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Article

Lessons from the Virtual Delivery of Building Information Modelling Modules in the COVID-19 Era

Fonbeyin Henry Abanda *, Avar Almukhtar and Mark Austin

School of the Built Environment, Oxford Brookes University, Oxford OX3 0BP, UK; a.almukhtar@brookes.ac.uk (A.A.); maustin@brookes.ac.uk (M.A.)
* Correspondence: fabanda@brookes.ac.uk

Abstract: Emerging building information modelling (BIM) can be complex to teach during a regular face-to-face class schedule, and even more challenging remotely or virtually. This has been further exacerbated by the outbreak of COVID-19 whereby the adoption of virtual teaching techniques in higher education has been strongly recommended. However, since the outbreak, in December 2019, there has been a paucity of research with regards to experiences with the virtual delivery of BIM. This study explores lessons learnt in engaging students through the virtual delivery of BIM courses during the COVID-19 pandemic. Quantitative data from a questionnaire and quantitative and qualitative data from the various module evaluation reports were used to inform this study. A main finding is that, despite being a technical course, BIM can still be delivered online without compromising any of its learning outcomes. In contrast to existing literature, the main contribution of this study is practical as it provides insights on methods that worked and those that can be used post-COVID-19 in delivering BIM courses. This study provides hope to prospective students, especially distance learning students, who often worry whether the technology aspects of BIM can be taught remotely. Although the study is grounded on BIM and driven by the COVID-19 context and distance learning, it has wider implications for learning and teaching in other technical disciplines and virtual learning in general. Specifically, the experiences and impacts of delivering BIM examined in this study can inform curricula design in other disciplines.

Keywords: BIM; blended learning; construction; COVID-19; experiences; virtual learning

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1. Introduction

In early 2020, the world was rocked by an outbreak of COVID-19, which affected every aspect of human life. The COVID-19 pandemic disrupted higher education significantly, requiring the adoption of virtual teaching methods to ensure the delivery of technical courses like BIM. The fatal nature of the virus and the speed with which it spreads have been a huge challenge to many governments and organizations. Consequently, countries, sectors, and organisations had to design measures for coping with, mitigating, and/or stopping the spread of the disease. One common measure was a resolve to "virtual" working that aimed to limit human-to-human interaction, thereby minimizing the rate of the propagation of the virus. The education sector has been one of those highly impacted by COVID-19 [1], with the need to adopt innovative measures including delivering high quality lectures that lead to optimal student satisfaction. It is important to note that, even before COVID-19, there had already been calls to use digital technologies in education [2]. From January through March 2019, 131 China Edtech ventures raised more than USD 1.86 billion

(RMB 12.51 billion), according to data compiled by Mission EDU and Jingmeiti [3]. It has been estimated that the Indian Edtech market will reach USD 2 billion by 2021 [4]. The global Edtech investments reaching USD 18.66 billion in 2019 and the overall market for online education is projected to reach USD 350 billion by 2025 [5]. Regardless of the kind of technology, such as language apps, virtual tutoring, video conferencing tools, or online learning software, there has been a significant surge in technology use since the outbreak of COVID-19 [5]. While such innovative measures could easily be applied in many sectors, the same cannot be said of education, where a number of specific challenges exist. Firstly, the unpredictable nature of the way COVID-19 unfolded in its early days meant it was difficult to establish with certainty which innovative measures work pedagogically. For example, some students were stranded at airports, or blocked at university hostels, while others flew back to their respective countries. Although the virtual delivery of lectures appears to be the obvious solution [6], it still fell short of meeting the needs of all students impacted by the outbreak of COVID-19. For example, a student who might have flown back to India, and was under lockdown may have really never had the opportunity to participate in any virtual learning. Early studies in the United States of America revealed that, institutional differences, as well as their locations, created uneven and unique challenges for educational establishments to fulfil their pedagogic goals [7]. Secondly, unlike in other sectors, time constraints were an important factor as the outbreak happened just at the start of the second semester in most UK universities. The challenge was how to still deliver lectures without having to extend the semester deadlines, as this may have ongoing implications, e.g., not meeting the graduation deadlines. Thirdly, another major concern was how to assess students' work whilst adapting coursework to accommodate the evolving difficulties posed by COVID-19. The evolving nature of COVID-19 has been characterized as being volatile, uncertain, complex, and ambiguous, which has disrupted the educational enterprise [8] and has had implications on the assessment of students' work. Fourthly, the technical nature of some courses such as lab-based or experimental kinds of subjects meant that delivering lectures remotely was a challenge. Ref. [9] articulated the challenge in delivering technical subjects as "... a mammoth roadblock for chemistry courses because of laboratory classes...". The authors, i.e., ref. [9], developed a concept map of assessments and "split-half" laboratory classes for safe distancing in lieu of in-person written examinations and tests in the chemistry module. Similarly, due to its technical nature, BIM can be complex to teach during a regular class schedule, and the COVID-19 pandemic made it even more challenging [10,11]. Lastly, recently, research investigating different aspects of COVID-19 implications on the delivery of science and technical disciplines covered chemistry [9], mathematics [12], engineering [13,14], medical and allied health [15], physical education [16], and architecture [17,18], with very sketchy studies in the BIM domain [19,20]. While Leon et al. [19] explored BIM's role in space optimisation and Boton [20] assessed student satisfaction with BIM teaching during COVID-19, both studies overlooked the effectiveness of specific teaching strategies and delivery modes. Furthermore, Ahmed and Opoku [21] and Iglesias-Pradas et al. [22] highlighted broader challenges in technical education delivery during the pandemic, such as ensuring active engagement and addressing technical barriers. Recent studies [23,24] revealed other significant challenges in the delivery of online courses caused by the outbreak of COVID-19. Tang et al. [23] focused on the investigation of students' readiness to participate in the real-time online learning implemented during the coronavirus outbreak. Fretheim et al. [24] investigated the association between different teaching modalities and COVID-19 risk, quality of life (subjective well-being), and teaching satisfaction in Norwegian universities. Yau et al. [25] investigated the teachers' and students' perceptions of online teaching and learning in Hong Kong higher education during the COVID-19 pandemic. This study builds on these findings by investigating the effectiveness of blended and HyFlex learning methods for BIM delivery, addressing gaps in teaching strategies, and evaluating their impact on student satisfaction and outcomes. As very few studies have conducted a thorough investigation on delivering BIM courses during the COVID-19 pandemic, the result is that significant research questions (RQs) need to be asked.

- RQ1: What are the effective strategies that enhanced students' learning during hands-on workshops in a virtual setting, specifically for technical subjects like BIM?
- RQ2: Which are the best educational learning modes that worked well during the COVID-19 pandemic for delivering BIM workshops?
- RQ3: What are the benefits of adopting different educational delivery methods (e.g., blended learning, HyFlex, and online) for teaching BIM during the COVID-19 pandemic?
- RQ4: What are the challenges/barriers in enhancing learning during BIM hands-on lectures?
- RQ5: What are the best educational learning methods to be used post-COVID-19?
- RQ6: What are the effects of the sudden switch to blended learning on the quality of students' satisfaction?

Although this study is founded on the need to deliver a technical and complex discipline, BIM, the ultimate goal is to learn from it and lay the ground work for further applicability of its results to other fields as well as raising global interest in the design of virtual learning pedagogic approaches in normal times, as well as during pandemics or any other similar situations. To better design an appropriate research methodology that can aid in exploring the aforementioned research questions, it is imperative to examine the main concepts relevant to the domain of research in the following section.

2. Literature Review

2.1. Lecture-Delivering Techniques

In degree programmes, a document often called the "module handbook" is designed to contain information that when fully and appropriately implemented should enhance students' learning and improve their satisfaction. It is important to examine some concepts often considered in designing module handbooks, which will aid in understanding the different learning modes adopted during COVID-19 pandemic. Some of these concepts have been widely examined in the literature [26–29] and include the following:

Course design: Course design is the process of creating high quality learning environments that enhances students' learning experiences. The main goal of course design is to ensure the optimal learning experiences of students in an environment that is supportive and appreciative of learning and intellectual development. Empirical evidence by Almaiah and Alyoussef [30] revealed that a course that has been properly designed has positive impacts on the use of electronic learning systems, which in turn enhances students' learning satisfaction. The key elements that should be considered in course design are instructional materials, learning activities and interaction, and students' ability to access information, obtain skills, and practice higher levels of thinking.

Learning outcomes: Prøitz [31] defines learning outcomes as competences, which students are to achieve in certain aspects of a module or course. Roksa et al. [32] further argued that learning outcomes are measurable statements of student knowledge and abilities, described "as existing at the intersection of concepts (what students know and understand) and competencies (what students are able to do)".

Electronic course environment: This is a Web-based platform where learning is organized, instructional materials are shared, assessments are undertaken, students meet with staff and other students, etc., with the ultimate goal of optimizing for a better learning experience [33]. In other words, it provides an environment that enlivens and enriches the learning process, where learners can interact with one or more collaborating peers to solve a given problem [34]. In practice, this platform is often referred to by various names, including collaborative learning environments, virtual learning environments (VLEs), or systems such as Blackboard and Moodle.

Interaction with peer students: This element involves interactive communication processes where students share information about both the learning material and socio-emotional aspects. Students gain several benefits from this approach: collaborating in small groups to build understanding, receiving mutual socio-emotional support, and engaging in a cohesive and positive learning environment. The sense of mutual support and group cohesion enhances students' perception of social presence, their participation in teamwork, motivation to engage in the learning process, and overall course satisfaction [33].

Interaction between students and instructors: Instructors need to perform a range of tasks in the teaching process, such as structuring the learning content, providing feedback on students' achievements, motivating students to engage with and reflect on the content, and assisting them in participating in learning activities. A study involving 313 students in emergency online learning settings with limited resources found that strategies for engaging with content, such as screen sharing, summaries, and class recordings, were perceived as the most effective. These were closely followed by student–teacher strategies like Q&A sessions and reminders [35]. The same study indicated that student–student strategies, including group chat and collaborative work, were seen as the least effective.

Individual learning processes: E-learning students often have numerous opportunities to practice and apply their knowledge. The self-regulation of learning is a crucial aspect of e-learning courses, as students can decide the time, place, and overall regulation of their learning processes [36]. Lecture delivery can occur through various modes: face-to-face (F2F) learning, online, blended (F2F and online), and HyFlex.

F2F learning: This is a people-based instructional method of learning whereby the instructor and the learner are both present in the same instructional physical space. The course content and learning material are taught in person by the instructor to a group of students. This allows for a live or real-time interaction between a learner and an instructor. The interaction can be between instructor and students, students and students, or instructor and instructor in the case of team teaching. It is the most traditional type of learning instruction. Despite a recent surge in the uptake of online/virtual learning [37], many students still consider F2F as the most effective learning method. A study conducted by Dios and Carlo [36] found that 88 out of 100 students found F2F teaching effective compared to 68 students for e-learning. Tucker [38] highlights that face-to-face (F2F) teaching, while primarily technical, also promotes socialisation through collaboration, peer interaction, and direct engagement. These social skills, often overlooked in technical education, are critical for professional growth and teamwork in BIM-related fields. However, it is important to note that the success of the face-to-face (F2F) method is heavily influenced by institutional conditions, such as the quality of classroom facilities, availability of up-to-date technological infrastructure, and stable internet connectivity. These factors, while essential for effective instruction, are not always within the control of the instructors. Limitations in these areas may create barriers to delivering seamless learning experiences, especially for technical subjects like BIM, where hands-on software demonstrations are crucial.

Online learning: This refers to an educational method where instructions and learning material are delivered through a digital medium, like a computer or mobile phone. The internet is the key for a successful delivery of lectures using an online delivery method of learning. The term is variously known as e-Learning (short for electronic learning), mobile learning, web-based learning, virtual education, or virtual learning. In a nutshell, synchronous online learning is just one type of "distance learning"—the umbrella term for any learning that takes place across distance and not in a traditional classroom. The outbreak of COVID-19 has led to many educational establishments resorting to online learning [37,39]. It is important to note that recent interest in online learning has also led to a surge in the uptake of digital learning technologies including e-Learning environments [40].

Blended learning: While widely adopted, the term 'blended learning' is frequently characterized by ambiguity and a lack of a universally accepted definition [41]. Blended learning is an instructional approach that includes a combination of learning media [42]. For example, a course might include e-Learning plus scheduled sessions for synchronous discussions. Also, participants can complete online self-paced lessons by a certain date and then meet on-site or online for additional learning activities.

HyFlex: The hybrid flexible, or HyFlex (also known as blendflex [43]), course format is an instructional approach that combines F2F and online learning. Each class session and learning activity is offered F2F, synchronously online, and asynchronously online [44]. Students have the choice of how to participate or attend. Milman et al. [44] argued that the flexibility of the HyFlex model demonstrates a commitment to student success, and that flexibility can also enable institutions to maintain educational and research activities during a disruption.

In practice, the terms Hyflex and blended learning are used interchangeably. However, there is a slight difference between the two concepts. In blended classes, instructors mix elements of both, although students are generally expected to attend scheduled class sessions. On the other hand, in blendflex, students can choose to attend as many or as few F2F sessions as they want and complete the rest of the course online with no consequence [43]. Furthermore, students can seamlessly, at any time during the semester, move back and forth within their course delivery [43].

When designing courses with e-learning components or instructions in general, instructors are faced with many considerations and decisions which affect how students experience instructions and how they construct and process knowledge.

EdTech: The term EdTech stands for "education technology", which refers to the combination of IT tools and educational practices aimed at facilitating and enhancing students' learning. There are so many EdTechs in the market. Despite this, prior to the COVID-19 outbreak, some institutions have hardly used them in teaching [45]. Although the list is inexhaustive, common components of EdTech are hardware (computers, projectors, camera, and many others), software (including learning management systems), the internet (World Wide Web), and their combinations as important factors in curriculum design nowadays [46]. Furthermore, the recent advent of smart phones and tablets has led to a surge in the use of emerging technologies in teaching and learning, often called mobile learning (m-learning) [47]. Other technologies include Moodle, Microsoft Teams, Adobe Connect, Panopto, and Zoom. In addition to the aforementioned platforms, AppsAnywhere and Parallel are software delivery and virtualization solutions for Higher Education. AppsAnywhere allows students a consistent way to get the software they need to get work done on any device, on and off campus. On the other hand, Parallel allows students to be able to access university computers remotely and use any software without having to install the software on any personal computer.

2.2. Overview-Related Research About Virtual Learning

On reviewing the literature, it was clear that existing research about virtual learning can be grouped into three categories. Firstly, most studies tend to focus on experiences with delivering learning online from a general pedagogic perspective with less focus on specific disciplines (e.g., [48–51]). Rapanta et al. [48] investigated and suggested expert insights into online-learning-related pedagogical content knowledge, with the goal of helping non-expert university teachers (i.e., those who have little experience with online learning) to navigate the challenging COVID-19 times. Vielma and Brey [49] investigated perceptions of online course delivery and challenges faced during the transition to online learning amongst Polish first-year students during the COVID-19 pandemic. Joia and Lorenzo [51] investigated the factors necessary for courses mediated by technology to attain their pedagogical objectives during the COVID-19 pandemic. Cicha et al. [50] investigated first-year students' expectations about the education shift to distance learning. While the aforementioned studies [48–51] were detailed and focused, they were not subject or discipline specific.

The second category of studies relates to research about the online delivery of lectures in BIM modules or programmes prior to the COVID-19 outbreak. An important aspect of this proposed research is to gain an understanding of how BIM modules and/or programmes have been delivered using virtual learning techniques during the COVID-19 pandemic. Consequently, it is imperative to review existing literature about BIM teaching in built environment programmes to gain an understanding of the various pedagogical approaches adopted. Agirbas [52] focused on how to teach BIM in construction sciences. Peterson et al. [53] discussed experiences and lessons learned during the introduction of building information models in construction engineering project management courses. Specifically, they found that the introduction of building information models allowed educators to design a class project that allowed the use of more realistic cases that better simulate real-world project conditions, and helped students to learn how different project management methods integrate with each other, integrate change management tasks in a class assignment, and learn how to optimize project plans. Babatunde and Ekundayo [54] identified 30 barriers that can hinder the incorporation of BIM into quantity surveying undergraduate curriculum in Nigerian universities. The barriers were grouped into six main categories, namely, high security risk, the high cost of implementation, the lack of accreditation standards and requirements, staff resistance and the non-availability of industry experts, the lack of an enabling environment, and the scale of cultural change. Casasayas et al. [55] identified 14 barriers that can hinder the integration of BIM education into programmes in Australian higher education institutions. The barriers were categorized into four main groups: change management, educators, industry and curricula, and content-related. Although these two studies relate to Australia and Nigeria, some of their barriers were similar. In the educator's category, the main common barrier was the lack of skills amongst staff. In the curricula and content category, difficulty in designing BIM modules and existing curriculum being at full capacity with limited or no room to introduce BIM were the common barriers. In the industry category, the main common barrier was the lack of accreditation standards and requirements to guide the implementation of BIM within a curriculum (in the case of Nigeria) or an unfavourable accreditation process (in the case of Australia). A major difference was change management challenges, which was common in the Australian study and not in the Nigerian case. Perhaps, this was due to the low adoption of BIM in higher education in Nigeria, which means they could not be talking of change management when the BIM adoption level in the country is still very low. Tian and He [56] used BIM as a tool to facilitate learning and understanding in conventional engineering disciplines often considered difficult to teach and learn. Anderson et al. [57] investigated and designed a course that brought students from different universities to work on a multi-disciplinary, interdependent project where teams created 3D models and 4D construction simulations. Espinoza et al. [58] conducted a study which revealed that integrating BIM and virtual reality can be used in improving the teaching and learning of sanitary engineering courses. Li and Liao [1] used the analytic hierarchy process to analyse factors influencing the teaching of the BIM-based engineering management specialty. Yin [59] conducted a study that demonstrated the use of Revit 2022 software as the medium to analyse, in detail, the application of teaching methods in the BIM learning process, improve teaching quality, and stimulate students' interest in learning. Wang et al. [60] examined how BIM can be incorporated in the final semester undergraduate project of construction management in Fuzhou University. Xu et al. [61] combined new construction engineering technology with BIM involving the visual simulation method, and introduced them into the teaching programmes. Kovačić et al. [62] discussed the experiences of delivering an interdisciplinary BIM design course conducted at the Vienna University of Technology. Ghosh et al. [63] discussed the evolution of the BIM curriculum and focused on the vertical integration of upper-division and lower-division students for a site logistics assignment to improve upon the BIM education continuum. Wu and Luo [64] examined the strategies of implementing and managing a joint course project, and shared various metrics and tools adopted in project evaluation. The results and the findings of this course project shone light on competency-based programme assessment and future BIM curriculum innovation.

The first paragraph of Section 2.2 focused on studies about the pedagogy of online delivery of teaching. While the second category was about the online delivery of BIM courses, it failed to take into account COVID-19 or any other pandemic. With the COVID-19 pandemic, it is important to know how BIM was rolled out in teaching. Thus, the third category of studies is about research on BIM teaching during the COVID-19 pandemic. Only two studies, Leon et al. [19] and Boton [20], belong to this category. Leon et al. [19] investigated the use of BIM in optimizing space management during design to comply with COVID-19 measures. Boton [20] conducted a study that investigated the overall satisfaction of the learners, and how to improve a BIM course delivered during the COVID-19 pandemic. This study was limited with respect to sample size as only 45 students participated in the study. While these studies are by far the nearest to our proposed study, the authors focused more on how the new communication technologies were used and the challenges experienced. There was a limitation in covering other aspects such as impacts of sudden change, highlighted by Ahmed and Opoku [21], to blended learning on students' feedback, the effectiveness of the teaching strategies adopted, the benefits of the various BIM delivery modes, and the best educational teaching mode (during and post-COVID-19) and the effects of sudden change to blended learning during the COVID-19 pandemic. These gaps constitute the basis upon which this study is grounded.

3. Methods

3.1. Research Model and Procedure

The use of research models in driving scholarly investigation is of great importance in any field, including information systems (ISs) [65–68]. According to Joosten [68], there are four primary components that compose the research model for online learning including: inputs and outputs, process, context, and interventions. To facilitate understanding, the research model, capturing the different concepts as discussed in Joosten [68], is presented in Figure 1.

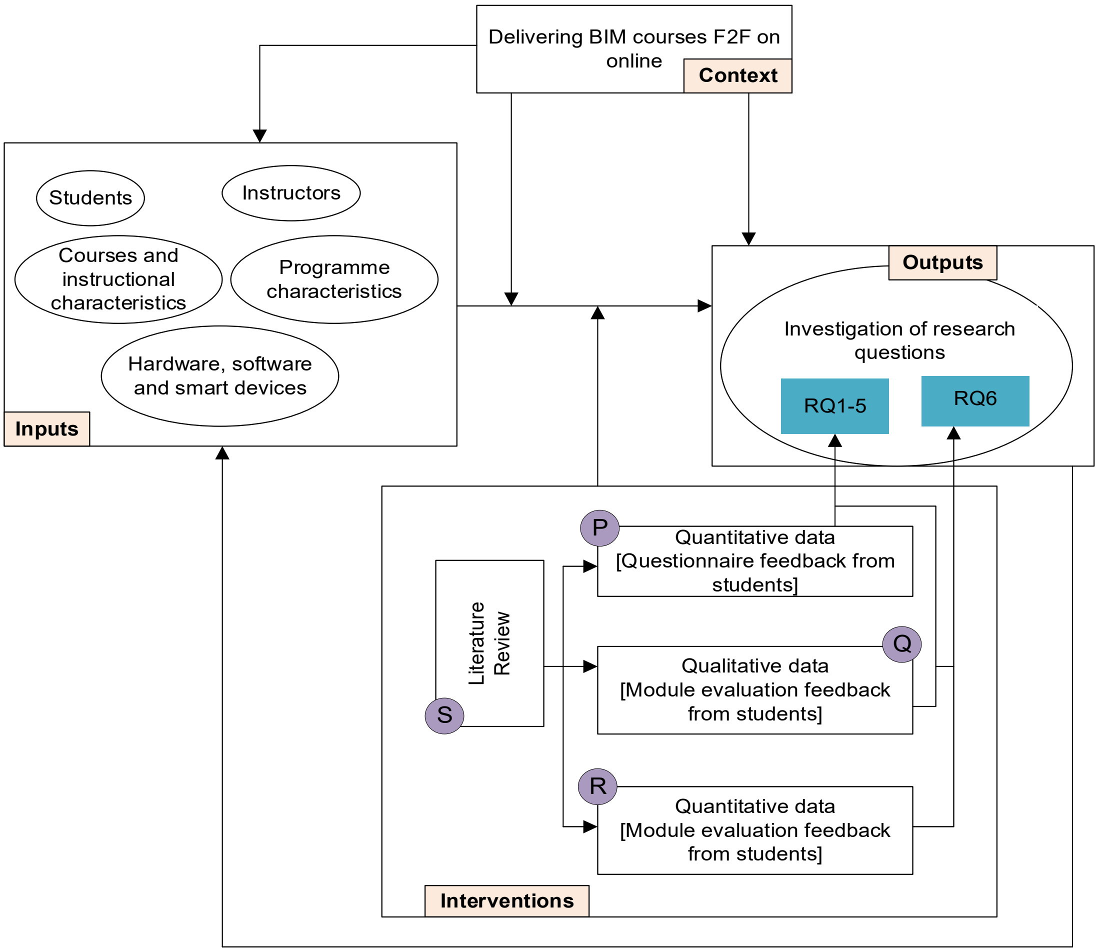


Figure 1. Research method framework. Source: author.

To develop a clearer understanding of the problem, two quantitative techniques were employed. The first method involved a fully structured questionnaire with closed questions (see P in Figure 1), designed by the authors. The second method utilised a quasi-structured questionnaire (see Q and R in Figure 1), incorporating both closed and open-ended questions. Through the combined method, it was possible to get feedback via a diverse population from the different programmes and modules, i.e., breadth. Based on a preliminary analysis of the quantitative data, an in-depth analysis (depth) was used to further gain an understanding of the problem. An advantage of combining quantitative and qualitative feedback, suggested by Jogulu and Pansiri [69], is that amalgamating statistics with thematic approaches avoids over-reliance on the former and can also capture "soft-core" views and experiences necessary to elucidate complex social situations. To address research questions RQ1 to RQ5, a structured questionnaire and qualitative data from the module evaluation reports were used. A structured questionnaire (see P in Figure 1) was used as an instrument to collect data from the students in the different programmes. To maximize the response rate and ensure that the views of all or most of the students were captured, the population sample was used as the target sample. All of the students (161 in total) in the different modules/programmes were invited to respond to the questionnaire. In total, 72 provided complete answers to the questions, representing a response rate of 44.7%. Feedback from the questionnaire has been presented in bar chats with explanations provided underneath. Also, qualitative data (see Q in Figure 1) collected from the module evaluation reports is examined and discussed taking into account aspects that reflect the research objectives of this study. The qualitative feedback was gathered from the module evaluation reports of the different BIM modules. This latter approach was important as it allowed for the researcher to identify any new concepts and issues that might have cropped up as a result of virtual teaching during the COVID-19 pandemic.

To address research question RQ6, quantitative (see R) and qualitative (see Q) data from the module evaluation reports were used. For research questions RQ1 to RQ6, the quantitative data were analysed using descriptive statistics. Similarly, the qualitative data (module evaluation feedback) were analysed using content analysis. The content of module evaluation reports for the past three years was analysed to find emerging issues which may reflect changes due to COVID-19.

All methods were carried out in accordance with relevant guidelines and regulations.

3.2. Research Context and Sample

There is a lack of consensus as to what research context really means. However, the usage of the term in peer-reviewed articles reveals a common feature as articulated in the definition of "context" by Tennant [70] which reads as follows:

Context can be defined as follows: "The circumstances that form the setting for an event, statement, or idea, and in terms of which it can be fully understood". The key in this definition is "circumstances", or lens background information through which research can be viewed, which can inform the research questions, methods, arguments, findings, conclusions, recommendations, research site, and even participants. Given this is the Methods and that the lens or groundwork for the study was laid in the Background section, the following paragraphs will focus solely on the research site and sample.

The research participants for this study were construction project management and quantity surveying students in undergraduate programs (BSc CPM, and BSc QS) and postgraduate programs (MSc PMBE, MSc CPM, MSc BIM&M, and MSc QS) at the School of the Built Environment at Oxford Brookes University. All of the authors of this study work as lecturers for the aforementioned programmes.

With respect to the research sample, depending on the type of research, different statistical models can be used to determine the sample size of a study. The choice of the model also depends on whether the target is small or large. For example, the Yamane formula is often used to determine the sample size in situations where the target population is small or large and yet representative. This study had a well-known number of students in the different programs, and given the challenge of obtaining module evaluation feedback from students, the researchers opted to maximise the response rate. To achieve this, the entire population was the target, i.e., the target and sample size were equal.

Teaching BIM at Oxford Brookes University During COVID-19

In the School of the Built Environment at Oxford Brookes University, a suite of built environment-related programmes has been on offer for a number of years. These are BSc Construction Project Management, BSc Quantity Surveying and Commercial Management, MSc Construction Project Management, MSc Quantity Surveying and Commercial Management, MSc Project Management in the Built Environment and MSc BIM & Management. Other than MSc BIM & Management, which is a specialist BIM programme, all other programmes have BIM modules embedded within them.

This study focused on three modules. The first was Managing Technology for Sustainable Environments with module code PMAN7004. This module is taken by students enrolled in MSc Quantity Surveying and Commercial Management and MSc Project Management in the Built Environment. The second module was Advanced Construction Technology & BIM with code PMAN7006. The third was Construction Communication and Information Technology 2 with code CONM5006. This is taken by students in BSc Construction Project Management and BSc Quantity Surveying and Commercial Management.

Without going into too much detail, the contents of these modules have one thing in common—they all contain BIM technology. The technology component explores both advanced construction technologies and innovations, and the use of BIM in managing and organising construction project information. The learning outcomes expected of the technology component of these modules are as follows:

- To manage a BIM collaborative environment to enable teams to effectively share a building model.
- To appraise BIM protocols, inter-operability, and standards.
- To professionally produce nD modelling using selective BIM software.
- To work independently to develop skills in information management and problem-solving.

From a software technology perspective, students are taught various software tools for different applications. A holistic approach is undertaken whereby students are introduced to an extensive review of 122 software programs including criteria for their selection, as covered in [69]. Building on the software criteria selection in [71], students are able to confirm or validate the choices of the different software they have been taught such as: Revit, iTwoCostX, Navisworks, and BIM360 (now Autodesk Construction Cloud) amongst others.

Learners are first taught how to design a model using Revit. Based on the developed model, schedules and quantity take-offs are then generated. Furthermore, using the model in combination with MS Excel, students are taught how to develop cost plans and evaluate the sustainability performance of construction projects. Specifically, learners are taught how to compute embodied energy and carbon, operational energy, and the carbon footprint of buildings.

Secondly, students are then taught how to measure from 2D PDF, image, and CAD files using iTwoCostX. They are also taught how to generate quantities from Revit and iTwoCostX and then generate cost plans in alignment with standard measurement methods such as the Standard Method of Measurement (SMM7) and New Rules of Measurements. Finally, students are taught how to conduct clash detection using Navisworks.

The second aspect taught to students is the development of project programmes. They are taught how to develop programmes from scratch within the software and how to import programmes from MS Excel, MS Project, Navisworks, and Asta PowerProject and then federate with 3D models from Revit (.RVT) or Industry Foundation Classes (IFC). The computation or generation of quantities in alignment with standards such as Uniformat and the Construction Specifications Institute (CSI) are taught as well. To develop students' critical/analytical thinking, they are shown examples of research that informs what has been taught or is being taught (e.g., [72,73]). In [72], learners explore how to develop a BIM model using Revit, convert it to green building Extensible Markup Language (gbXML) and export it into Green Building Studio where the impacts of building orientation on household energy consumption are investigated. Students learn the theoretical concepts of embodied energy and carbon and how their computation can be conducted in a BIM software environment examined in [73]. Ref. [71] explores how to develop digital standard measurements methods, in this case, the UK New Rules of Measurement, from scratch instead of just using those embedded within the Navisworks 2022 software. This work, i.e., ref. [74] served as the foundation of 5D BIM for students in our BIM courses. Building on [74], ref. [75] developed a Revit-based plugin that can be used in computing cost in real-time during the design of a building. The learning points for students in [75] were the use of the digital standard measurement method developed in [71], integrating it with the

3D-BIM model, and computing the cost of a project during design. This work, i.e., ref. [75] was extended in [75] to include embodied energy and carbon assessment. Collectively, refs. [72–75] cover some aspects of BIM applications also taught in the BIM courses in the School of the Built Environment in Oxford Brookes University. Sharing the aforementioned literature with students in the School of the Built Environment at Oxford Brookes University is a great way of encouraging research-informed teaching which inspires critical and analytical thinking in students, as argued in [6,76].

Lastly, students are taught how to manage construction project information using common data environments (CDEs). This is operationalized using BIM360 (today known as Autodesk Construction Cloud), where the modules BIM360 Doc (Document Management) and Field Management are taught, especially their use in practice and in compliance with the latest standards such as ISO 19650 [77] Although studies experimenting with the teaching of CDEs are not too common, a rare study by [78] on graduate students in a BIM course revealed the ease of use of the platform, better communication of ideas and concerns, real-time collaboration opportunities, and model coordination in Next Gen BIM 360 cloud services.

The standards of the delivery of these modules in the School of the Built Environment at Oxford Brookes University are high and have been reflected in our successes in UK BIM competitions where our students have been amongst the top finalists.

In 2019, students from our MSc BIM&M who took PMAN7006 participated and took the first two spots in the 1st World Skills UK Building Information Management (BIM)—Regional Competition. Then, in 2020, a student from the same programme took second place in the 1st UK Autodesk Digital Construction Challenge [79]. In 2021, a student from MSc CPM who took PMAN7006 was amongst the finalists of the Regional WorldSkills UK Digital Construction Competition. The student participated in the National finals that took place between the 17 and 20 November 2021.

Previously, like all other modules, PMAN7004 and PMAN7006 were delivered synchronously to both distance and full-time learners. The F2F sessions are conducted in the School's Master Studio while distance learners can attend remotely via Adobe Connect at the time of delivery or catch up later using recorded sessions. For the undergraduates, although all the lectures have been F2F, they are often delivered using Adobe Connect and the sessions are recorded. With the outbreak of COVID-19, and with government measures in place, a number of changes had to be undertaken to ensure the quality of learning did not suffer. These were as follows.

Online/and F2F: During the initial phase of the pandemic, lectures were delivered online for both full-time and distance learners, which was a common practice in universities worldwide. Iglesias-Pradas et al. [22] examined the transition to emergency remote teaching at the Universidad Politecnica de Madrid in Spain, while Poitras et al. [80] studied the use of technical tools for distance learning in an engineering program at the Université de Moncton in Canada. Grodotzki et al. [81] investigated the impact of the sudden shift to online education among international mechanical engineering students specializing in manufacturing technology at TU Dortmund University in Germany.

As the understanding of COVID-19 increased and certain restrictions were eased, learners were given the option to participate in F2F sessions, although attendance was not mandatory. F2F sessions were particularly popular among postgraduate students, with an attendance rate of approximately 10% in our BIM-related programs, mainly consisting of students who were already in Oxford prior to the lockdown. However, undergraduate students, who had left their accommodations and returned home, showed less interest in F2F sessions.

The introduction of Parallels (RAS): In addition to AppsAnywhere, which has been in existence at Oxford Brookes University for some time, Parallels Remote Access System (RAS) was introduced during the COVID-19 pandemic. Unlike AppsAnywhere, Parallels allowed students to use any software on the university computers without the need to download and install it on their machines. This means students did not need to buy high spec computers, which were already hard to afford at a very difficult time.

Extra sessions/IT surgery: In addition to the normal programme hours, an hour was set aside for short catch-up with those struggling. Also, during the sessions, students with any particular IT issues were provided support. Examples of issues include the installation of files, converting a Revit file into IFC, and saving iTwoCostX files.

Formative activities: In the early weeks of delivering hands-on workshops remotely, the teaching team decided to give small pieces of assignments to undergraduate students. This was because, given this was the first time teaching BIM completely online, the team needed to identify software-related issues that can affect students' learning. Although formative interventions have been part of our teaching strategy in the School of the Built Environment at Oxford Brookes University, the outbreak of COVID-19 made it imperative, especially in a technical course like BIM. The approach was recommended by Grodotzki et al. [81] who argued that formative activities were amongst the most significant and effective strategies that can be used to enhance learning and students' engagement during the COVID-19 pandemic.

Zoom/Panopto: Zoom and Panopto were introduced as other tools for delivering live lectures and/or hands-on workshops. Zoom and Panopto were introduced as tools for delivering live lectures and hands-on workshops while simultaneously recording sessions. Zoom, a video conferencing platform, enabled real-time communication, screen sharing, and interactive features like annotations, enhancing live demonstrations. Panopto, a lecture capture and video management tool, automatically stored and organised recordings for easy access through the learning management system. Both tools minimised staff intervention—sessions were created, delivered, and recordings were shared efficiently—ensuring students could revisit the content at their convenience. Using these tools, it was possible to deliver lectures while recording at the same time. The two were set up in such a way as to minimize staff intervention. The only input from staff was creating the sessions and sharing the recorded lecture after.

The bold involvement of an assistant: In the past, an assistant supported the main instructor during the delivery of hands-on workshops in helping struggling students (F2F for undergraduate students and F2F and remotely for postgraduate students). With the outbreak of COVID-19, this role was expanded, such that the assistant could also lead the teaching of some sessions. This, in part, aided the main instructor not to tire out from talking for long periods over Zoom. It was organized in such a way that the assistant was given the opportunity to take some minutes, say 20–30 min, of a 2 h session. This was great in the sense that students were not bored hearing one voice and seeing the same face throughout.

In addition, the assistant used the annotation tool in Zoom during hands-on workshops to enhance clarity and engagement. The annotation tool in Zoom allows users to draw, highlight, or mark specific areas on a shared screen or presentation. For instance, while the main instructor demonstrated specific icons or tools within BIM software, the assistant simultaneously highlighted these icons using annotations such as circles, arrows, or underlines. This real-time visual aid ensured that students could easily identify the features being discussed, improving their understanding of complex software interfaces.

The annotation tool was particularly beneficial in virtual learning environments, where pointing to specific elements verbally may cause confusion. By synchronising the instructor's explanations with the assistant's on-screen highlights, the learning process became more interactive, visual, and accessible for all participants.

3.3. Instrument Used and Their Validation

The research instruments used were two structured questionnaires. The first was designed by the researcher to address research questions RQ1 to RQ5. Given that this was designed by the researcher, it was imperative to validate it to ensure it captured what it was intended for. A pilot study was conducted to validate the clarity, structure, and content of the research tools—specifically the structured questionnaire used to address research questions RQ1 to R5. The pilot aimed to ensure that the questions were understandable, concise, and capable of eliciting responses relevant to the study objectives. Eight participants, all alumni who had previously undertaken BIM modules and were working in the industry, were selected for the pilot. In total, 8 alumni, evenly distributed between distance learners and full-time students, participated in the pilot study. The participants were contacted via LinkedIn. Their feedback highlighted areas requiring refinement, such as rephrasing ambiguous questions and streamlining terminology for consistency. The revisions resulting from the pilot study strengthened the validity and reliability of the questionnaire prior to its full implementation with the target population. The second questionnaire which was composed of structured closed questions and open qualitative questions was employed to address research question RQ6. The closed type questions allow for a standardised way of collecting data from participants. The open questions allowed for qualitative data to be collected. Given this second questionnaire is being used for the evaluation of all modules of the different degree programs and that it aligns with the National Student Survey, validating it was not necessary as it had already been validated by our University and nationally to ensure a consistent way of collecting data from all universities.

3.4. Data Analysis

For the quantitative data, preliminary analyses from Google Survey were explored. This was followed up by using MS Excel to analyse feedback from closed types of questions from the questionnaire designed by this author and that from the university's standard module evaluation survey. As argued by Boynton and Greenhalgh [82], tables and figures are appropriate for presenting results from quantitative study. Therefore, figures were used to present the results of this study. To facilitate fluency and understanding, the figures will be inserted in the manuscript.

4. Results

4.1. Profile of Respondents

The BIM module for undergraduates is called CONM5006: Construction Communication and Information Technology 2. This module is/was taken by students in BSc Construction Project Management and BSc Quantity Surveying and Commercial Management. The total number of students in both programmes is 52.

The modules taken at postgraduate levels are PMAN7004: Managing Technology for Sustainable Environments and PMAN7006: Advanced Construction Technology & BIM. PMAN7004 was taken by students in MSc Quantity Surveying and Commercial Management and MSc Project Management in the Built Environment (65 in total). PMAN7006 was taken by students in MSc BIM & Management (10) and MSc Construction Project Management (34). The total number of students was 161. The proportion of feedback for the different courses is presented in Figure 2.

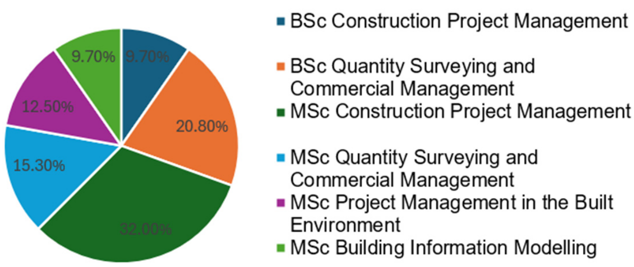


Figure 2. Proportion of feedback for the different programmes.

To facilitate understanding, the findings will be aligned with the research questions posed in Section 1.

4.2. Strategies Enhancing Learning During Hands-On Workshops (RQ1)

A number of strategies were put in place to enhance students' learning during hands-on workshops. A question was used to determine whether the strategies deployed during the COVID-19 pandemic were effective. The results are presented in Figure 3.

Based on Figure 3, the top four strategies were the availability of recorded lectures (51, first), the BIM Workbook (36, second), the visual annotations on the screen to improve the clarity of teaching materials (31, third), and the use of an assistant to collect and address questions related to software installations (30, fourth), and these were considered "Highly Effective".

Also, YouTube videos (31, first), setting aside time at the start of each session so that all students can get their computer and software running (27, second), and alternating teaching, i.e., giving some sections to the assistant to teach (23, third) were considered "Effective", respectively.

On analysing the module evaluation feedback, the following emerged: "Use of two lecturers (one the main tutor and the other the assistant) on call, one to teach and the other to annotate (See Figure 4) and bring up points" in CONM5006.

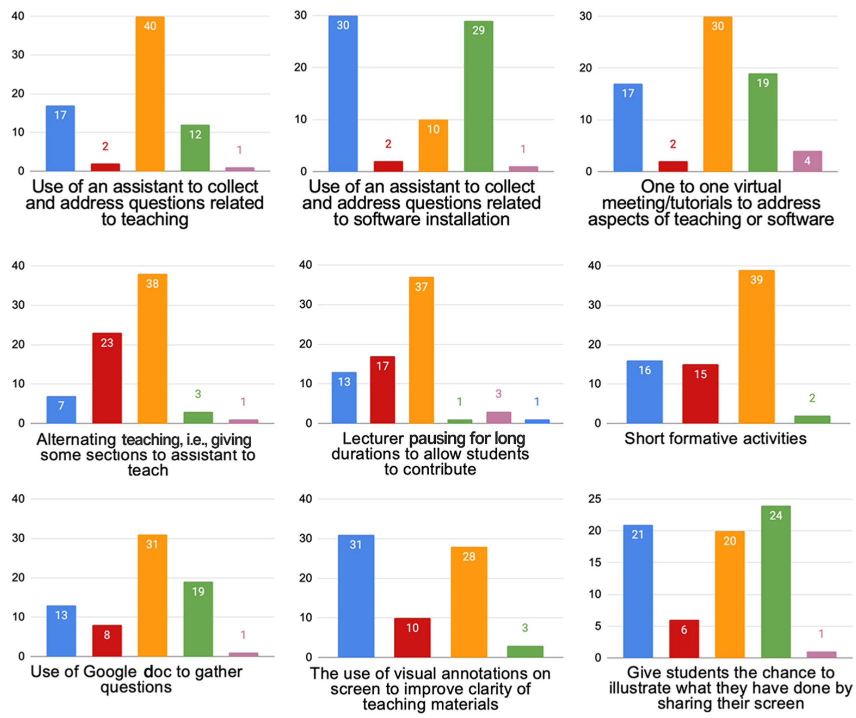


Figure 3. *Cont.*

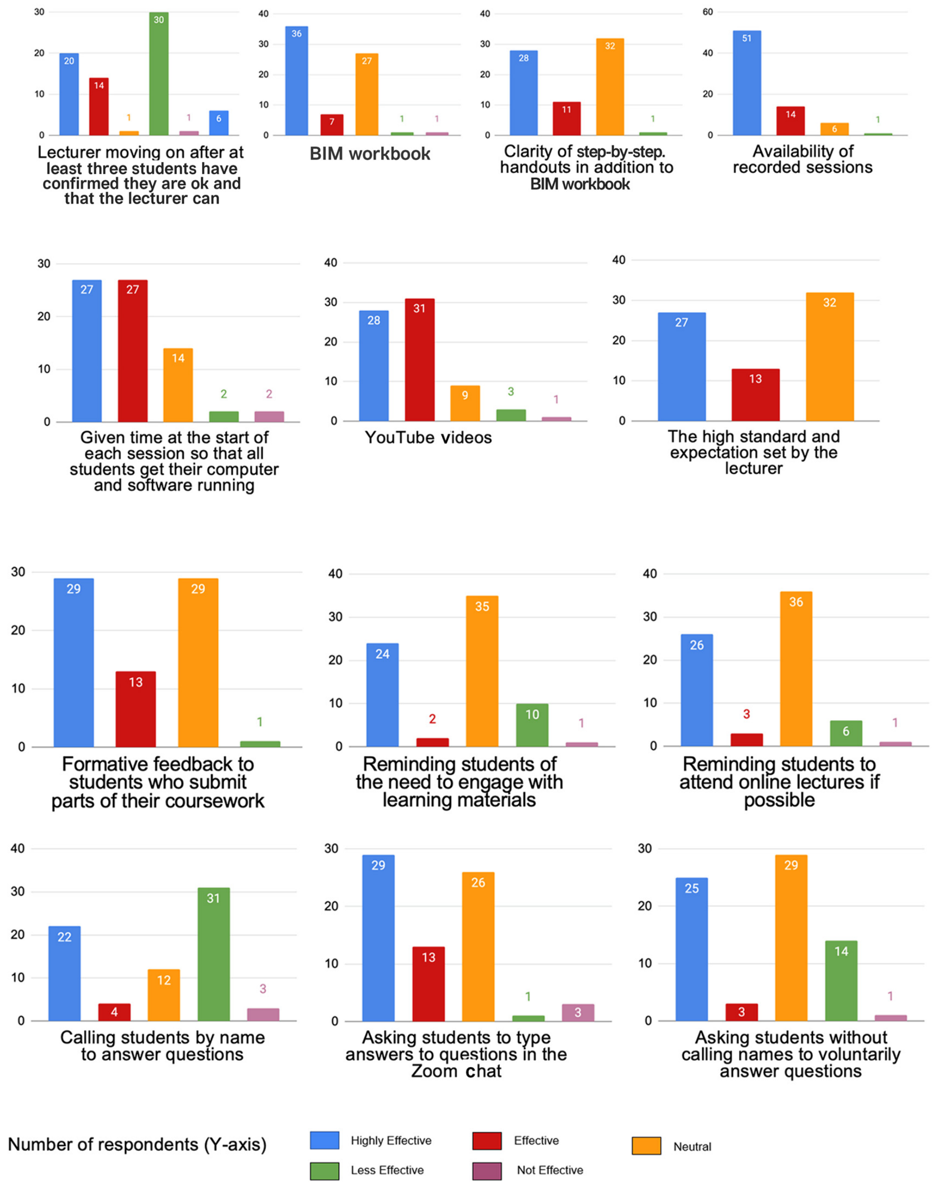


Figure 3. Strategies that enhanced learning during hands-on workshops.

As can be seen in Figure 4, two teaching staff are able to use annotation tools simultaneously (Green and red arrows for two different staff respectively). This is very important as it allows one to point at a geometrical element in the workspace while the other points at its equivalent in the identity data in the dimension group. This is similar to Revit where one staff can be pointing at the geometrical element while the other points at the equivalent name in the Properties Palette. In Navisworks, one can be pointing at a geometrical element while the other is pointing at its equivalent in the selection tree. By so doing, students can easily understand what is going on and can easily establish the relationship between geometrical and non-geometrical data.

The effectiveness of using annotations in learning has been significantly observed in this research. It has been found that video sources are more effective as learning resources when segmented and integrated with annotations from other media types. Additionally, the use of Zoom's annotate function has been found to promote active learning. These findings support the notion that Zoom annotation functions are effective for enhancing online learning experiences.

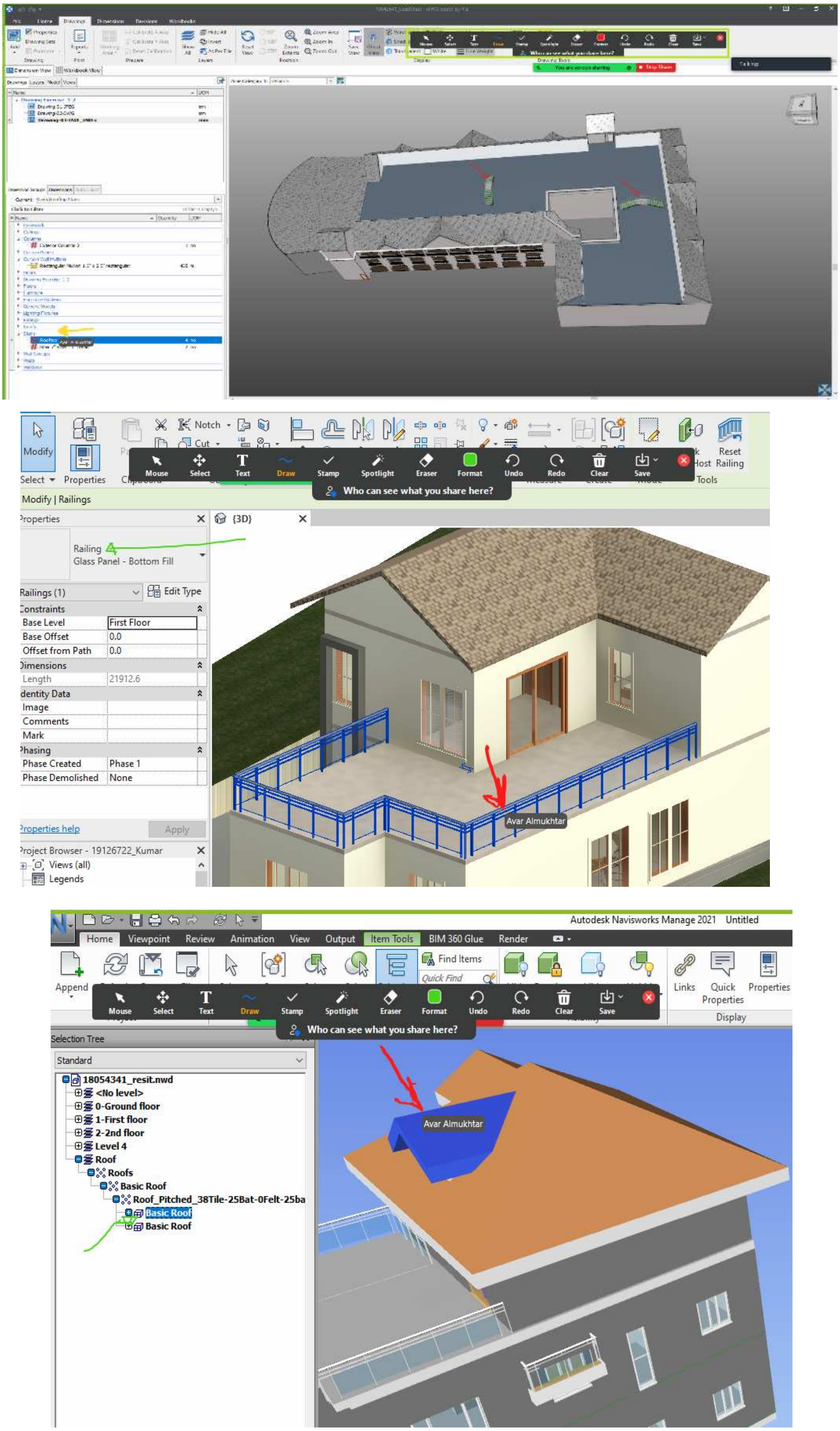


Figure 4. Visual annotations in Zoom by an assistant.

There were other nice statements in the module evaluation feedback of PMAN7004 and PMAN7006. One of the students said, “The online lectures which you screen share has helped significantly—especially recording each lecture so if I’m busy I can re-watch later on”. This highlights the benefits of screen sharing and recorded sessions, which allow for convenient re-watching when unable to attend live. Another student also stated, “The videos recorded for the BIM were very explanatory and in-depth as a tutorial and helped us a lot in understanding the application of the process both in our learning of the software and completion of the course work”. This is positive feedback highlighting the effectiveness of the BIM tutorial videos, which were praised for being highly explanatory and in-depth, greatly supporting software learning and coursework completion. Given this was the first time that undergraduate students were to take the module CONM5006 completely online, it was imperative to introduce formative assessment exercises to enhance understanding, and monitor progress being made by students. This was done through very short exercises such as drawing four walls of a room in a week. The subsequent week, students were asked to add doors, windows, and roofs, followed by the dimensioning and annotation of the designed model. This helped in spotting struggling students earlier on.

The teaching team’s past experiences revealed that students often fail to submit their project in the correct file formats, especially those rushing to do so on the neck of the deadline. Some may erroneously submit a Revit template instead of a Revit project file (.RVT).

A question was given to explore the impact of the formative activities, with results presented in Figure 5. This question was limited to CONM5006 students, as this was their very first time receiving lectures completely online, and therefore, it was important that their engagement and progress were noted.

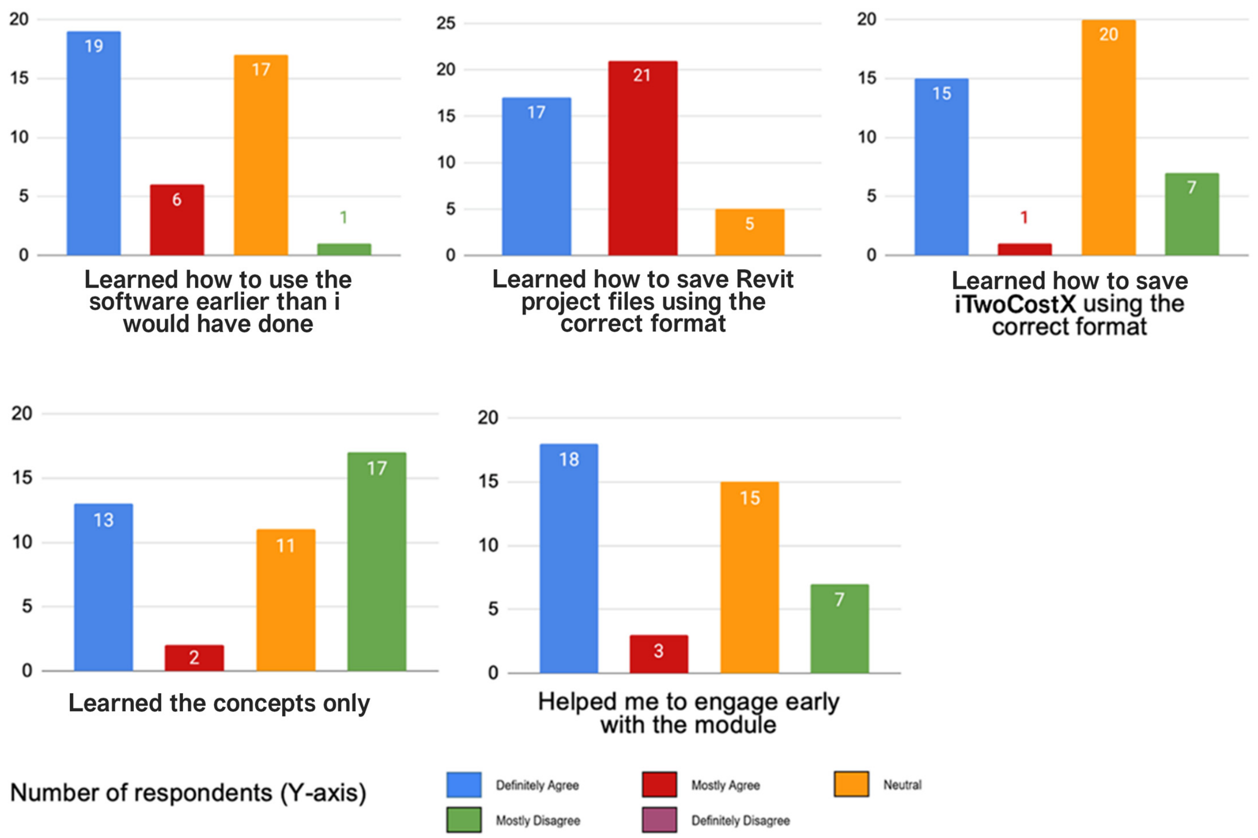


Figure 5. Contribution of formative activities to learning.

The results showed that 17 students "Definitely Agree" and 21 "Mostly Agree" that the formative activities helped them to understand how to save a project in Revit or to save it as an .RVT file. The second best result was that students "Definitely Agree" (19) and "Mostly Agree" (6) that, with the formative activities, they "Learnt how to use the software earlier than they would have done".

4.3. Methods That Worked Well During the COVID-19 Pandemic (RQ2)

Although blended learning was used to deliver all of the modules during the pandemic, students were asked to state the best method that could work well. The results are presented in Figure 6.

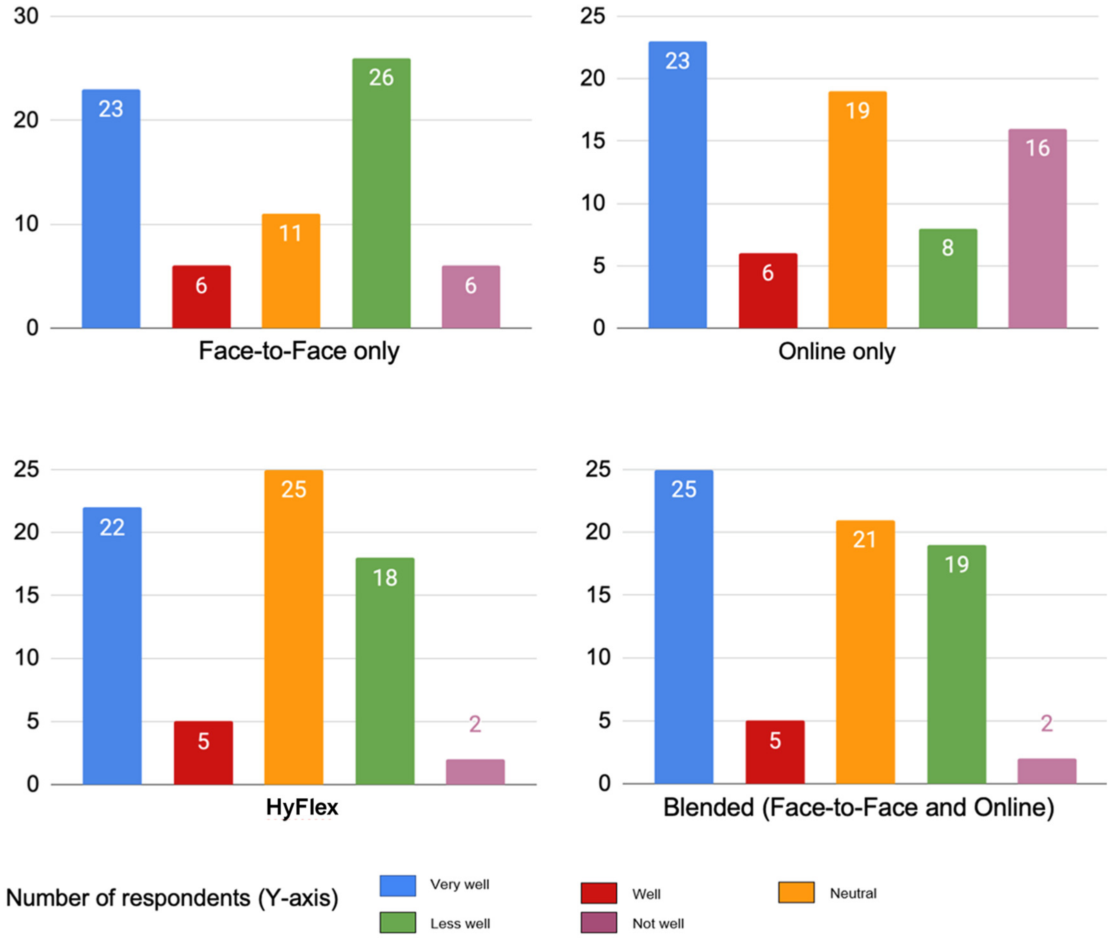


Figure 6. Lecture delivery mode that worked out well for students.

Based on Figure 6, the most preferred learning method was blended learning, where twenty-five students thought it went "Very well" and five thought it went "Well". This was followed by HyFlex where twenty-two students thought it went "Very well" and five thought it went "Well".

On examining the module evaluation report, students mentioned F2F to be great, with some stating online as great as well. Some memorable quotations were "This module has been the best so far. I'd love for all modules to be the exact same format. The online lectures which you screen share has helped significantly—especially recording each lecture so if I'm busy I can re-watch later on". This feedback from a student highlights the module as highly effective, emphasizing a desire for all modules to adopt the same format, with special appreciation for the screen-shared online lectures and recorded sessions, which enable convenient re-watching. Meanwhile, another student stated, "The problem of using software would be easier to solve through F2F learning", and another student also mentioned "More F2F conversation". This split was really between full-time (FT) and part-time (PT) students or distance learners (DL) (both to be used in this manuscript to mean the same) though. In a nutshell, a kind of mixed or combination of learning methods (F2F and Online) was the preferred mode to address the needs of both FT and PT students. Although this may not be a significant change to postgraduate students, it is and will be for undergraduate students, as their mode of study had been predominantly F2F.

4.4. Benefits of Mode of Delivery During the COVID-19 Pandemic (RQ3)

The researchers also sought to find out the benefits of the different delivery modes during the pandemic. The results are presented in Figure 7.

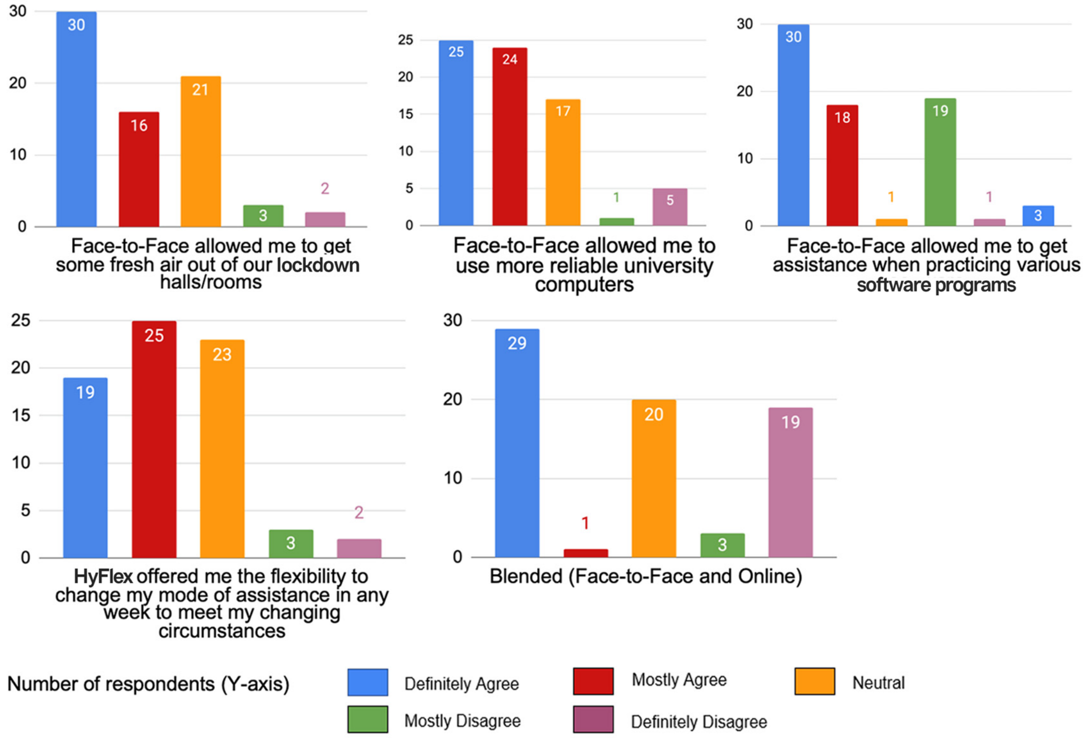


Figure 7. Benefits of the mode of delivery during COVID-19 pandemic.

The results in Figure 7 showed that F2F learning was more beneficial than other modes of delivery. Firstly, 25 and 24 students "Definitely Agree" and "Mostly Agree" that F2F allowed them to use more reliable university computers. The second main benefit was associated with F2F where 30 and 16 students "Definitely Agree" and "Most Agree" that F2F allowed them to get some fresh air. The third was HyFlex, where 19 and 25 students "Definitely Agree" and "Mostly Agree" that it offers the flexibility to change their mode of attendance every week to meet their prevailing circumstances. The results of the module evaluation also indicated the need for F2F to be used. This is reflected in many qualitative statements, such as "The problem of using software would be easier to solve through F2F learning".

4.5. Challenges/Barriers Hindering Learning During Hands-On Workshops (RQ4)

Here, the main goal was to identify the main challenges that hindered learning during the delivery of hands-on workshops remotely during the COVID-19 pandemic. The results of the survey are presented in Figure 8.

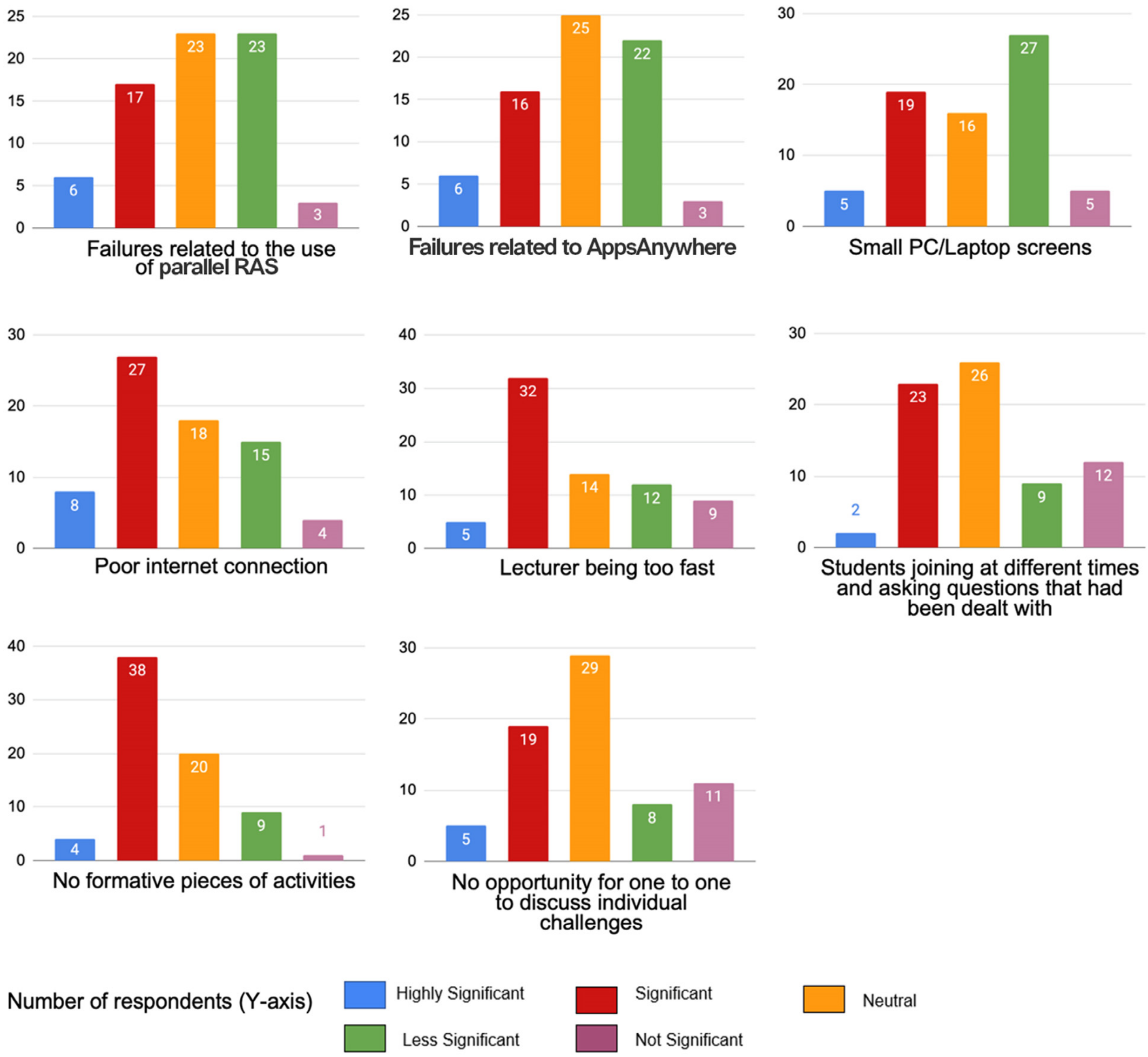


Figure 8. Challenges/barriers hindering learning during hands-on workshops.

Based on Figure 8, the first main barrier was the lack of formative pieces of activities. The responses to this were four for "Highly Significant" and thirty-eight for "Significant". It is important to note that this response is likely to have been from MSc students who were not given formative assessments. The second barrier was the speed of the lecturer, where five and thirty-two students stated this as "Highly Significant" and "Significant", respectively. The third barrier was poor internet connection with eight and twenty-seven students stating it as "Highly Significant" and "Significant", respectively. This was also stated in the module evaluation "internet signal was really poor and many of the lectures were difficult to hear and follow". Surprisingly, AppsAnywhere and Parallel were not major barriers, despite Parallel being introduced just this year as an alternative to accessing software remotely.

4.6. Post-COVID-19 Learning Methods (RQ5)

Having tried blended learning in delivering BIM workshops, a question was set to find out which of the methods should be used in the future or post-COVID-19 pandemic. The results are presented in Figure 9.

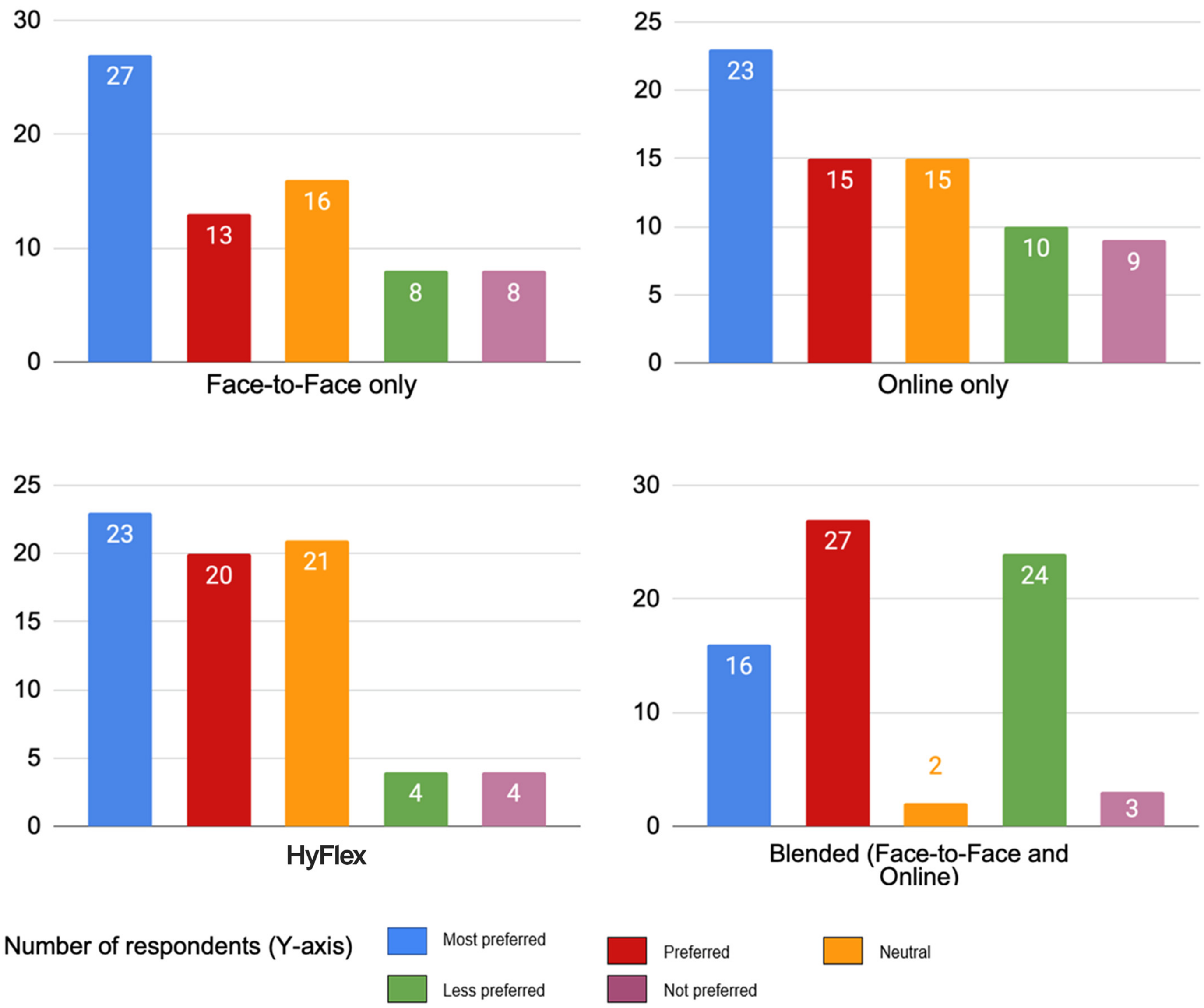


Figure 9. Preferred learning method post-COVID-19.

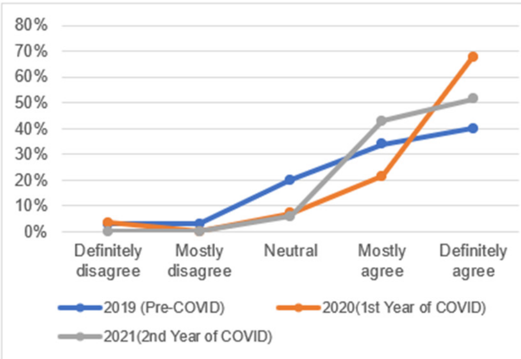
Based on Figure 9, it is clear that students want F2F learning to be the main mode post-COVID-19, with 27 students stating it as the Most Preferred. However, HyFlex and blended learning came first when the responses of the first two criteria were added together. The sums of the responses for the first two criteria are 43 (Most Preferred = 23 and Preferred = 20) and 43 (Most Preferred = 16 and Preferred = 27) for HyFlex and blended learning, respectively. The module evaluation also showed student's preference for blended learning: "A F2F would have been really useful, particularly for BIM which requires a hands-on, in real-time approach". It also revealed that student's preferred to have the option to download recorded lectures so they could watch them offline: "it will be nice if these can be saved as MP4 videos and shared with the students" and a benefit "is that student can download professor's video lectures".

4.7. Effects of Sudden Switch to Blended Learning on the Quality of Students' Satisfaction (RQ6)

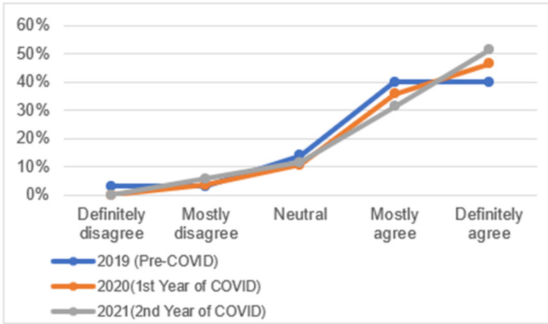
With the fear that came with COVID-19, educators focused on delivering lectures instead of structuring and collecting data that could help understand the rapid conversion of most instruction to online platforms. We therefore used the module evaluation data for 2019, 2020, and 2021. Based on the quantitative data, the following graphs were generated.

To facilitate understanding, the analysis will be conducted in alignment with the four evaluation criteria (i to iv) for PMAN7006, PMAN7004, and CONM5006.

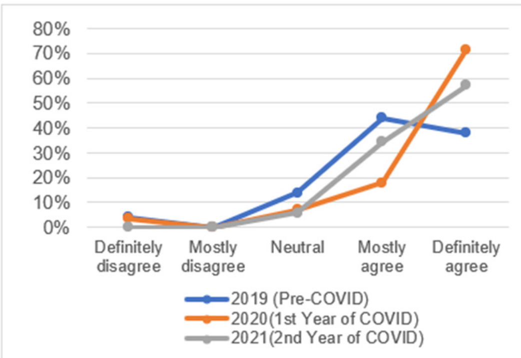
With regards to PMAN7006 (Figure 10), firstly, 89% (68% + 21%) at least agreed that the module provided an excellent learning experience in 2021 compared to 94% (51% + 43%) in 2020 and 74% (40% + 34%) in 2019. Secondly, 82% (46% + 36%) at least agreed that PMAN7006 challenged them to do their best in 2021 compared to 82% (31% + 51%) in 2020 and 80% (40% + 40%) in 2019. Thirdly, 89% (71% + 18%) at least agreed that PMAN7006 found the support they received from teaching staff appropriate for their needs in 2021 compared to 91% (57% + 34%) in 2020 and 82% (38% + 44%) in 2019. Lastly, 86% (54% + 32%) at least agreed that the assessment methods used in PMAN7006 enhanced their learning in 2021 compared to 80% (51% + 29%) in 2020 and 79% (31% + 48%) in 2019.



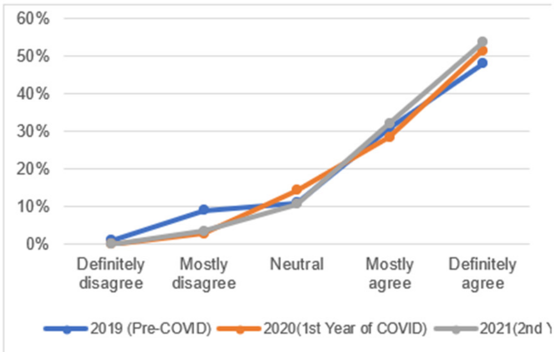
i. Overall, I found this module provided an excellent learning experience



ii. This module challenged me to do my best



iii. I found the support I received from the teaching staff on this module was appropriate for my needs



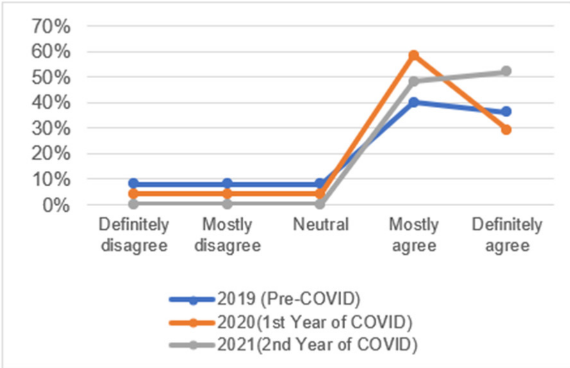
iv. The assessment methods used on the module enhanced my learning

Figure 10. Module evaluation feedback for PMAN7006: number of respondents for 2019 (17/43); number of respondents for 2020 (35/41); and number of respondents for 2021 (28/34).

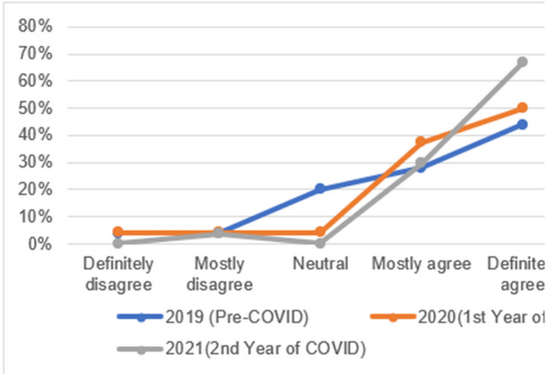
A visual glance at the graphs in Figure 10 revealed a kind of balance for the feedback category "Definitely Agree" amongst the four evaluation criteria for the years 2019 to 2021. For whether the module provided an excellent learning experience and whether the students received support from staff, the feedback for 2021 was slightly lower than that of 2020. For whether the students were challenged by the module and whether the assessment methods enhanced their learning, the feedback for 2021 was better than the previous 2 years.

With regards to PMAN7004 (Figure 11), 100% (52% + 48%) at least agreed that the module provided an excellent learning experience in 2021 compared to 88% (29% + 58%) in 2020 and 76% (36% + 40%) in 2019. Secondly, 96% (67% + 30%) at least agreed that PMAN7004 challenged them to do their best in 2021 compared to 88% (50% + 38%) in 2020 and 72% (44% + 28%) in 2019. Thirdly, 89% (56% + 33%) at least agreed that, in

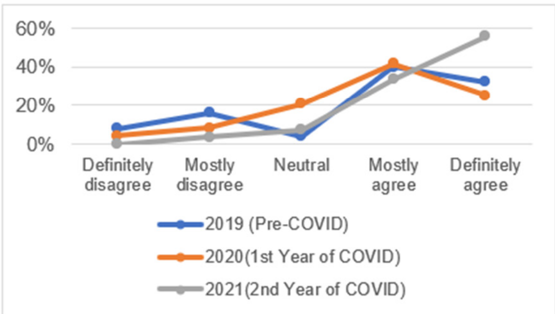
PMAN7004, they found the support they received from teaching staff appropriate for their needs in 2021 compared to 67% (25% + 42%) in 2020 and 72% (40% + 32%) in 2019. Lastly, 96% (66% + 30%) at least agreed that the assessment methods used in PMAN7004 enhanced their learning in 2021 compared to 79% (46% + 33%) in 2020 and 76% (24% + 52%) in 2019.



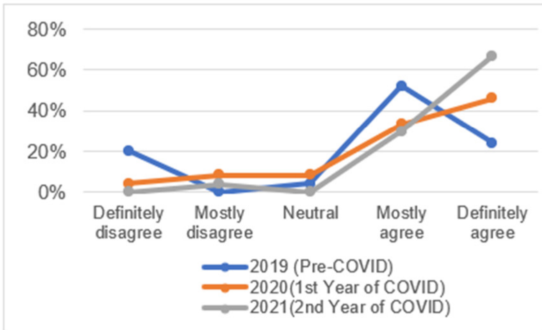
i. Overall, I found this module provided an excellent learning experience



ii. This module challenged me to do my best



iii. I found the support I received from the teaching staff on this module was appropriate for my needs



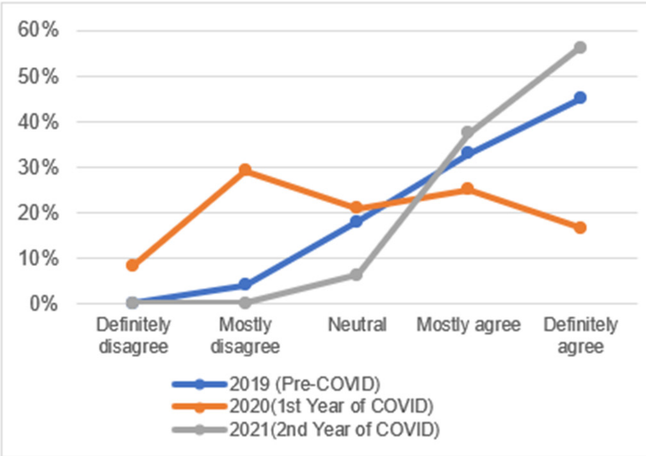
iv. The assessment methods used on the module enhanced my learning

Figure 11. Module evaluation feedback for PMAN7004: number of respondents for 2019 (25/69); number of respondents for 2020 (24/65); and number of respondents for 2021 (27/75).

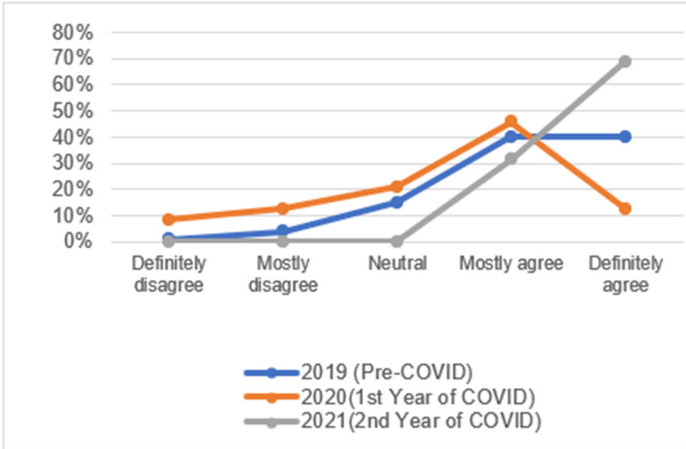
Similarly, with regards to CONM5006 (Figure 12), firstly, 94% (56% + 34%) at least agreed that the module provided an excellent learning experience in 2021 compared to 42% (17% + 25%) in 2020 and 78% (45% + 33%) in 2019. Secondly, 100% (69% + 31%) at least agreed that CONM5006 challenged them to do their best in 2021 compared to 58% (46% + 13%) in 2020 and 80% (40% + 40%) in 2019. Thirdly, 81% (44% + 38%) at least agreed that, in CONM5006, they found the support they received from teaching staff appropriate for their needs in 2021 compared to 38% (25% + 13%) in 2020 and 64% (34% + 30%) in 2019. Lastly, 94% (50% + 44%) at least agreed that the assessment methods used in CONM5006 enhanced their learning in 2021 compared to 42% (17% + 25%) in 2020 and 78% (48% + 30%) in 2019.

For PMAN7004 and CONM5006, the feedback improved in 2021 for all of the evaluation criteria compared to the previous 2 years.

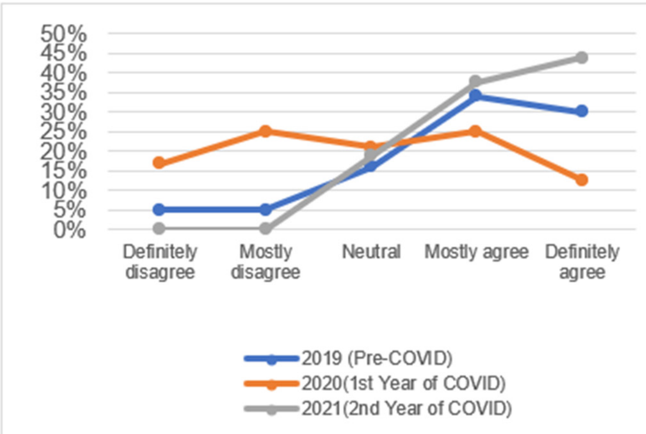
In addition to the four quantitative questions presented in Figures 10–12, two qualitative evaluation parameters often included in the module evaluation will be examined. The parameters are the good aspects of the module and the ways in which the modules can be improved. However, the goal here is to discuss factors that have bearing on the impact of the COVID-19 outbreak and nothing else.



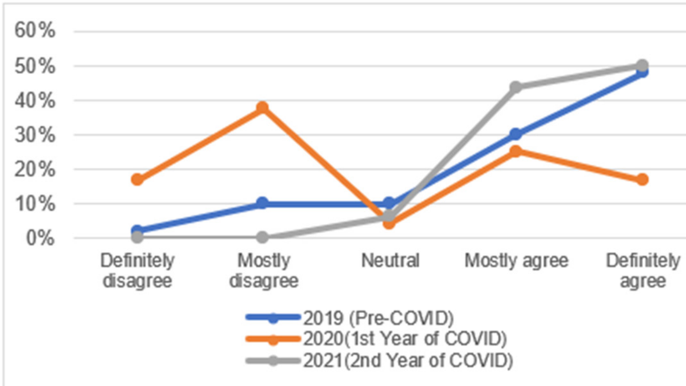
i. Overall, I found this module provided an excellent learning experience



ii. This module challenged me to do my best



iii. I found the support I received from the teaching staff on this module was appropriate for my needs



iv. The assessment methods used on the module enhanced my learning

Figure 12. Module evaluation feedback for CONM5006: number of respondents for 2019 (47/51); number of respondents for 2020 (24/50); and number of respondents for 2021 (16/52).

On the very good aspects of the modules, two main findings emerged, amongst others. Firstly, recording lectures was highly commended by students in PMAN7006, PMAN7004, and CONM5006 for the COVID-19 periods (2020 and 2021). Prior to the COVID-19 pandemic, lectures in these modules were conducted using Adobe Connect and a camcorder for recording. Although in the past, recording using Adobe Connect and camcorders has been appreciated by students, it has, on occasion, received negative feedback with regards to the timing of upload and release for students to access. Recording a 2 h lecture using Adobe Connect and camcorders can easily take hours to be processed before uploading, leading to lecturers uploading recordings a day after the delivered lecture. On the other hand, using Zoom and Panopto recording was easy, and by the evening of the same day, the lecture was released to students. Two examples of feedback from students are as follows:

“I found this module extremely beneficial which is even more impressive considering it was taught mainly over Zoom”.

“The Videos recorded for the BIM were very explanatory and in-depth as a tutorial and helped us a lot in understanding the application of the process both in our learning of the software and completion of the course work. it will be nice if these can be saved as MP4 videos and shared with the students. Having these videos will enable us to refer to it once in a while if we forget the process of some of the applications in the future. Even YouTube videos are below comparisons with these videos".

Another aspect that was commended was the BIM workbook. Some of the feedback read as follows:

"The resources available and the BIM workbook were really good".

"Good to learn new techniques, with the guide book (BIM workbook) being a very effective revision material".

"Excellent learning materials provided by X (Name of one of the teaching staff) with both the booklet (BIM workbook) and the video lectures".

The BIM workbook is a step-by-step guide for learning the different applications of BIM software in practice. This was developed by this researcher about 6 years ago for students to use in learning the different BIM software programs independently, from the comfort of their homes with little or no supervision. While the BIM workbook was initially published six years ago, it is updated annually to incorporate advancements in technology. These updates ensure that the content remains current, relevant, and aligned with contemporary trends in BIM and related fields. Although the book has been provided to students, years before the COVID-19 outbreak, not all students really exploited it, especially those attending F2F lectures. With restrictions due to COVID-19 measures, many students including FT and PT students used the manual and found it beneficial.

On what could be done to improve the modules, an issue related to the timeline with software installation emerged. Given the abrupt outbreak of COVID-19, FT students had limited time to purchase hardware to install software necessary to complete the different coursework components. This is reflected in one of the following statements by a student:

"It must be made clearer to students before starting the course what type of laptop they should have to run the different software. I know students will be on site but if they wish to work on iTwoCostX and Revit on their own laptops they need to know which processor and RAM is required. I lost all of my work 2 weeks before the deadline because my Mac really struggled running the software even though I bought it just before the course started".

The results in the preceding paragraphs revealed that the sudden change to online learning did not affect the students' satisfaction level.

While there is a paucity of research about how students performed during the COVID-19 period compared to previous years, a study by Rapaport et al. [83] actually revealed that students struggled during the COVID-19 period. The study funded by the Bill and Melinda Gates Foundation and the National Science Foundation surveyed 1335 households with at least one pre-K-12th grade child, and as of our most recent wave found that students still at home, or even those in a hybrid schedule, were hardly better off than they were in the spring. Furthermore, the findings from our study contrast that of Joia and Lorenzo [48], which revealed that hard skill disciplines, when they migrate to technology-mediated environments, are more likely to fail to achieve their educational goals than soft skill disciplines subject to the same migration. Perhaps one of the reasons for the good student satisfaction feedback is because, at the postgraduate level, blended learning has been in place for some years, although the technology was not well-developed, as it was during the COVID-19 pandemic. The transfer from blended learning to online learning was therefore seamless, boosted by more efficient technologies such as Zoom, Panopto, AppsAnywhere, etc.

5. Discussions

Based on the analysis presented in the preceding section, a number of recommendations can be made. To facilitate understanding, the summary of the recommendations in alignment with the research questions RQ1 to RQ6 have been presented in Table 1.

Table 1. Summary of main outcomes and lessons learned.

Factors	Outcomes	Lessons/Recommendations
Effective strategies enhancing learning during hands-on workshops (*RQ1*)	HyFlex and blended learning were the most preferred Use of an assistant Formative activities BIM workbook	While HyFlex, blended learning, and formative activities were preferred, the main lesson here is the use of an assistant (co-teacher) to ensure their success during implementation. Using an assistant aligns with recent calls for the adoption of team teaching in higher education [84].
Learning mode that worked well during the COVID-19 (*RQ2*)	Blended learning HyFlex F2F by FT students Online by distance learners	The stated learning modes that worked during COVID-19 must take into account whether students are FT or PT. Nonetheless, if blended and/or HyFlex modes are adopted, the lectures should be recorded so that those that cannot attend live can watch after.
Benefits of BIM educational delivery methods during COVID-19 pandemic (*RQ3*)	F2F was more beneficial (F2F allowed students to use more reliable university computers) HyFlex offers the flexibility to change their mode of attendance every week to meet their prevailing circumstances	One of the main reasons learners preferred F2F was because they could depend on more reliable university computers. For the future, to ensure PT students do not struggle, computer specifications should be provided in advance to allow them to buy and be ready for lectures. Secondly, AppsAnywhere and similar technologies should be used to make sure students can access university computers remotely.
Challenges/barriers hindering learning during hands-on workshops (*RQ4*)	Limited or lack of formative activities The speed of the lecturer Poor internet connection	More formative activities should be included and the teaching team should make sure the speed of teaching/communication is appropriate. Students should be reminded of the possibility of poor internet during lectures, so that they can have alternative back-up plans.
Post-COVID-19 learning methods (*RQ5*)	HyFlex and blended F2F	The HyFlex and blended modes should be the way forward. However, sessions should be recorded for students who cannot attend live sessions.
Effect of sudden switch to blended learning on the quality of students' satisfaction (*RQ6*)	The data from module evaluation reports revealed students experiences prior and during the COVID-19 pandemic and that the rapid unplanned switch to online learning did not affect students in BIM courses	Despite studies (e.g., [51]) showing that technical subjects are more likely to fail when migrated to technology-mediated environments, our experiences show the contrary. In fact, BIM can be delivered entirely online without jeopardizing students' learning experience, although more resources may be required.

With regards to effective strategies that enhanced learning during hands-on workshops, four main results stood out.

Firstly, HyFlex and blended learning were the most preferred modes of learning and also were recommended as the way forward post-COVID-19. Although these approaches to learning had already been adopted by universities, the pace of uptake has been very slow and mostly applied to some postgraduate programmes. The findings from this study now show undergraduates want elements of blended learning as well. This is a new development, as undergraduate programmes are delivered F2F in most universities.

Secondly, using an assistant to deliver hands-on BIM sessions worked out well. It worked well as using two instructors meant students were not bored hearing the same voice and seeing the same face throughout. The assistant also contributed in annotating different sections of the illustrative task on the software being screened, which aided active learning. The role of the assistant also included monitoring the chat box and the shared Google Document where students were engaged in asking questions without the need to disturb the flow of the session. However, it is important to note that using two staff members and the annotation tool in Zoom for delivering hands-on workshops may not be necessary for other disciplines such as in the social sciences where a hands-on demonstration of the application of software is seldom taught. The assistant was also used in gathering and answering certain questions from FT and PT students. As noted early in the challenges section, Section 4.5, the lead instructor always stayed around the presentation computer station to ensure the sound was correctly captured for PT students. Consequently, FT students struggled to hear and also may pose questions that PT students do not hear and may ask again. The assistant can deal with these questions in the chat without involving the main tutor, thereby not interrupting the flow of lectures.

Thirdly, formative activities should be used to enhance students' learning. Not only will these enhance subject learning, but they will help students learn how to save files and how to avoid the technical challenges that students often face in the last minutes of submitting their coursework. Furthermore, breaking activities into small tasks provides opportunities for formative feedback at the start, before moving into more complex tasks. As presented in Section 4.2, formative activities were highly commended by undergraduate students as they helped them overcome challenges such as the installation of software, saving files, and early engagement with learning materials. This could be taken forward by breaking down the final task into small tasks to provide opportunities for formative feedback at the start, before moving into more complex tasks.

Fourthly, the qualitative feedback revealed the need to continue using the BIM work book and recording lectures and converting the latter into MP4 files for students to be able to export them out of Moodle-the learning environment used in our school. Also, it emerged that students should be provided with information about the software and hardware specifications early on for students to know exactly which to buy. Furthermore, in providing the specifications, it is important to specify which software is Windows or Mac compliant. Some BIM software cannot be installed directly on Mac and may require additional cost to buy a boot camp—a utility that allows for a switch between macOS and Windows.

With regards to the best educational learning mode that worked well during the COVID-19 pandemic for delivering BIM workshops, the most preferred learning method was blended learning followed by HyFlex learning. However, a detailed analysis showed more FT students preferred F2F while more PT students preferred online. Also, a significant number of undergraduate students also preferred blended and HyFlex modes. Although this may not be a significant change to postgraduate students, it is and will be for undergraduate students, as their mode of study had been predominantly F2F.

The main benefits of BIM educational delivery methods during the COVID-19 pandemic were the reliability of university computers associated with F2F and flexibility to change their mode of attendance every week to meet their prevailing circumstances associated with HyFlex.

The main challenges/barriers that hindered learning during hands-on workshops were the limited or lack of formative activities, fast speed of the lecturer, and poor internet connection. Educators should adjust the speed of teaching and communication to an appropriate level. More formative activities should be included to enhance students' engagement.

For post-COVID-19, the main preferred learning methods are HyFlex and blended learning followed by F2F learning. Given that the proportion of PT students in postgraduate courses is increasing, it is imperative to record sessions for PT or any other student that could not attend the live sessions.

The sudden switch to blended learning did not have an effect on the quality of students' satisfaction. The data from module evaluation reports revealed students experiences prior and during the COVID-19 pandemic and that the rapid unplanned switch to online learning did not affect students in BIM programmes. The feedback should be considered with a caveat that the data was not segregated between FT and DL as respondents blindly edited or provided their feedback. As part of future studies, data collection should take into account learning modes as well as the diverse background of learners.

Although a subject of ongoing debate, the academic achievement gaps between white and black students have been well-documented and showed white students tend to fare better than students from ethnic minority groups [85]. Studies are already showing students from ethnic minority background are likely going to experience the impact of COVID-19 more than their white counterparts [86,87]. Designing any BIM virtual learning course should take into account causes of the differences in attainment gaps [88]. In other words, it is important to design any BIM module to be as inclusive as possible to meet the needs of students from different backgrounds now and in the future in the unfortunate event of another disease outbreak or pandemic. Educators should consider cost and choose the best or optimal technology solution affordable, especially to those from disadvantaged backgrounds. AppsAnywhere and Parallel are examples of such solutions which can help students avoid buying very high spec hardware which may not be affordable. Affordability can be an issue for students from disadvantaged backgrounds. Also, providing the specifications of the hardware in advance may help students to decide whether to buy macOS or Windows—of course with additional cost implications with the former, due to the need to purchase boot camp. Another example is designing coursework that is inclusive. For example, in one of the coursework activities common to the PMAN7004, PMAN7006, and CONM5006, students are expected to design a domestic building of their choice, of course with some specifications such as GFA, the number of rooms, parking, etc. However, they can choose any standard of any country. Given some students were based in their country of origin, with little or no UK experience, they could easily just design a building using their country's standards rather than one for a country they have not been used to. In another course activity, students were expected to visit sites and identify issues, take photos, and attach them to the digital equivalent in a common data environment. It would have been impossible to carry out this task by students not residing in the UK if UK projects were the only cases required for the coursework. On the other hand, some students may be interested in learning something new, e.g., exploring UK projects in their coursework where they have little knowledge and not focusing on projects from their home country, which they are already used to. The take-away here is for educators to not assume the choices of students based on their background or distinct features. Educators should be open and inclusive and leave the ultimate choices to students themselves. To conclude, the authors recommend that programmes should be inclusive and adaptive in nature to avoid significant changes in the case of any pandemic. Adaptive design here is used with a similar connotation as in architecture. Adaptive architecture is defined as a framework that changes its structure, behaviour, or resources according to request. Modules should be designed in such a way that adapting them to any condition should have very minimal impacts on students.

Given the practical nature of BIM, it is imperative to provide recommendations on how this study can be useful from a practice perspective. Firstly, it is hoped that instructors can learn from this to inform their teaching and learning, especially when designing BIM courses during and post-COVID-19 or any other pandemic with similar characteristics to that of COVID-19. Secondly, students can learn from what worked well and what did not in order to better prepare for BIM lectures or similar technology-based modules presently or post-COVID-19. For example, using formative activities proved successful in enhancing students learning. In the future, students should engage with all BIM formative activities to gain the best learning experience.

To conclude, this study has the potential to increase knowledge and understanding of ways in which virtual teaching techniques using digital technologies (e.g., Zoom, AppsAnywhere, etc.) can be used in enhancing digital construction technology (in this case BIM) education. Although this study is grounded on the virtual delivery of BIM, it is broad enough to be of interest to a wider education community and especially those in the computer and education fields. This is because the study covers many pedagogical aspects, as highlighted in research questions RQ1 to RQ6, that can inform the develop of educational curriculum.

6. Implications, Future Research, and Conclusions

6.1. Implications for Practice and Theory

This study was developed to share experiences and lessons learned in delivering BIM lectures during the COVID-19 pandemic. Adapting virtual learning techniques to technical subjects like BIM posed unique challenges, unlike other disciplines where the shift to virtual learning was more straightforward. The findings of this study offer valuable insights for both practice and theory.

Students demonstrated a clear preference for blended learning techniques, which effectively addressed the needs of both full-time (FT) and part-time (PT) students. The flexibility and accessibility offered by blended approaches allowed students to balance their studies with other commitments, enhancing their overall learning experience.

The use of two staff members—one as the main instructor and the other as an assistant—proved particularly effective in improving engagement during hands-on workshops. This approach also helped reduce Zoom fatigue, a common issue for both students and lecturers in virtual environments, by providing additional support and ensuring a more interactive and focused delivery of content.

Another key finding was the importance of implementing formative activities early in the semester. These activities were essential for engaging students, identifying challenges at an early stage, and mitigating potential issues that could otherwise disrupt the learning process later in the course.

The study also makes a significant pedagogical contribution by highlighting strategies that are not only relevant to BIM education but are also transferable to other technical disciplines. These strategies include effective virtual learning delivery methods, the benefits of blended approaches, and the critical role of formative assessments in ensuring student engagement and success.

From a theoretical perspective, the study addresses the paucity of research on virtual learning delivery for BIM education. By providing insights into practical teaching strategies and their effectiveness, the study contributes to the development of inclusive, adaptive, and engaging pedagogical approaches for technical, hands-on courses.

This combined understanding of practical and theoretical implications provides a valuable framework for improving virtual and blended learning delivery in BIM and related technical disciplines.

6.2. Future Research Directions

Several areas for further research have been identified. First, future studies should provide more detailed analyses of full-time (FT) and part-time (PT) students. While FT students experienced a significant shift in learning methods during the pandemic, PT students, who were already familiar with remote learning, may have had a different experience. Disaggregating the data between these two groups would allow for a more nuanced understanding of their respective challenges and needs.

Another important direction for future research is the development of virtual BIM programmes that are both inclusive and adaptive. Ensuring equity in learning experiences for diverse student groups, including those with varying technological access or learning preferences, is essential for the broader implementation and success of virtual learning methods.

Finally, given the domain-specific focus of this study, future research should explore the applicability of the pedagogical strategies identified here to other disciplines that require technical and hands-on demonstrations. Such investigations would help determine the extent to which these approaches can be generalised, offering further insights for technical education delivery across various fields.

6.3. Conclusions

This study demonstrated that virtual learning methods can effectively deliver BIM education, addressing concerns about the feasibility of teaching technical, hands-on content remotely. Key findings include the preference for blended learning, the importance of dual-staff support, and the role of formative activities in maintaining engagement and addressing challenges early.

While the study primarily focused on postgraduate BIM programmes, its pedagogical insights are relevant and transferable to other technical disciplines. Despite limitations such as the lack of disaggregated data for FT and PT students, this study provides valuable strategies to enhance learning delivery, offering a framework for educators to adapt in both crisis and non-crisis scenarios.

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