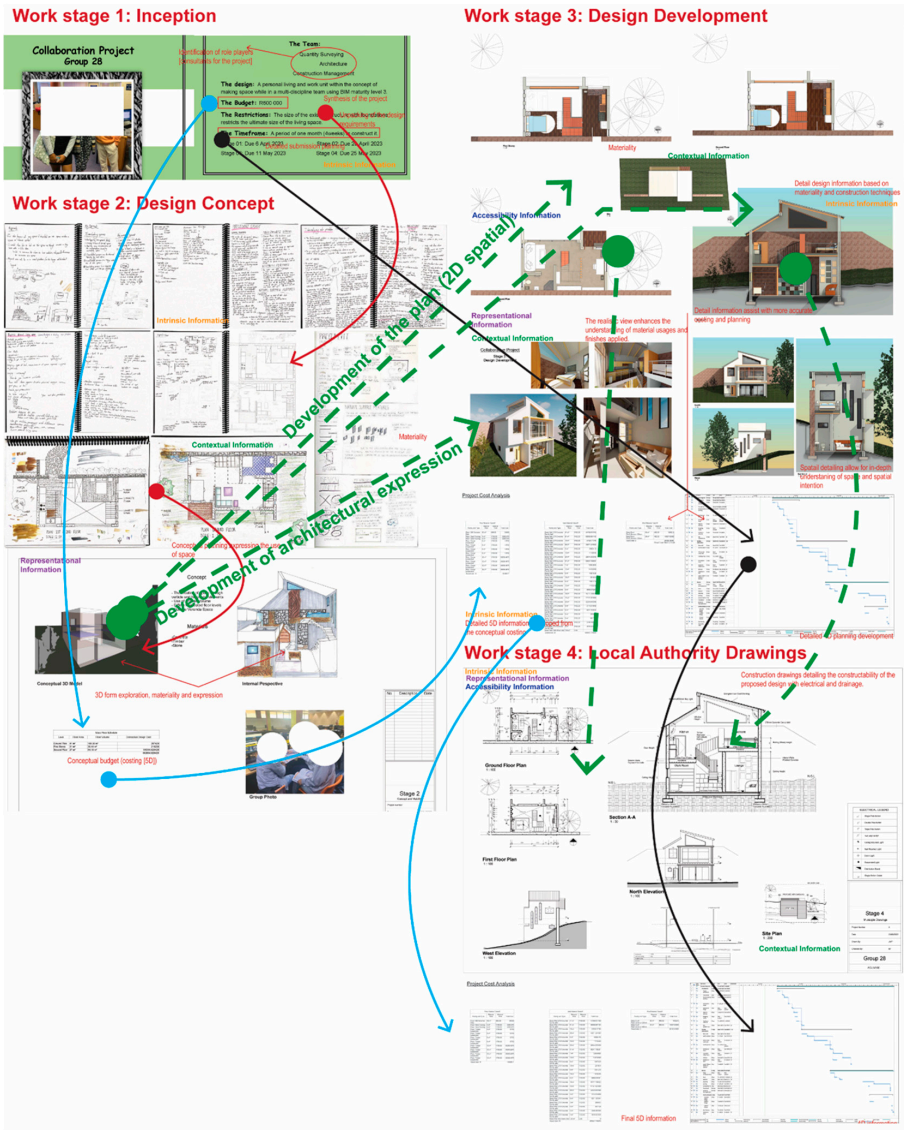


Figure 3. The holistic development of information is evident in the project produced by Student B, 2023 cohort. The blue arrow indicates the input from the quantity surveying student throughout the project where the black arrows indicate the construction manager student's input. The green arrows show the continues development of the project between the stages.

The 2022 cohort, who produced isolated information in their drawings, also produced essays that lacked contextual, representational, and accessible information. Compared to the 2023 cohort, intrinsic, contextual, representational, and accessible information quality are evident in their writing and drawings, as indicated in Table 8. All projects were evaluated using the same assessment rubric and marking criteria applied across both cohorts by the same lecturer, thereby reducing evaluator variability and enhancing assessment consistency.

Table 8. Grading criteria comparison.

Grading Criteria		Cohort 2022	Cohort 2023
Professional Documentation	Accessible information quality	3.79	4.57
Content Completion	Contextual information quality	2.64	4.43
Content accuracy	Intrinsic information quality	3.86	4.50
Formatting	Representational information quality	4.43	5.00
Collaboration		N/A	5.00

The comparative information quality results indicate that BIM Level 3 influences not only representational but also contextual coherence and accessibility of project outputs.

7. Discussion

This discussion examines how communication within the BIM collaboration framework supports the development of critical thinking in interdisciplinary built environment education. The themes come from our analysis and address issues in the literature, such as siloed practice, fragmented information, and reduced creativity in digital workflows.

7.1. Linguistic Arts and Criticality

Communication action recognises that language conveys information and has meaning, distinguishing communication acts from mere behaviour [9]. Therefore, linguistic acts can be examined through observable characteristics such as frequency, content, and quality [25]. Davies and Bennet [27] defined criticality as the ability to demonstrate critical action, reasoning, and self-reflection, and therefore, a critical person is grounded in dialogue and praxis [27]. This study did not measure those dimensions directly but interpreted communication patterns as conditions that may enable or constrain these dimensions.

The 2022 cohort engages in weekly critique sessions using the traditional design process, where students (all architecture students) and lecturers (architectural staff members in the department) are familiar with each other. The 2023 cohort, using the BIM process and unfamiliar with one another at the start of the project, demonstrated more frequent communicative engagement at the start of the project and again at moments when problem-solving was required. This pattern aligns with Marlow et al. [25], who noted that in unfamiliar teams, there is a stronger sense of frequency of initial communication as the roles and project expectations are negotiated. Frequent communication allowed the BIM cohort to engage in more opportunities to analyse arguments, evaluate information, examine the basis of assumptions, and consider contradictory evidence, which supports the development of critical reasoning skills and effective communication. This, in turn, supports more effective communication. The 2023 cohort reflections demonstrated more relational communication compared to the 2022 cohort, which reflected predominantly task-related communication activities. The literature suggests that relational communication supports shared meaning-making and collective problem-solving, which promotes critical action in communication [30]. Critical action enables students to be aware of those around them and to implement change through critical consciousness and action. The data indicated that communication frequency, content and quality impact students' ability to apply critical reasoning, self-reflection and actionable skills. The data suggests that more frequent communication promotes students' ability to practice critical reasoning, including task-oriented and relational content, thereby increasing critical self-reflection, improving information quality and strengthening critical action skills.

Collectively, the findings suggest that structuring linguistic acts through a BIM Level 3 collaboration framework results in communication that is more distributed, multimodal, and integrative. These conditions appear to support reasoning, reflection, and action associated with critical educational practice. However, the results indicate an association rather than definitive evidence of transformation.

7.2. Holistic Versus Isolated Information

Mai [26] describes information quality as comprising intrinsic, contextual, representational and accessibility dimensions. Intrinsic information focuses on the accuracy and credibility of information, while contextual and representational quality concern how the information is presented, organised, and understood within a broader picture.

There is a clear difference between the two groups. The BIM cohort (2023) developed design project information in a more integrated manner, with cross-references across different drawing information. This resulted in clear contextual and accessible information qualities in their work.

In comparison, the 2022 cohort had design projects that were accurate and technically sound, but the information within the drawing sets was fragmented and isolated. The information was page-specific and not linked across different work stages. This resulted in submissions that demonstrated strong intrinsic quality but limited contextual integration. The data support the findings of Zhao et al. [7] and Muse et al. [31] that BIM has the potential to enable interdisciplinary collaboration, deliver transparent projects, increase productivity, and improve the overall quality of information. Therefore, BIM supports a process-driven approach, unlike the product-driven approach evident in the traditional, discipline-based studio as used by the 2022 cohort. The findings above support Eastman et al. [6] and MacDonald and Mills [20], who state that the traditional design process is an individualised, siloed model in which knowledge becomes fragmented and lacks holistic integration, making it error-prone, costly, delay-inducing, and prone to friction within team settings.

Generation Z is digitally connected to a world of information at their fingertips, which they can quickly access. However, because information is readily accessible, students may be inclined to procrastinate and allocate insufficient time to examine the content critically [32]. Both cohorts used Autodesk's Revit® (2022 and 2023) software, which supports BIM. The difference between the cohorts using the same software (tool) lies in the processes they followed. The BIM Level 3 Framework required teams to work together, coordinate tasks and coordination points, and assume roles that depend on one another. The 2023 cohort structured their projects effectively with information that cross-referenced drawings. The 2022 cohort lacked structure and submitted incomplete work, presenting overwhelming information that they struggled to process and present.

From a pedagogical perspective, the difference between focusing on the process and focusing on the product is important. When collaboration is built into the workflow, information develops in a more systematic and context-aware way. This means that structured BIM education can help support integrated information practices in undergraduate AEC programmes.

7.3. Technology and Creative Engagement

Researchers and professionals in the built environment have closely examined the influence of information technology on problem-solving within the framework of Industry 4.0. BIM has received criticism regarding its potential to automate decision-making or limit traditional design workflows. Both cohorts in this study used Autodesk Revit® (2022 and 2023) to create architectural drawings, which include both 2D and 3D representations. Both cohorts demonstrated strong technical skills and high-quality information in their work. The primary distinction between the cohorts lay in process integration rather than software proficiency. The 2022 group used a workflow specific to their discipline. The 2023 group worked within a structured BIM Level 3 Framework, which involved shared modelling, systematic coordination and checking work across different disciplines. The 2022 cohort lacked contextual and accessible information quality, whereas the 2023 cohort exhibited a higher level of both in their projects. Both groups successfully produced representational and intrinsic information. Information technology plays a significant role in shaping how students generate, access, and interact with information in digital environments. Critical thinking and the ability to evaluate the validity of information are essential in this interconnected context.

These findings indicate that digital tools alone do not determine the depth of students' creative or critical engagement. Instead, it is the pedagogical approach to technology that

influences how students synthesise, verify, apply and communicate information. In the context of BIM, the framework allowed students to collaborate, evaluate, and communicate their ideas rather than serving as a platform for automating problem-solving. Creativity in BIM-based education appears to depend more on the extent to which students are encouraged to engage critically with shared information than on mere access to the software.

8. Conclusions

This study examined how a seven-step BIM Level 3 collaboration framework influenced an architectural design project in an undergraduate interdisciplinary AEC setting. By comparing two cohorts (2022 and 2023) of students who had the same design brief, assessment criteria, supervision, and institutional conditions, the study identified the BIM collaboration framework as the main teaching difference using a theory-informed analytical lens grounded in communicative action. The 2022 cohort used the traditional, discipline-specific, siloed approach, whereas the 2023 cohort used the proposed BIM Level 3 Framework, which focused on interdisciplinary collaboration. Findings demonstrated that the structured BIM Level 3 framework implementation influenced communication patterns across the dimensions of communication frequency, content and quality. Through more strategically clustered communication and making use of more digital platforms, the BIM cohort (2023) used a combination of task-related and relationally oriented communications and demonstrated design projects and self-reflection narratives that showcased more contextual, representational, and accessible information communication. The 2022 cohort demonstrated primarily intrinsic information quality in their communications, with limited contextual integration across design stages.

Importantly, the findings indicate that using BIM software alone does not automatically improve collaboration or criticality (critical reasoning, self-reflection and action). Therefore, when BIM is used within a structured framework where roles are clearly defined, communication responsibilities are easily understandable, and students then move from a simple exchange of information to meaningful coordination. In this study, communication was used as a measurable evaluation tool to support learning, thereby positioning it as a central mechanism for interdisciplinary collaboration rather than an isolated learning outcome.

By operationalising communication frequency, content, and information quality within a Level 3 collaborative setting, this research extends existing BIM education frameworks beyond competency mapping and curriculum alignment toward empirically examined collaborative dynamics. In a developmental undergraduate context, the results demonstrate that structured digital interdisciplinary collaboration can support students both technically and in communication, contributing to teamwork, transparency, and the sharing of information.

9. Future Studies

Future research should examine whether this framework is applicable across different institutions and educational levels, especially where resources and disciplines vary, and should also include the seven-step Framework in the assessed curriculum. Long-term studies could also investigate whether structured BIM Level 3 collaboration influences graduates' professional communication and collaborative practices.

Future research into measurable approaches for tracking communication in digital design could improve how we assess students and help integrate communication skills within BIM education globally.

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Abbreviations

The following abbreviations are used in this manuscript:

BIM	Building Information Modelling
AEC	Architecture, Engineering and Construction
CAD	Computer-Aided Design

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