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Abstract

Purpose: Building Information Modelling (BIM) is an innovative, collaborative process underpinned by digital technologies introduced to improve project performance in the Architecture, Engineering and Construction (AEC) sector. Growth in industry demands has necessitated BIM inclusion into the Higher Education (HE) curricula as both a pedagogic and practical objective to prepare and develop aspiring Built Environment (BE) professionals with the required competence for contemporary practice. However, comprehension of BIM concepts and subsequent development of the skill set required for its application remains overwhelming for students. In mitigating this challenge, adopting appropriate learner-centred strategies has been advocated. Problem-based Learning (PBL) is becoming a widespread strategy to address concerns associated with authentic practices.

Design/Methodology/approach: This paper evaluates the impact of the PBL strategy on students' accelerated learning of BIM based on a case study of 53 undergraduate students in a BIM module. The network analysis and centrality measures were employed in understudying the most applicable BIM skills.

Findings: From the analyses, PBL benefits students' knowledge acquisition (cognitive and affective) of BIM concept and development of transferable skills (academic and disciplinary), equipping them with capabilities to become BIM competent and workplace ready for the AEC industry.

Originality/Value: The BIM pedagogy evolves, and new skillsets emerge. Analytical, communications and collaboration skills remain sacrosanct to delivering BIM modules. These skills mentioned above are essential in getting undergraduate students ready to apply for BIM in the AEC sector.

Keywords: Building Information Modelling, Built environment undergraduate students, Problem-based learning, Sparse Network analysis

1.0 Introduction

Building Information Modelling (BIM) is an innovative, collaborative process underpinned by digital technologies which unlock more efficient methods of designing, creating and maintaining built assets (Blackwell, 2012; Eastman et al., 2012). It was introduced in the Architecture, Engineering and Construction (AEC) industry to improve project performance and encompasses a wide range of concepts, tools and workflows employed to create and manage all information on a project – throughout the project lifecycle (Succar et al., 2012). Past and recent construction literature (Farmer, 2016; Olatunji, 2018) continues to elucidate its relevance in the construction industry, arguing that the construction business (of the future) must either adopt (or adapt to) BIM (today) or die. Therefore, providers of construction education such as Higher education institutions need to ensure that potential graduates in the BE discipline are trained to develop the required skills and competencies to become BIM-ready graduates. Yu et al. (2014) espoused that potential BIM-ready graduates must be able to work and share value across multidisciplinary teams and various stages of the project life cycle.

Furthermore, the increasing demand for BIM education demonstrates the need for graduates to possess effective communication, creative, analytical, and problem-solving skills alongside competency in using appropriate BIM tools (Akanmu et al., 2016; Olatunji, 2018). BIM inclusion into the BE curricula is a pedagogic and practical objective to develop and prepare future BE professionals for contemporary industry practice. Underpinned by authentic practice, it encourages learning strategies to thrive in a multidisciplinary environment (Luo and Wu, 2015). However, introducing BIM into traditional pedagogies is not precisely straightforward because there are no definitive universal models (Olatunji, 2018). Some educators still struggle to understand how to teach the concept of BIM to undergraduate students (Sacks and Pikas, 2013; Wong et al., 2011). The lecture-based strategy seems to be the most predominant model for teaching BIM in many Higher Education Institutions (HEI), particularly in the early years of study. This pedagogy model with linear and fragmented teaching presentations has been criticised for depriving students of the opportunities to learn the holistic nature of a discipline. Hence, inefficient to assist students in developing the prerequisites for professional expertise (Chinowsky et al., 2006; Forsythe et al., 2013). Models of teaching strategies such as the Learning pyramid model have further highlighted the “practice by doing” teaching strategies such as problem-based learning, project-based learning, and experiential learning as the most effective in promoting students’ retention rate (Macdonald, 2012; Yildirim et al., 2014). Therefore, integrating the “practice by doing” strategy in delivering BIM modules can improve students’ learning curves.

Despite the novelty of BIM as a tool in the AEC industry, there is no known study that proposes the synthesis of problem-based learning (PBL) strategy and network analysis approach that could effectively enhance the competencies of undergraduate students, particularly those in the built environment, which is a major gap that this study seeks to fill. In understanding this strategy’s contribution to students’ development, this study explores the impact of the PBL strategy on undergraduate students’ learning of BIM. It explores both tutor and student perspectives to evaluate the capability and benefits of PBL in improving student learning and the development of BIM-based competencies at the undergraduate level. It describes the procedure, experience, and benefits of employing PBL to deliver an undergraduate BIM module. The paper concludes by identifying the effects of PBL on students’ cognitive and soft skills development which are relevant in preparing them to become BIM-ready graduates. The results and findings of this research are expected to shed more light on innovative teaching strategies for BIM curriculum delivery.

2.0 BIM Education Framework

BIM Education is considered a viable and sustainable approach to producing graduates equipped with the relevant knowledge and skillset required to generate BIM deliverables that satisfy defined project requirements (Succar et al., 2012). Globally, BIM Education is gaining wide acceptance and recognition in HEI. For example, in most universities, BIM is taught mostly at the postgraduate level (Kocaturk and Kiviniemi, 2013; Mandhar and Mandhar, 2013) while gradually gaining ground for inclusion in the undergraduate curriculum (Sanchez et al., 2019). Many attempts have developed frameworks for successfully integrating BIM into HE curricula across the AEC disciplines. The BIM Academic Forum (BAF) learning outcome framework (Underwood et al., 2015), the most referred to in the UK, outlines expected learning outcomes for teaching BIM at the various level of HE study (see Table 1).

Insert Table 1 here

The framework highlights three main development sections: knowledge and understanding, practical and transferable skills. It is required that undergraduate students develop an understanding of the concept of BIM and its relevance to various disciplines in the built environment. The application of BIM tools and the importance of collaboration and multidisciplinary collaborative working are some of the key practical and transferable skills that potential BIM-ready graduates should develop. However, the content and strategy for delivering and developing these required cognitive skills are unclear (Kocaturk and Kiviniemi, 2013). This vagueness posed unique challenges in BIM pedagogy (Boton et al., 2018), especially to BE students who question BIM's relevance to their disciplinary roles (Leite, 2016). Consequently, studies by Shelbourn et al. (2017), and Barison et al. (2013) on BIM education, have highlighted the need to adopt appropriate pedagogical practices for teaching BIM. They all share the ideology of Koltich and Dean (1999 cited in Shelbourn et al., 2017) on the engaged critical model of teaching rather than the transmission model in BIM pedagogy. They argued that the engaged critical model allows students to better understand a subject/topic by engaging in what is studied. This engaged critical model promotes teaching methods such as problem-based learning. This finding corroborates the Learning pyramid model. In practice, young professionals need to possess the ability to analyse problems and provide potential solutions to them without losing sight of the whole picture (Yew and Goh, 2016). Therefore, BIM educators must adopt practice-by-doing teaching strategies. This study evaluates the impact and benefits of one of such strategies, PBL, in delivering BIM modules to enhance students learning of BIM concepts and development of practical and transferable skills at the required level.

3.0 Problem-based Learning

PBL is an approach to professional education that emphasises real-life problems as a stimulus for teaching and learning, bridging the gap between academia and practice (Smith, 2005). PBL is a model for a classroom activity that shifts away from teacher-centered instruction to student-centered projects and promotes a learning environment where the problem drives the learning (Klegeris and Hurren, 2011). It employs collaborative peer group work and problem-solving as a vital tool for critical thinking and self-directed learning in a scenario that reflects real-life situational settings (Loyens et al., 2015; Fukuzawa and Boyd, 2016). PBL, unlike other students, does not define the expected outcomes of an investigation but promotes the learner's role in setting the goals and solutions for the set problem. Several studies have employed PBL to deliver modules in Civil Engineering, Construction Management, and Architecture disciplines (Bridges, 2007; Ahern, 2010; Jefferies et al., 2012; Yildirim et al., 2014). However, narratives on its use in teaching BIM modules, especially in BE disciplines, is rare. Defining the problem and developing a range of possible solutions is important in a real-world context. Many undergraduate BE students undertaking a BIM module are not familiar with BIM. Hence, rather than imposing the knowledge, it would be effective to allow them to inquire into the cause of a problem and what could be the potential solutions. After that, the proposed solutions are discussed and linked with the purpose and benefit of BIM. The specific feature of the PBL displays its appropriateness for teaching introductory courses or levels where acquisition and not application-based knowledge is required. Given that introductory modules are acquisition centric, the PBL appears most appropriate to support introductory modules on BIM learning outcomes aligned to the BIM education framework at the required undergraduate level.

Scholars from different disciplines have highlighted the benefits of PBL to both the students and teachers. According to Steinemann (2003), PBL's approach focuses on solving problems and makes knowledge and information more accessible and applicable to students. Students can develop skills useful in solving real-world and practical issues. Unlike the conventional teaching approach, which involves transmitting information and knowledge from the teacher to students, PBL provides problem-solving opportunities that improve their learning and thinking skills and cognitive abilities (Smith et al., 1995). This view aligns with Ertmer et al. (2000) and Weyer's (2006) assertion that with PBL, students can acquire problem-solving skills through in-depth evaluation of situations instead of looking at them from just the surface. The Genuity and relevance of the PBL approach foster higher comprehension levels and skills development in students than in the conventional approach, which is perceived to impair students' ability to use their natural problem-solving skills (Albanese and Mitchell, 1993). Arguably, PBL facilitates knowledge development through a practical or hands-on approach to learning.

Likewise, Finucane et al. (1998) asserted that PBL aligns and agrees with modern learning theory by fostering students' active participation in their learning. Unlike tutors providing information, students are tasked with identifying what information to analyse to provide a solution to a given task. This aligns with Pawson et al. (2006) assertion that PBL promotes a student-centred approach to learning, which encourages greater understanding and helps students to acquire and retain knowledge. Steinemann (2003) added that PBL allows students to explore different sources in evaluating and making meaning of available information. While active student participation is considered essential to the PBL approach, scholars argue that students' active participation in their learning will further result in their ability to collaborate with other students (Beaumont et al., 2014). According to Hmelo-Silver and Eberbach (2012), collaboration is one of the several essential features of PBL in achieving desired learning goals.

Also, scholars have shown that PBL fosters students' interest in their learning by creating an avenue for student motivation in learning and solving problems. For example, Steinemann (2003) observed that students show interest in activities they can relate to personally or have societal relevance to their learning. Also, Klegeris and Hurren (2011) and Ertmer et al. (2009) reported that PBL fosters student engagement and increases their overall motivation toward learning. PBL grants students ownership status over their learning. In line with these views, El-adaway et al. (2015) assert that PBL inspires students to commit to continuous self-improvement while contributing to their learning development. Tiwari et al. (2017) stated that "PBL motivates students to connect with content areas text while increasing their knowledge of a topic".

Furthermore, PBL equips students with the appropriate knowledge. PBL focuses on facilitating learning by solving real-world problems in a classroom environment (Barrows, 2009). Besides, PBL allows students with a poor academic background to properly understand what is expected of them (Machika, 2014), given that PBL fosters an in-depth approach to learning. With PBL, teachers can create a closer relationship with their students (Enger et al., 2002). Also, teachers are relieved from the stress of providing students with information instead of serving as facilitators of a problem-solving process (Allen et al., 2011). Hence, students can ask one to one questions while contesting the existing knowledge, clarifying their understanding and making meaning of the problem (Machika, 2014). These views are consistent with Caesar et al. (2016) argument that PBL produces a practical learning experience through an appealing structure for teaching and learning.

The PBL procedure involves the tutor acting as a facilitator of the learning process, stimulating group discussions and monitoring the students' level of engagement in the groups (Klegeris and Hurren, 2011; Pastirik, 2006). The process empowers learners to conduct a constructive investigation, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem (Savery, 2006; Yildirim et al., 2014). Consequently, students' cognitive elaboration, critical thinking, and collaborative skills are developed. The remaining sections detail how PBL was integrated into the delivery of an undergraduate BIM module and its impacts on students' knowledge and skills development at the level required.

Table 2 depicts an overview and summary of relevant research on BIM and learning in HEI.

Insert Table 2 here

4.0 Research Methodology

This study is concerned with gaining a context-dependent understanding of how PBL can facilitate students' BIM knowledge and skill development at the required level. A case study of BE undergraduate students studying a BIM module at a university in the United Kingdom was investigated. Yin (2017) and Thomas (2011) maintained that a case study allows an empirical inquiry on a contemporary phenomenon within some real-life context to develop analytical generalisations. The underlying assumption is that PBL can accelerate BIM learning in the HE context. That reality (within this context) can be constructed by examining the performances and perceptions of undergraduate BE students enrolled on a BIM module. This paper leans towards pragmatism from a philosophical worldview perspective, aiming to contribute viable solutions to problems that can inform future practice (Saunders et al., 2019). This research was conducted in two phases. The first stage involved exploring the potency of PBL to engender the development of student knowledge and skill development of BIM based on the tutor's observations, formative reviews and assessment of student's summative performances. The second stage is to articulate students' perspectives on the impact of PBL on developing BIM competencies (Knowledge and understanding, including the development of practical and transferable skills) at the level required. Questionnaires were employed in this regard to gathering students' perceptions. This approach provided additional surety on the findings secured from stage one.

The data collected from the questionnaires were first analysed through descriptive statistics. Further analysis for validation purposes employed the spare network and centrality of measures analysis. According to Nykamp (2020), a network is a collage of nodes or vertices connected with edges or links. When the sizes of the edges are weighted in a matrix, it is denoted by thicker lines (Nykamp, 2020). Network diagrams mimic Synaptics in a brain and illustrate the strength of relationships between nodes. The centrality of measures addressed the density of the BIM competencies in terms of their betweenness, closeness and strength. The findings of the descriptive statistics, sparse network and centrality of measures were discussed for their implications on enhancing the BE students' BIM competencies at the level required.

4.1 BIM Module

This BIM module was designed to introduce students to the theory and practice of BIM. This undergraduate BIM module was integrated into the BE curricula in 2016 for Higher National Certificate (HNC), Higher National Diploma (HND) and Level four BSc undergraduate students in construction management, quantity surveying, building surveying and property management. The multidisciplinary environment and the co-location of these disciplines allow optimisation of multidisciplinary teaching and engagement, requiring group collaboration to achieve learning outcomes (Glanz et al., 2016; Wu and Luo, 2015). The module delivery was divided into Cohort 1 (HNC and HND) and Cohort 2 (BSc undergraduate students).

Consistent with the BIM Academic forum learning outcomes framework (2015), students are expected to be able to achieve the following by undertaking this BIM module:

- (L1) Demonstrate an understanding of the concept of BIM and highlight commonly used tools
- (L2) Understand the benefits of BIM for construction professionals in a multidisciplinary construction project environment
- (L3) Apply BIM tools for effective cost and schedule management
- (L4) Demonstrate improved analytical, communication, and collaborative skills relevant to working in a BIM project environment.

The topics cover the concept of BIM, process, standards, dimensions, levels, tools and key stakeholders. The learning outcomes were assessed in two parts. One part of the assessment focused on applying BIM tools. The other was a 1500 word count technical report demonstrating an understanding of the concept and benefit of BIM to professional practice and project outcomes in the AEC industry.

Initially, when the module was introduced, it was designed to be delivered using lectures, tutorials, and demonstration exercises. The following issues were identified through an evaluation of students' past performances, reports, and feedback on the module:

- The student understood BIM as software instead of a collaborative process,
- Students perceived no relevance of BIM to their professional discipline within the construction environment.
- Poor demonstration of analytical and collaborative skills which are relevant to working in a BIM project environment
- Students demonstrated an excellent understanding of the use of BIM tools.

Therefore re-strategising the approach to teaching and learning, especially to improve students' performance in L1, L2 and L4 of the module outcome, became evident. As a way of improvement, the PBL approach (based on its acclaimed benefits) was introduced as an instructional strategy to deliver those topics aligned to learning outcomes L1, L2 and L4 across 4 weeks alongside lectures. It was anticipated that integrating the PBL model would help address the inherent issues identified. To measure PBL's impact on students' knowledge and skill development of BIM in line with the learning outcomes, formative review (observations and presentations), technical report (summative assessment) and survey of students' opinions were summarised in Table 3.

Insert Table 3 here

4.2 PBL approach

The PBL integration into the teaching and learning cycle for the BIM module is conceptualised in Figure 1.

Insert Figure 1 here

Two PBL learning scenarios were developed to encompass topics aligned to learning outcomes L1, L2 and L4 of the BIM module. The scenarios included instances of traditional and BIM-enabled projects; each learning scenario took two weeks to complete. The PBL design included an in-class and off class interactive session. The in-class interactive session was designed as a 4-hour session. The tutor delivered a 40-minute lecture, 20-minute class discussion, 2.5-hour group activities, and 30 mins presentation of group progress to the tutor/class. The problem-solving out of class session is a 6 days window. Based on findings from their self-directed study, group members are required to initiate, contribute, and discuss their ideas with their group members via the module website discussion page in preparation for the next in-class meeting. The sample of the 4-hour in-class session is depicted in Table 3.

Insert Table 4 here

The problem scenarios were designed to be inclusive, relevant to all the disciplines and mirror real professional practice in a BIM project environment. The students were divided into sixteen groups, each of seven-member students and given autonomy to determine their own grounds rules and allocate member roles. Although each team was required to maintain a communication platform, which was only available to them, they were expected to upload their findings via the school's virtual teaching and learning platform, which should be updated weekly. This was set up to promote better documentation and information exchange management. The students were required to examine the scenarios, identify BIM tools, best/poor practices, process challenges, and benefits, and recommend possible solutions for future projects. The students had little or no knowledge of BIM, so we are encouraged to draw from their diversity and disciplinary knowledge in executing the task. Incorporating these multiple perspectives was used to inspire them to take ownership of their learning process. After the 4week PBL period, students were required to present their group findings to the tutors and class through a presentation and allowing for cross-examination of ideas. Students were judged based on their level of engagement, analysis, findings, recommendations, and collaborative and presentation skills.

Upon completing the module, 112 students enrolled on the module were contacted to participate in the survey. Questionnaires were administered face to face and via email to all the students contacted, comprising HNC, HND and Level Four BSc undergraduate students (construction management, quantity surveying, building surveying and property management). The questionnaires, in addition to observation and assessment of technical reports, were designed to investigate students' performances and gather the student's perceptions on the impact of PBL on their understanding of BIM as a collaborative process, the relevance of BIM to their professional discipline and interdisciplinary practices, the development of their analytical, communication and collaborative skills as necessary to operate in a BIM project environment. The questionnaire was designed to reflect the benefit of PBL in attaining the module learning outcomes aligned to the BAF, capturing knowledge and understanding, practical skills and transferable skills. A five-point Likert scale, ranging from "very high impact " to "no impact", was used in the design of the questionnaire. Before the study, ethical approval was sought and was granted by the University ethics board.

5.0 Result and discussion of findings

Students' understanding of BIM concepts, their relevance to their professional discipline and development of skill set (communication, collaboration and analytical skills) at the level required were measured using the assessment design detailed in Table 1. The results obtained are detailed in the following subsections.

5.1 Formative review

This theme assessed the communication and collaborative practices as individuals and as a team using the online data management and discussion platform created to arrive at the group results presented to the class. During the PBL process, students were involved in a series of discussions and brainstorming exercises in class and through online group chats, which gave room for constructive criticisms from both teams and interdisciplinary perspectives. These interdisciplinary and interactive features fostered team spirit within the groups, which was evident in their final presentation and reflections. Understanding the importance of collaborative skills is a key threshold concept underpinning BIM that the students could now readily embrace. Many corroborated that the style of teaching (PBL) was very interesting and engaging, which significantly helped me understand the relevance of BIM from a disciplinary and a construction industry perspective. Findings from this case validate previous findings (such as Klegeris and Hurren, 2011; Pastirik, 2006) on the benefits of PBL on the development of collaborative and communication skills espoused in previous studies.

5.2 Technical reports

The 1500 word count technical report submissions demonstrated high-performance competence in students understanding of the concept and benefit of BIM to professional practice and project outcomes in the AEC industry above the level required. The knowledge gained in the analysis of the PBL scenarios was captured in the technical reports, reflecting currency and extending understanding of BIM applicability. Module performance reports showed a 98 per cent pass rate and students' average performance above 80 per cent compared to previous years. This performance indicates that the level of engagement and delivery was much enriched using the PBL. These findings agree with previous studies (Klegeris and Hurren, 2011; Fukuzawa and Boyd, 2016; Loyens et al., 2015) on the benefits of PBL in the student learning process.

5.3 Survey

The researchers administered 109 questionnaires; 57 were completed and returned, accounting for a 51% per cent response rate. The frequency distribution of total respondents shows that 53% were BSc (Hons) students, 17% HND and 30% HNC students. As illustrated in Figure 2, findings also show that 65% of respondents were part-time students, and 35% were full-time students. Further analysis of their responses reveals that over 85 per cent of the students who responded to the survey agreed that PBL significantly impacted their learning process. PBL aids in improving their understanding of BIM and its relevance to professional disciplinary practices while improving their communication, analytical and collaborative skills relevant to prepare them to become BIM-ready graduates for practice.

Insert Figure 2 here

5.4 Sparse Network Analysis of the BIM competency variables

The network analysis in this study provided the interconnectivity between BIM pedagogy and their influence on degree classification, a network of five nodes bothering communication skills; analytical skills; collaboration skills; professional discipline; and understanding. The sparse network for the BSC and HNC qualifications is 0.20, and HND is 0.10. Sparse networks indicate fewer edges than the regular maximum edges in a network (Scholz, 2015). Consequently, the edges in BSC and HNC connote 20% of the regular network, and HND is 10%. The opposite of a sparse network is a dense network.

Nykamp (2020) also noted that the adjacency matrix is a matrix of ones and zeros. one indicates the presence of a connection. The non-zero edges in Table 5, BSC and HNC, have 8 edges providing a connection, while HND has 9 out of 10 possible edges.

Insert Table 5 here

The adjacent matrix has been prepared for each skill based on the respondent's intended qualifications. The red lines indicate that the negative weightings represent an inhibitory connection, and the positive weights are the excitatory association. This implied that there might be an impediment to effective BIM pedagogy when the skills with red lines are matched for BSc degrees.

In the BSc category, analytical skills show a weighted value of -0.839 when connected with communication (See Table 6). This negative value is indicated with the bold red line in figure 2. Communication is also strongly linked to professional discipline, with a value of -0.783. Understanding and collaboration have a weighting of -0.855. The positive relationship between the nodes can be found between communication and collaboration with a soft edge of 0.457.

Insert Table 6 here

The HNC students' development of analytical skills are positively associated with communication, understanding of BIM relevance to professional discipline and interdisciplinary practices, and collaboration with values of 0.664, 0.614, and 0.629, respectively. Hence, HNC students would develop more analytical skills and understand BIM's relevance to professional discipline and interdisciplinary practices, communication, and collaborative skills using PBL. Further, Figure 3 indicates a positive relationship between the skills mentioned above and the BSC network. This implies that a combination of the positive edges in Figure 4 will provide a stronger BIM pedagogy for HNC programmes in the BE.

Insert Figure 3 here

Insert Figure 4 here

Insert Figure 5 here

The HND network plot in Figure 5 also reiterates analytical skills as an important skill for learning and delivering BIM modules. The combination of analytical and understanding of BIM relevance to professional discipline practices weighs 0.8883. When analytical skills are combined with understanding, the weighting of -0.649 is produced. Thus, creating a negative relationship at this level of study. Communication and collaboration have a positive association of 0.663. According to the studies, analytical skills and understanding BIM relevance to professional discipline skills practices in HND qualifications are very important.

In the BSc, HNC and HND network plots, "analytical" has been highlighted in larger text, representing a key dependency for all other skills. The students feel that their analytical skills are enhanced with PBL to understand BIM. This is based on the needs of the respondents for BIM pedagogy. The sparse network has been used to identify the core skills for BIM pedagogy based on the direction of educational qualification. For an intense study into the abovementioned skills, the density of the pairwise plots can be derived through a centrality plot for each qualification.

5.5 Centrality measures of the BIM competencies

Centrality measures are common with social network analysis (Hafner-burton, Montgomery and College, 2010; Zhang and Luo, 2017; Gómez, 2019; Laura, Robert and Johanna, 2019). Depending on the balanced or generalised perspective, certain variables can be closer to other variables within a network (Zhang and Luo, 2017). Hence, there are betweenness, closeness and degree measures of centrality.

When analysing a variable's betweenness, the variable is central if its position in the network lies on the shortest path between many other variables. This shortest path is called the geodesic. In this measure, it is assumed that the variable prefers to make connections through the shortest pathway. According to Hefner-Burton and Montgomery (2010), the betweenness of variables in a centrality measure will be:

$$C'_B(n_i) = \frac{\sum_{j<k} g_{jk}(n_i)/g_{jk}}{[(g-1)(g-2)/2]} \quad (1)$$

F g is the number of nodes, g,j, and k is the number of geodesics linking actors j and k, and g,j, k(ni) is the number of geodesics that contain node I, then the betweenness centrality for node i.

In this analysis, BSc has improved in BIM understanding, collaboration, and communication skills with similar betweenness of 0.730. Analytical skills are the highest point with a betweenness measure of -1.0-95. HNC understands BIM's relevance to professional discipline practices and the BIM concept as the similar betweenness of 0.239. Analytical skills are the highest among HNC students, with a value of 1.434. HND also has analytical skills as the highest value in-betweenness with 1.565. Collaboration, understanding of BIM relevance to professional discipline practices, and understanding of BIM concept all have -0.671 each. Analytical skills are the most dominant competency developed across BSc, HNC, and HND programmes from the centrality measures.

In terms of closeness, the distance between the variables is considered. The distance between each variable to the main "actor" variable must have the shortest mean pathway for closeness to be measured (Hafner-burton, Montgomery and College, 2010; Gómez, 2019). In this analysis, analytical skills are the main actor, and the distance between other variables to analytical skills is measured.

According to Hafner-burton, Montgomery, and College (2010) and Gómez (2019), the closeness measure will have d(ni, NJ) as the number of edges in the geodesic linking actors i and j. The closeness of actor i is given as:

$$C_C(n_i) = \left[\sum_{i \neq j}^{g} d(n_i, n_j)\right]^{-1} \quad (2)$$

This formula can be normalised by multiplying it by the number of nodes in the graph other than node i:

$$C'_C(n_i) = (g-1)\left[\sum_{i \neq j}^{g} d(n_i, n_j)\right]^{-1} \quad (3)$$

From the centrality measures table and plot, under the BSc category, understanding BIM relevance to professional discipline practices has the highest closeness value to developing analytical skills. The value of 0.8626 indicates a strong closeness measure. In HNC, the development of analytical skills has a value of 1.434. The closest measure to the development of analytical skills understands BIM's relevance to professional discipline practices, with a value of 0.150. HND also indicates analytical skill as the main actor in this network with a value of 0.979, and the closest variable is the development of communication skills with a value of 0.727.

The degree of centrality is also known as the strength of the measures (Zhang and Luo, 2017; Laura, Robert and Johanna, 2019). This variable has the most links to other variables in a network. The measure's strength can be calculated by adding the number of direct links they possess. Hafner-burton, Montgomery and College (2010) noted that xij is the strength of the tie between actors i and j, and the strength centrality of the variable i is given as:

$$C_D(n_i) = \sum_j x_{ij} \tag{4}$$

The centrality tables (See Table 7) indicate a strength of 0.773 for communication under BSc, followed by analytical skills, having a value of 0.625. The negative value of -1.590 for collaboration connotes a strong weakness in this network. The HNC network indicates that analytical skill is the strongest variable in the network after having a value of 1.617. This assertion can be repeated for analytical skills in the HND programme BIM pathway. 1.117 was provided as a measure of strength for analytical skills. This is closely followed by communication with a value of 0.675.

Insert Table 7 here

Insert Figure 6 here

From the centrality measures shown in Table 7 and the plot in Figure 6, it can be deduced that all the students view the development of analytical skills as the central skill required to fully understand BIM modules. This finding is across the cohort and centrality measures. Analytical skill was deduced to have a very high impact in the bar chart in Figure 1. Consequently, the implications of analytical skills on delivering BIM concepts to built environment students in higher education will be discussed below.

6.0 Implication of findings

PBL has been used as a teaching method in health care (Owen, 2019), business management (Gidman and Mannix, 2019), and experimental approaches for dentistry (Azeem *et al.*, 2018) to improve the analytical skills of their students and this study confirms same for BE undergraduate BIM students. Analytical skills have been described as the ability to deal with problems in a deductive or inductive manner (Abazov, 2016). Analytical skills provide a methodological approach to solving problems. In associating analytical skills with BIM, Rahman et al. (2017) considered analytical skills the core skills BIM professionals must have, and analytical tools must be used to aid analytical skills. Built environment students in higher education may not have the emotional intelligence to break down problems into subsets for ideal decision-making, and years of experience may be required to develop analytical skills. BIM demands the use of technology as a tool for making decisions.

Therefore, the technical know-how and IT BIM capabilities depend on the analytical skills of the BIM expert (Aranda-Mena *et al.*, 2009; Rogers, Chong and Preece, 2015; Oduyemi, Okoroh and Fajana, 2017). In higher education, prior experience in problem-solving can aid students' development of deductive and inductive reasoning. Hence, problem-based learning must focus more on developing analytical skills in students through role-playing, case studies and site visits. BIM experts may support teaching as guest lecturers. New concepts such as BIM for deconstruction and 4D BIM (Magill *et al.*, 2020; Obi *et al.*, 2021) must be taught with the aim of developing analytical and technical skills. Guest lectures should provide examples of real-life problems encountered while using BIM. In developing the analytical skills of BIM students through problem-based learning, the tutor must carefully profile the student's prior knowledge. Create a learning set that should be less than 15 for effective student collaboration and permit instances for autonomous learning. Hence, students can develop analytical skills from their peers and learn to work alone. One way to develop the analytical skills of BIM students is the yearly placements before graduation. Placement opportunities for BIM students will provide an opportunity for the enshrinement of analytical skills through problem-solving. Finally, analytical skills must focus on applications of knowledge and transfer of knowledge. This implies that students with some analytical skills may be engaged in mentoring activities for other students.

Further interpretive case studies through problem-based learning role-playing may reveal how BIM students can develop their analytical skills to become BIM experts in higher education. Using machine learning tools such as an artificial neural network to analyse empirical large data set collected from BIM students in higher education may reveal the best teaching pattern.

7.0 Conclusion

Accelerating the learning curve to develop relevant knowledge, skills, and competencies required to operate successfully in a BIM project environment is essential to integrating HE curricula for BE disciplines. PBL is often advocated as an appropriate strategy in this regard. This study employed the PBL pedagogical principles and methodology to examine its impact on students learning of BIM and the development of the cognitive and required skill set relevant to function in a BIM project environment. The study creatively positioned the learning outcomes in alignment with the model assessment design. This research showed significant growth in students' knowledge and understanding (cognitive and affective) of BIM and practical and transferable skills (presentation, communication, and collaborative skills) at the required level compared to previous years. This study provided a timely example of the potential benefits of applying PBL in BIM modules to enhance student learning and skill development to function within a BIM project environment. The research findings have several implications for BIM educators in HEI to cultivate desired BIM competency (Knowledge and Skills) of the future BE graduates. The study will significantly benefit module leaders and course designers on BIM curriculum in HEI. Built environment students as stakeholders in HEI will gain from this approach if incorporated in their learning, thereby their competency in BIM can be enhanced. Future studies can seek to integrate PBL holistically in the delivery of the undergraduate BIM module to measure its effectiveness. Finally, it is recommended that future studies adapt the methodology as applied as a platform to investigate PBL benefits using a case study of postgraduate BIM modules.

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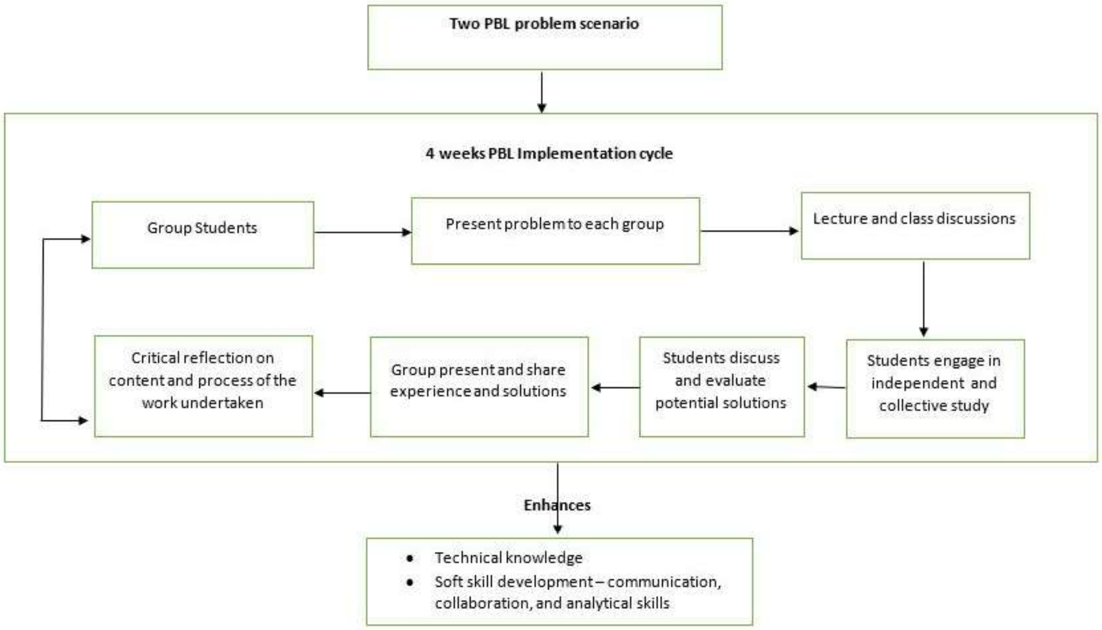

Figure 1: The PBL teaching and learning cycle

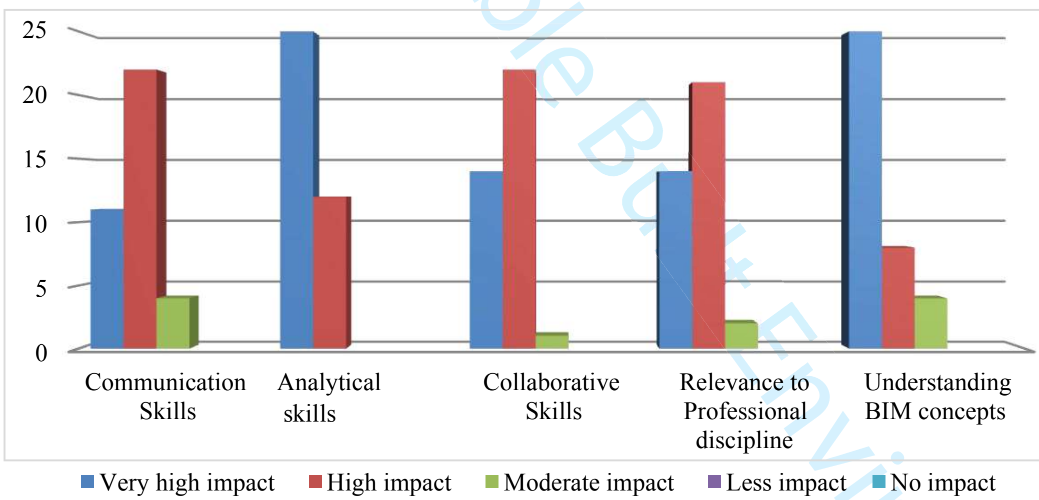

Figure 2: Results on the Impact of problem based learning on student learning curve

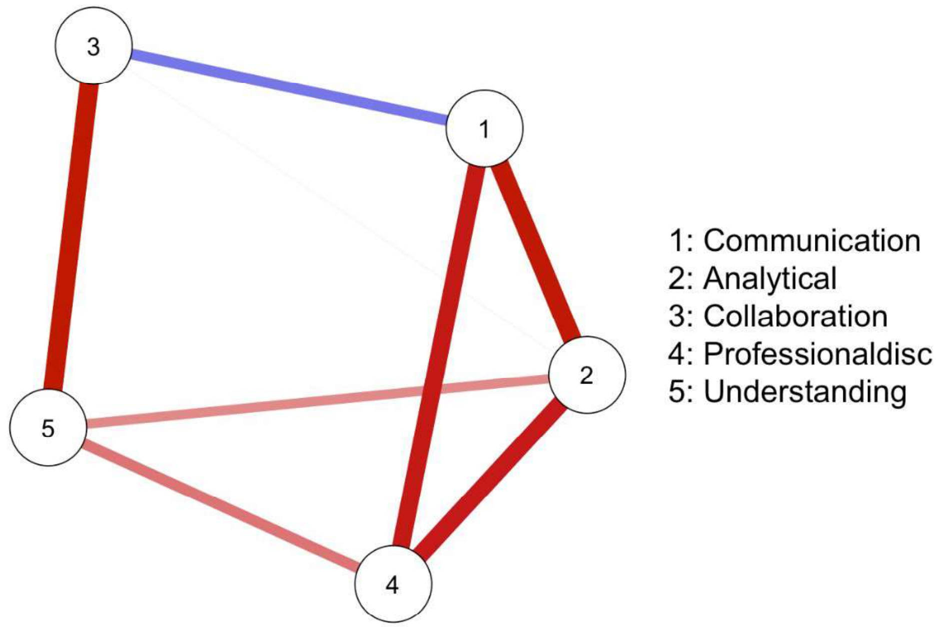

Figure 3: BSc network plot

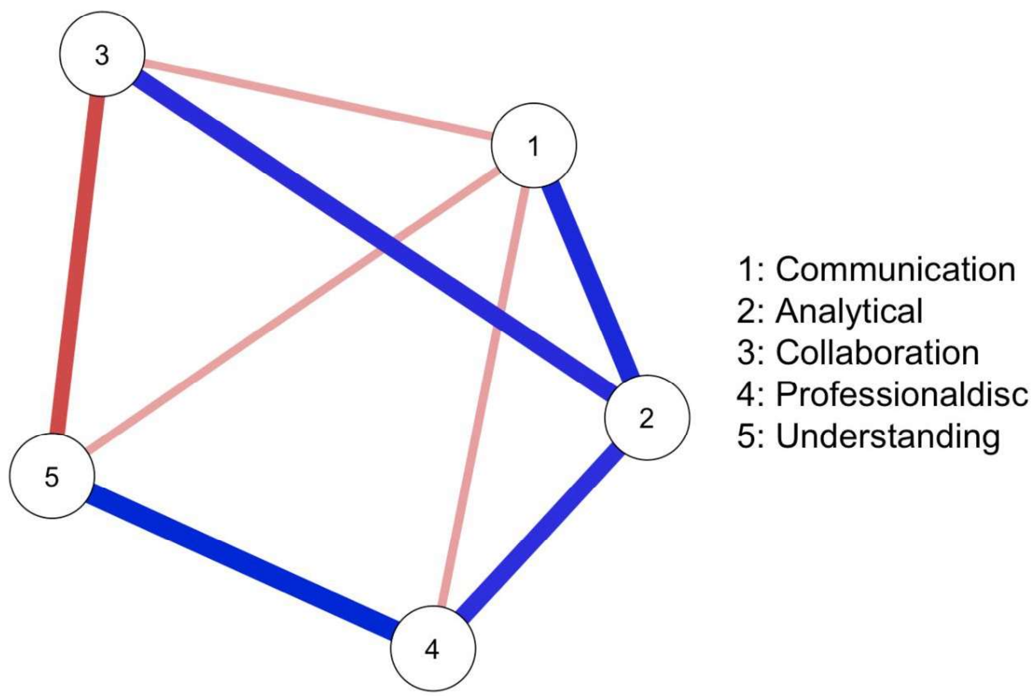

Figure 4: HNC network plot

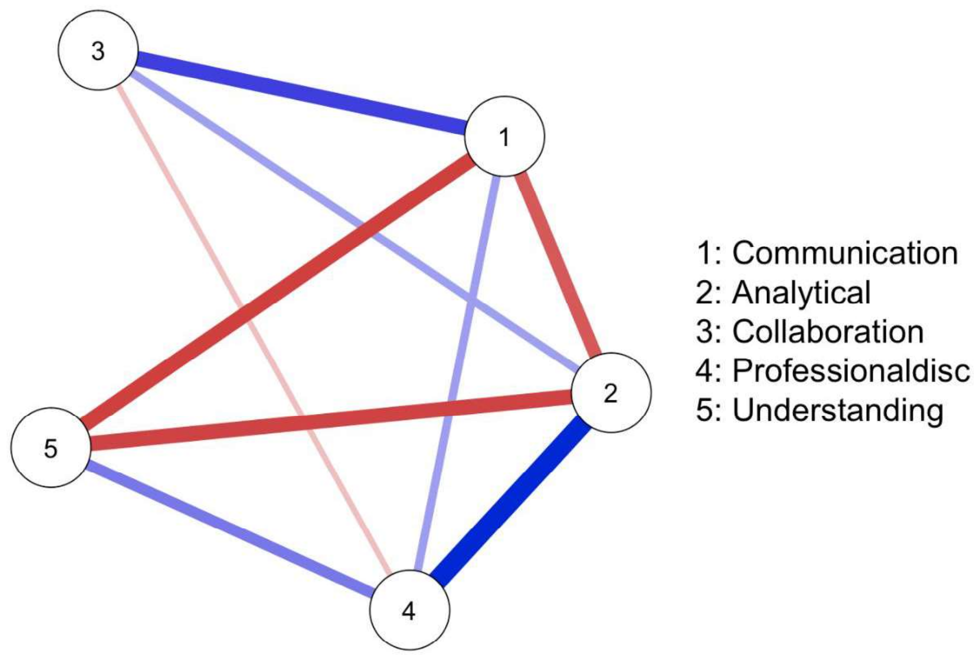

Figure 5: HND Network plot

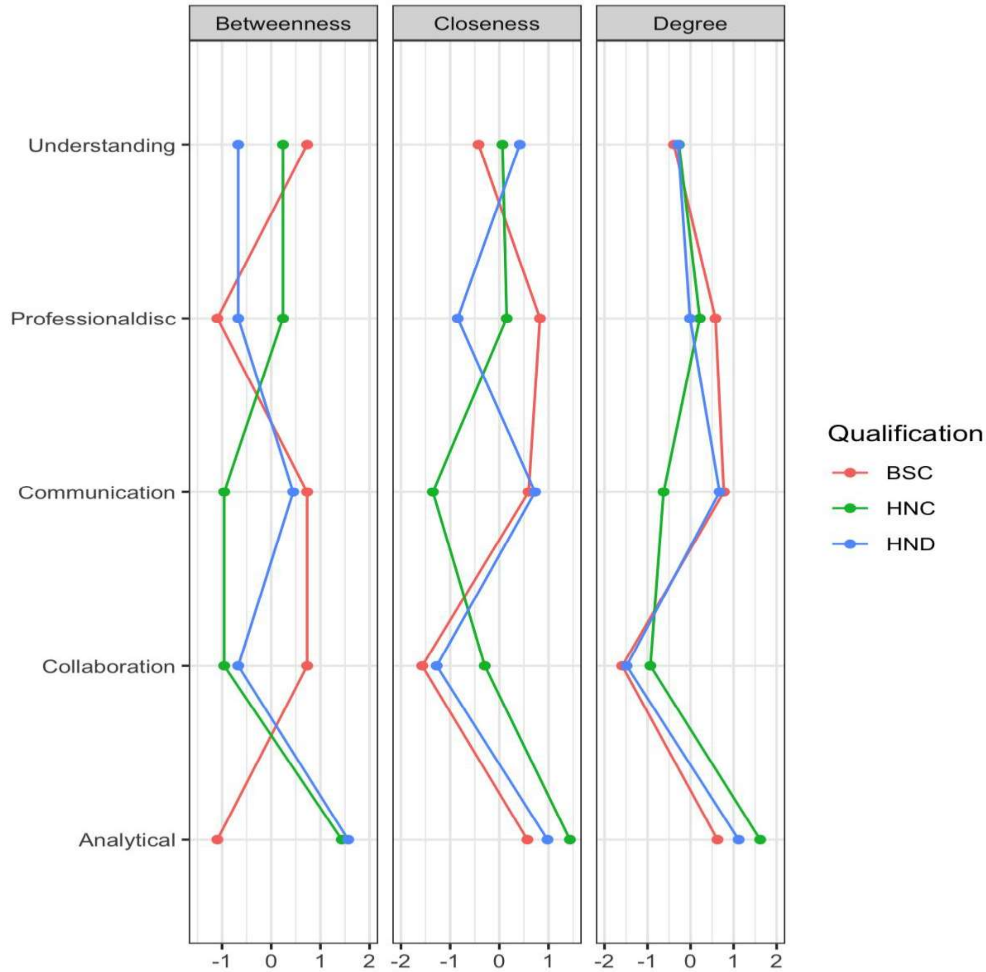

Figure 6: Centrality plot for BIM pedagogy

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Table 1: BIM Academic forum learning outcomes framework **Source:** Underwood et al. (2015)

LEVEL	Undergraduate			Post graduate
	4	5	6	7
Knowledge & understanding	• Importance of collaboration. • The business of BIM.	• BIM concepts – construction processes. • Stakeholders' business drivers. • Supply chain integration.	• BIM across the disciplines. • Contractual and legal frameworks/regulation. • People change management	• Collaborative working, BIM, information management and its application in the built environment. • Commercial implications – contractual/legal, etc. • De-risking projects through BIM and risk management. • Understanding nature of current industry practice. • Client value – soft landings. • Business value – RoI /value proposition. • Understanding supply chain management. • Lifecycle management of BIM – asset, performance in use, etc
Practical skills	• Introduction to technology used across disciplines.	• Use of visual representations. • BIM tools and applications. • Attributes of a BIM system.	• Technical know-how. • Structures and materials. • Sustainability.	• Demonstrate ability to adopt different platforms. • Critically judge/evaluate various BIM tools applications. • Protocols/interoperability/standards. • Capability evaluation. • Change in way projects are to be delivered. • Visualisation of large data sets. • Lean principles and links to BIM. • Use of BIM enabled technology, e.g. palm devices.
Transferable skills	• BIM as a process/ technology/people/poli cy.	• Value, lifecycle and sustainability. • 'Software-as-a-service' platforms for projects. • Collaborative working. • Communication within interdisciplinary teams.	• Process/management. • How to deliver projects using BIM. • Information and data flows. • BIM protocols/EIR.	• Project level application. • Cross discipline and team working. • Importance of effective communication and decision making – human interaction! • Process mapping and BPR. • Change management and cultural gap. • Masters level thinking – strategic/technical/ managerial. • Ability to assess barriers to BIM at various levels, e.g. corporate/project.

Table 2: Overview of research on BIM and learning in HEI

Embedding interdisciplinary learning into the first-year undergraduate curriculum: drivers and barriers in a cross-institutional enhancement project (Turner, Cotton, Morrison & Kneale (2022)	This paper reports on an enhancement project that sought to engage first-year students with interdisciplinary learning.
Applying Problem-Based Learning in a Building Information Modeling Course (Rahman, Ayer & London, 2019)	The study 15 proposes a structured process for developing learning modules.
Problem-based learning: enhancing students learning of building information modelling. (Obi, Tochukwu, & Chukwudi, 2018)	This paper evaluates the impact of PBL strategy on students accelerated learning of BIM based on a case study of an undergraduate BIM module.
Developing students' collaborative skills in interdisciplinary learning environments (Gnaur, Svidt & Thygesen, 2016)	The paper focuses on characteristics of effective educational environments and experiences for preparing students for future challenges by exploring ways in which professional learning is encouraged.
Project-Based learning in a building information modeling for construction management course (Leite, 2016)	This paper describes experiences of a university course on Building Information Modeling that was developed to educate the next generation construction managers to understand BIM and effectively use an existing BIM in plan execution for construction projects.

Table 3: Assessment

	Learning outcomes	Observation presentation	Technical report	Survey
L1	Demonstrate an understanding of the concept of BIM and highlight commonly used tools	√	√	√
L2	Understand the benefits of BIM for multi-disciplinary construction professionals in the construction project environment	√	√	√
L4	Demonstrate analytical, communication and collaborative skills for working in BIM project environment	√	√	√

Table 4: Sample of 4hr session for a week

Sessions	Main facilitator	Purpose	Outcome
Lecture/ demonstration	Tutor	Provide a basic knowledge of the principles and concepts understudy	Overview of basic principles and concepts understudy
Class discussion	Tutor and students	Provide a platform for questions and answer to clarify any queries	Comprehension of information provided
Problem-solving (in-class session)	Students	Engage in group working, collaboratively evaluating problem-solving to proffer potential solutions to the scenario investigated	Cognitive and skill development

Table 5: Sparse Network

Programme	Number of nodes	Number of non-zero edges	Sparsity
BSC	5	8 / 10	0.200
HNC	5	8 / 10	0.200
HND	5	9 / 10	0.100

Table 6: Adjacent matrix for qualifications and skills

	BSC					HNC					HND				
Skills	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1.Communication	0.000	-0.839	0.457	-0.783	0.000	0.000	0.664	-0.270	-0.282	-0.273	0.000	-0.571	0.663	0.335	-0.660
2.Analytical	-0.839	0.000	-0.025	-0.772	-0.397	0.664	0.000	0.629	0.614	0.000	-0.571	0.000	0.333	0.883	-0.649
3.Collaboration	0.457	-0.025	0.000	0.000	-0.855	-0.270	0.629	0.000	0.000	-0.533	0.663	0.333	0.000	-0.221	0.000
4 Technical knowledge of BIM concept (Professionaldsc)	-0.783	-0.772	0.000	0.000	-0.463	-0.282	0.614	0.000	0.000	0.750	0.335	0.883	-0.221	0.000	0.467
5. IT capabilities of BIM (Understanding)	0.000	-0.397	-0.855	-0.463	0.000	-0.273	0.000	-0.533	0.750	0.000	-0.660	-0.649	0.000	0.467	0.000

Table 7: Centrality measures

	BSc			HNC			HND		
Variable	Betweenness	Closeness	Strength	Betweenness	Closeness	Strength	Betweenness	Closeness	Strength
Communication	0.730	0.595	0.773	-0.956	-1.352	-0.627	0.447	0.727	0.675
Analytical	-1.095	0.570	0.625	1.434	1.435	1.617	1.565	0.979	1.117
Collaboration	0.730	-1.568	-1.590	-0.956	-0.296	-0.934	-0.671	-1.274	-1.487
Technical knowledge of BIM concept (Professionaldsc)	-1.095	0.826	0.578	0.239	0.150	0.215	-0.671	-0.847	-0.014
IT capabilities of BIM (Understanding)	0.730	-0.423	-0.386	0.239	0.063	-0.272	-0.671	0.416	-0.291