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SUPPORTING THE OPENBIM TRANSITION

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Abstract

The AEC industry is concerned about the value for money, interoperability and innovation of closed BIM software. A maturing OpenBIM ecosystem of free and Open Source (FOSS) tools may soon provide viable alternatives to closed BIM tools. University BIM education could support a transition in the AEC towards OpenBIM tools. Based on an evaluation of an existing BIM course and BIM education literature, this paper identifies OpenBIM principles, learning objectives, activities, future roles and vision to support the transition to OpenBIM. It proposes that this can be achieved by extending existing BIM curriculums to include OpenBIM Ontologists and OpenBIM Champions.

Introduction

BIM has long promised to be the solution to many interconnected problems in the AEC industry (Bosch-Sijtsema et al., 2021). However, recent public letters to the closed BIM software industry (Day, 2022) argue that proprietary (closed) BIM software is not providing what architects and engineers 'need' in terms of value for money, interoperability and innovation. This ultimately affects the AEC industry's ability to deliver the promises of BIM. The OpenBIM standard Industry Foundation Class (IFC) provides a data model that allows models from different native closed BIM applications to be queried in a standardised way. An example is in the use of the ifcOpenShell Python library, which has now been combined with the free and Open Source modelling platform Blender to create BlenderBIM. Such tools, when combined with open standards, provide an opportunity to address the challenges of value for money, interoperability and innovation in BIM. It is therefore important to understand how to use this opportunity to support the AEC's transition to OpenBIM. BIM education is essential in supporting the promises of BIM (Sacks & Barak, 2010) and is now widespread in universities. Although BIM education should focus on BIM concepts not BIM tools (Sacks & Barak, 2010), the provision of free 'educational' licenses of closed BIM software means that many courses have become reliant on closed BIM modelling and analysis tools which affects the scope of Open BIM tools, data and processes that they can explore (McGinley & Krijnen, 2021). Ghosh et al., (2014) state that effective BIM education requires a mix of theory, practical experience and technology driven collaboration environments. However, use of closed BIM tools maintains and reinforces traditional single or multi-disciplinary BIM for federated models (McGinley & Krijnen, 2021). It is therefore responsible in part for maintaining silos in the AEC industry. The challenge in BIM education is therefore to balance the need to provide students with industry relevant skills 'whilst avoiding the devolution [of BIM education] into the simple teaching of a software' (Benner & McArthur, 2019). Trevelyan (2019) also warn of the dangers of developing curriculum only based on the current needs of industry. Refocusing on the needs of students; this paper argues that the OpenBIM transition requires professionals that can develop, maintain and analyse: OpenBIM tools, models, processes and ontologies using OpenBIM standards. So how can university education support the transition to OpenBIM? Firstly, we need a model to understand it. We could use change management theories of organizational change in the use of BIM (Liao & Ai Lin Teo, 2018). An alternative approach would be to view BIM as part of a socio technical system (Sackey et al., 2014). This enables us to align the 'OpenBIM transition' with sociotechnical transitions literature, which involve a transition from one socio technical system to another (Geels, 2019). The potential transition to Open BIM could then be viewed in parallel with other contemporary transitions including:

Digital: The shift from desktop solutions to the cloud, the dangers of proprietary cloud lock in and automation including AI and the digital transformation more generally (Türkeli & Schophuizen, 2019).

Sustainable: The sustainable (green) transformation (Geels, 2019). This transition provides, for instance, a need for life cycle analysis of the products in the BIM model alongside the OpenBIM transition.

Educational: This includes the student's own transition from student to the workplace (Trevelyan, 2019) (or perhaps vice versa in the case of continuing education). As well as increased use of online teaching.

Methodology

The transition to Open BIM therefore provides an opportunity to support more interdisciplinary thinking through an emerging ecosystem of open interoperable BIM, that can be modelled as part of a wider socio technical transition. However, the door is closing on this opportunity. Universities therefore have a responsibility to 'open the door' for students to learn 'howto' BIM within a scaffolded, disruptive, innovative and interoperable Open BIM ecosystem of data and tools (McGinley & Krijnen 2022). So how should a BIM education support its own transition to OpenBIM whilst still situating itself in the student's own, student to professional, transition within the global digital and green transitions? To address this question, this paper identifies: (1) future OpenBIM roles and (Open)BIM learning objectives (Adamu & Thorpe, 2016; Sacks & Pikas, 2013); (2) Analysis of the student feedback of a postgraduate OpenBIM course; (3) Supporting OpenBIM tool development (4) proposed course activities; (5) a future OpenBIM vision. These are then discussed and evaluated to identify future work to support the AEC's transition to OpenBIM. In support of this, three OpenBIM principles are proposed:

P1) Open, FAIR and Standardised

Aim: Be agnostic about data and platforms and focus on supporting the interfaces of disciplines and tools.
Learning Objectives:

1. Identify, locate and extract information for a specific use case from an IFC model.
2. Apply appropriate OpenBIM standards such as ISO 19650 and guidelines to support open and FAIR data, tools and processes for a specific use case.

P2) Reusable and Maintainable

Aim: Understand that work (the data, guidance, models and analysis) is precious and should be reused and maintained where possible.
Learning objectives:

3. Teach a learnt concept or skill in OpenBIM to peers.
4. Create, Fork, branch and collaborate with peers in a code repository.

P3) Agnostic and Guiding

Aim: To be agnostic about the tools they require and have the ability to develop their own OpenBIM tools. Learning Objectives:

5. Apply and improve their existing programming skills to develop or maintain an OpenBIM tool for a specific use case.
6. Guide other members of the design team with the creation or maintenance of an OpenBIM tool that provides professional disciplinary guidance for a specific use case.

To support these principles, this paper argues for the extension of the traditional BIM education roles of modelling, coordinating and managing (Pauwels & Petrova, 2020). Adamu & Thorpe, (2016) summarise four BIM roles as *Model Manager, BIM manager, BIM coordinator and BIM engineer* (Figure 1, bold) that represent emerging professions that should be offered in degree and graduate programs. The transition to OpenBIM will augment these existing roles as well as require new ones in the future. These roles require a fundamental shared understanding of the principles of OpenBIM and how to work, collaborate and support the construction and maintenance of an emerging OpenBIM ecosystem of FOSS OpenBIM tools with FAIR and Open data and standards.

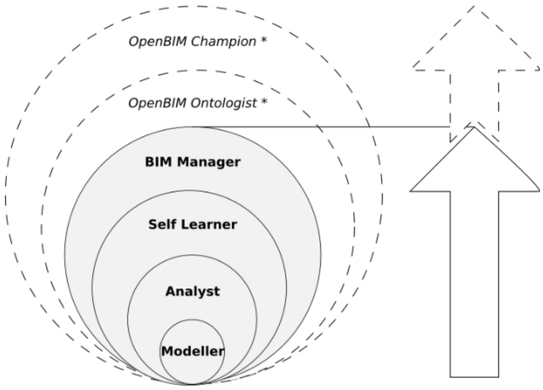

*Figure 1. BIM education levels (Adamu & Thorpe, 2016) in grey. The dashed and * levels suggest 2 further levels to support the transition to OpenBIM.*

1) OpenBIM Future Roles

Five OpenBIM roles are presented here, a three-level rubric based on Figure 2. Level 1 (beginner) would be an introductory exercise. Level 2 intermediate and advanced (Level 3) are explored through progressively more advanced projects. Following this an OpenBIM education framework is presented to explore the links between the proposed OpenBIM roles (Figure 2).

R1) OpenBIM Modeller

Firstly, the transition to OpenBIM modelling tools will affect ***BIM Modellers*** by encouraging IFC based modelling directly in the software in tools such as the free and Open Source software (FOSS) BlenderBIM. Furthermore, this supports working in emerging platforms such as Speckle, BHoM (Elshani et al., 2022) and IFC.js as well as the new tools and services that they afford.
Level 1: Modelling a building in native (closed) BIM software and exporting to IFC, with a focus on mapping modelled properties.
Level 2: Modelling and editing a model in BlenderBIM or FreeCAD for instance, including appropriate object meta information in conformance with the OpenBIM IFC standard.
Level 3: Parametric modelling of the OpenBIM objects using visual programming languages, such as Grasshopper, Dynamo and Sverchok / Geometry nodes in Blender(BIM) for instance.

R2) OpenBIM Analyst

The OpenBIM analyst role supports the modeller in the analysis and interoperability of their OpenBIM models, FAIR data and processes. New OpenBIM tools could be built by OpenBIM Analysts that would be trained in OpenBIM tool development. This would support the transition from file based information exchange, to the streaming and reframing of data services such as Speckle and the querying of OpenBIM data using OpenBIM analytical tools via an application programming interface (API). The skills and tools in this area are developing at such a rate that new technologies and tools arrive during a semester. Therefore, students need to be provided the foundational concepts and approaches so that they can use

‘self learning’ techniques to support their own transition to becoming an OpenBIM AEC professional.
Level 1: Analyse a standard IFC file in Excel generated using the IFA analyzer tool and create a new Excel sheet dashboard queried from the IFC information in Excel.
Level 2: Analyse the property sets of an IFC file in the BlenderBIM GUI and develop a simple Python Script in BlenderBIM using ifcOpenShell.
Level 3: Develop standalone Python programmes using ifcOpenShell for specific use cases.

R3) OpenBIM Manager

The OpenBIM Manager is based on the traditional BIM manager role. Based on these skills, students could then work to develop OpenBIM Manager skills.
Level 1: Analyse a standard IFC file in Excel generated using the IFA analyzer tool to check OpenBIM information availability and assign responsibilities.
Level 2: Apply BPMN / UML modelling and investigations to identify new processes, information flows and procedures based on ISO 19650.
Level 3: Systems Architect (McGinley, 2015) (operating at an information systems level) with process automation, possibly with Node-Red (*Node-RED*, 2023).

R4) OpenBIM Ontologist

Students interested in this area would focus on (re)organizing OpenBIM data including both classification systems and the Linked Open Building Data (Rasmussen et al., 2020), which typically focusses on semantic linked building data queries about the building, its systems, components, their relationships, and properties. This new role extends traditional Linked Building Data semantic analysis to organize the digital representation of the design systems to support design experimentation at a system rather than component level.
Level 1: Analyse a standard IFC file in Excel generated using the IFA analyzer tool and classify its objects.
Level 2: Apply, develop or extend an appropriate classification system for a specific use case.
Level 3: Focus on Linked Data and Ontologies such as the building topology ontology (BOT) (Rasmussen et al., 2020).

R5) OpenBIM Champion

The OpenBIM Champion should have mastered the other roles and specialise in two of them. The role includes an ability to support others to learn how to get the guidance they need through using or developing their own OpenBIM tools for instance (Figure 2). They will be able to provide the essential service in a knowledge-based industry, of being able to teach and mentor peers to develop OpenBIM skills and concepts in one or more of the other roles proposed here, eventually leading to the creation of more OpenBIM Champions to support the OpenBIM transition, which is the goal of the course.
Level 1: Write a markdown tutorial and concise video.
Level 2: Write a Jupyter notebook tutorial.
Level 3: Develop micro credentials / course activities for specific learning objectives.

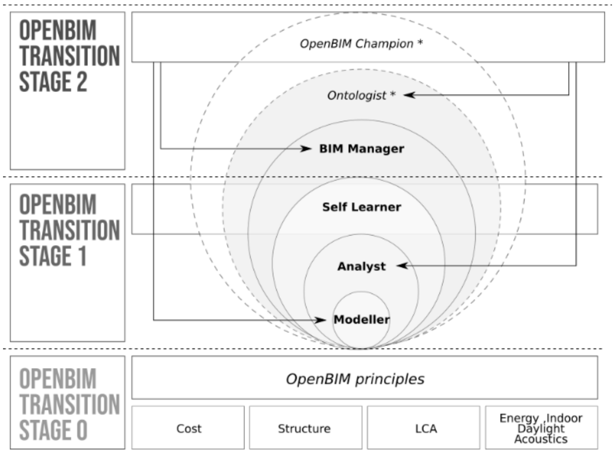

Figure 2. OpenBIM education framework, (middle, bold):Barison & Santos (2010) cited in Adamu & Thorpe (2016) left middle, italics: new levels proposed by author.

2) Previous BIM Course Analysis

Wang Liyuan et al., (2020) argue that BIM Curriculums should include both ‘BIM standalone’ and ‘BIM embedded’ courses such as (Karlshøj, 2016). Jolanta & Pupeikis, (2018) suggest a move towards BIM educations being incorporated into other courses rather than as ‘stand alone’. Furthermore, Ghosh et al., (2014) emphasise horizontal integration in BIM education where students collaborate across different disciplines. Ghosh et. al., argue that providing both horizontal and vertical integration (across degree levels) provides a more representative model of the experience of working with BIM in practice. Based on our previous attempts to support the OpenBIM transition through BIM education in BIM (McGinley & Karlshøj, 2022; McGinley & Krijnen, 2021, 2022) we have observed that students find different problem domains motivating i.e. structural, LCA, cost or indoor environment / energy as well as different interests in how they wish to design and analyse within that domain problem. Student motivation is precious (OpenBIM principle 2), so we decided to differ from Wang Liyuan et al., to bring the subjects into the BIM class rather than bring BIM into the subject class. This means that BIM education can ‘piggy back’ on the subject based motivation of the students. The aim is that students will see OpenBIM as supportive to their own learning goals and understands how it can support the current multiple transitions of the AEC that are relevant to them.

Learning from BIM

So how to offer the freedom to find new ways of working and ‘learning from BIM’ on the issues they are motivated by within a curriculum that effectively scaffolds their learning of complex concepts? The first assignment focuses on what we can learn from BIM (McGinley & Krijnen, 2021). This includes analysing examples from a previous student design course. This has previously been approached using the IFA IFC Analyser tool and last year also introduced BlenderBIM to help interrogate the properties in the IFC file.

OpenBIM Use case definition

(Jin et al., 2021) provide a critical analysis of 'disruptive digital-driven built environment education'. It identified that BIM courses have changed from the early focuses on modelling, visualization and collaboration. More recently they also focus on 'digital skill development and integration with other Industry 4.0 technologies (e.g., VR)'. This has resulted in an expansion of the educational space of traditional BIM courses. This potentially offers a greater opportunity to learn, but also has the parallel danger of 'course bloat' and lacking a clear structure that is easily perceptible to the students.

The use case and need, and the approach to solve it should therefore be identified by the student. Furthermore, it is important that the students are motivated by the use case they are investigating. In this iteration of the course, the students captured both the 'AS IS' and 'TO BE' system in BPMN files. This helped them to identify the flow of information and processes in the use case, but in the feedback they felt that the BPMN should have been explained better. This will be achieved in future work by linking it to the IDM explanations.

OpenBIM Modelling

In the autumn 2022 version of the course, BlenderBIM was introduced, however the focus was on using it to analyse and understand IFC models that the students imported into it. The scripting interface was presented as a potential OpenBIM Integrated Development Environment (IDE). This enabled the students to both query the models in python using IfcOpenShell and explore their properties graphically in BlenderBIM. The feedback received was that modelling was not addressed, although we did open the models in BlenderBIM, at the time, we did not have the experience in the teaching team to model in BlenderBIM. So, in the next iteration of the course it will be necessary to add a parallel modelling investigation option to this assignment to complement the existing strong analysis component.

OpenBIM Analysis

The course is an MSc level advanced BIM course for Architectural Engineers. Architects learn by designing, whereas Engineers learn by analysing. Therefore, Architectural Engineering requires a hybrid learning pedagogy that includes both learning from analysis and design. This signature pedagogy provides a mindset to support the development of new OpenBIM tools. However, this requires programming and software development skills in Python and knowledge of IFC and the IfcOpenShell library, as well as managing their group's code repository in Github and selecting an appropriate license to support testing and further development and ultimately contribute to maintaining and developing the OpenBIM tool ecosystem. Based on the Autumn 22 course, the students wanted:

- A better IFC example model (not IFC2x3 or the 'duplex' model), not too big, and that had the properties that were relevant to their use cases.
- A resource of common ifcOpenShell code including, functions etc. to help them develop their tools.
- More teaching / learning on the structure of IFC.
- To keep the Excel (IFA Analyser) exercise; as long as the model is also updated to IFC4.
- Basic Python should be made a course prerequisite. Perhaps it could be required to complete an online tutorial before the course starts, so that everyone has achieved the same basic level.

For students to be able to create their own OpenBIM tools, they need to learn several new concepts. This requires them to think differently. The feedback is that they are willing to learn and motivated to create their own tools but the process needs to be more carefully scaffolded to support their learning. To address this, the teaching team and students co-designed a 'development methodology for OpenBIM tools' during the course.

OpenBIM tool development methodology

To support the development of new tools (OpenBIM principle 3), we co-designed an OpenBIM development methodology with the students (Figure 3).

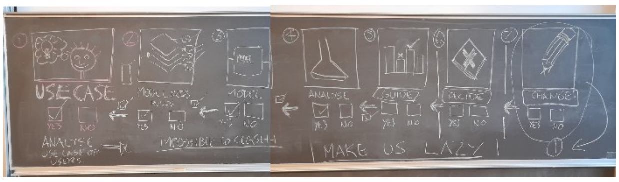

Figure 3. Student co-created OpenBIM development Methodology

The development methodology proposed in Figure 3 was intended to support the students to develop OpenBIM tools and processes based on the defined principles. The core methodology focuses on seven questions. The stage names of the methodology are the underlined words in the question.

1. What is the use case?
2. What does the user need to know?
3. What are the data inputs of the model?
4. What analysis needs to be performed?
5. What decision should the guidance support?
6. How does the guidance support a decision?
7. How is change in the model supported?

To address OpenBIM principle 1 an attempt was made to map the methodology to the ISO 19650 stages, to make the link to Open standards (Figure 4). This will be investigated more in the next iteration of the course, as it currently confuses the design, development, implementation and feedback stages of the methodology.

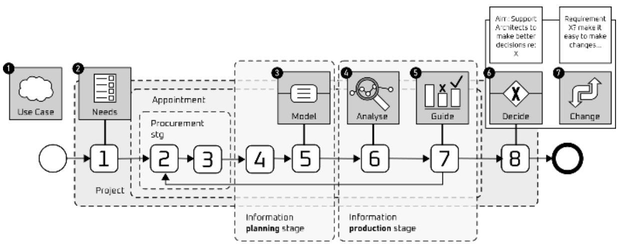

Figure 4. Mapping proposed stages to ISO 19650

3) Supporting OpenBIM development

To further support the proposed development process and to provide feedback to the students on the development of their analysis tools. The students were asked to fork an existing Github repository that contained python code for converting IFC files to a new speculative 'HTML-IFC' format. The students could then work with the converter code and also with the HTML5 code to display the resulting HTML-IFC file. The format was intended to provide a simplified 'sandpit' of the complexity of IFC files in an easily editable format. To support this, a custom web tool was developed that enabled editing and analysis of their code in real time using the Prism JS package.

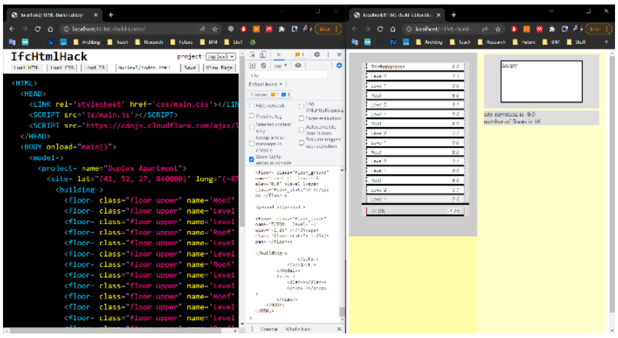

Figure 5. The Prism JS based custom developed code editor.

Some students choose to continue in this new approach but many decided it was too confusing and choose to focus on Python and outputting the result to Excel. However, one group managed to extend the provided approach to output the drawings in SVG which aligned well to the OpenBIM principles. We [the teaching team] tried this approach because we were comfortable with the IfcOpenShell Python tool development, but wanted to try to see if we could incorporate other approaches whilst retaining the common 'theme' of IFC. So, in 2022 we tried to explore different approaches (Speckle, IFC.js, Linked Data and also an emerging HTML-IFC process).

'Ended up doing a really cool project, but it was a confusing process throughout the course unfortunately. Yes we got introduced to multiple programs, but only introduced so you had no idea what to do with it or how to incorporate them. Loved the ifc coding part' (RESPONDANT A)

This turned out to be too ambitious, it was difficult to cover the approaches and students felt that they were exposed to too many different languages. Perhaps, it is also because the course tried to cover too many roles for a 5 ECTS course, in the future, students should be able to choose two roles to focus on.

'Exciting course, it has been very difficult to know what was expected in the various assignments' (RESPONDANT B)

Respondent B's point can be seen in overall feedback about student expectations. They felt that it did not support their learning overall (which fell by 0.2 points) and left them feeling that the expectations were unclear (which fell by 1.4 points compared to the previous year) this was despite a 1.3 point raise in happiness about the level of feedback compared to previous year, which suggests that the loss of expectations was very significant. Furthermore, the low expectations dampened a potential uptick in the learning Objective (LO) alignment, learning amount and activity motivation. So, it suggests that parts of the content are working but there are challenges with supporting the expectations (explaining what was expected of the students) which need to be addressed in the next iteration of the course. The student feedback for course improvements was to focus on 'just' IFC and python. This led us to consider that perhaps the python expertise should not be the focus of the course (it is a part of the wider digitalization transition for the students) because everyone entering the course is new to IFC (although this will change as this content is now being introduced in our undergraduate curriculum too). Additional feedback included:

- The students had different levels of skill in Python and lots of the work (on the course) requires high level of Python.
- They asked for more practical code examples.
- They had good ideas but were not able to implement them in code, which was frustrating.
- IFC and python was sufficient and difficult enough to understand by itself, without learning other languages.
- Basic things like navigation in the command line should be covered, as well as different methods to get data out of python.
- Require more support on how to deal with IFC PSETs and what to do if information is not there.
- Ability to make a contribution to an existing tool rather than have to 'reinvent the wheel'.

OpenBIM Reflection

At the end of the autumn 2022 iteration of the advanced BIM course, the students presented videos of their projects to each other and provided and received peer feedback in discipline specific groups. They followed this up with a reflection on their learning in the course. This helped the teachers and students to see the connections between the different tools and processes they had developed. The students felt that the course was hard and confusing but the final presentations at the end were fun. Based on their experience a generic adaptable course structure is proposed for future years.

4) Proposed OpenBIM Course Activities

*Table 1. Overview of assignments. Assignments with * have 2 activity options the students can choose (based on Figure 2)*

#	**Learning Activity**	
A1	Learning from BIM	
A2	OpenBIM Modeler*	OpenBIM Analysis*
A3	OpenBIM Manager*	OpenBIM Ontologist*
A4	OpenBIM Champion	

In the cases where the students have 2 options, they will help to evaluate and provide peer feedback on each other's work. The students will get an introductory lecture (video) to both options to support their choice (Adamu & Thorpe, 2016). In this way, the modelling groups will receive guidance from the analysis groups and provide feedback on that guidance back to them. This feedback should also include how it supported them to make decisions and ultimately if it was clear enough to help them to know how to change their model.

A1: Learning from BIM (Forensic BIM)

Focus on IFC analysis of real (previous) student building *design projects* from an advanced building design course that runs in the previous semester. Identify what the projects analysed, how did they test this? What was the domain focus of the investigation? Was it structural, energy and indoor, daylight, acoustic, LCA/LCC or something else? They should then be introduced to BPMN and use it to document the use case and explore the role of experts in OpenBIM. Following this, the students should review OpenBIM tools made in the previous year of the OpenBIM course and identify which tools could be used or adapted to solve the problem identified in the design project in the previous part. Finally, they could check the information validity of the models against the use case requirements they identified.

A2A: OpenBIM Modelling

This could include information and processes from other digital sources and platforms, i.e. 3D printing / rapid prototyping, as well as drone, mixed reality and laser scanning (Wang Liyuan et al., 2020). The main challenge here is to validate the BIM model and use current tools or tools of their own to fix issues efficiently. The model group would thoroughly check the received IFC file and fix missing or incorrect geometric and non-geometric information. This should be in collaboration with an analysis (A2B) group. Furthermore, they could develop their own models, but the emphasis in this assignment would be on maintaining, reusing and further developing existing models or sub systems (OpenBIM principle 2) for a specific disciplinary use case.

A2B: Analyse

This task would focus on analysing the models using scripts as in the previous years using BlenderBIM as an IDE (integrated development environment) incorporating a console, 3d view, IFC data model hierarchy, and IFC property views in one place. Additionally, this assignment would provide the opportunity for the student to develop their own OpenBIM tools in Python.

A3A: Manage

This task focuses on ISO 19650. The intention for autumn 2022 was to integrate real examples of 19650 into the course with practical examples, for instance by prototyping a total process using Speckle that complied to ISO 19650. However, time constraints in planning the course meant that this was ultimately replaced with traditional lectures from external parties. These provided informative content to the students but on their own were not enough for them to see the alignment to the other activities. A future BIM course should be focused on thinking in and gaining experience using ISO 19650 rather than just 'teaching' it. The experience of the autumn 2022 course enabled a proposal to map the development methodology (Figure 3) to ISO 19650 (Figure 4).

A3B: Ontology

The focus of this assignment is to support the Ontologist role. This should cover both Open Linked building data and traditional classification systems.

A4: OpenBIM Champion

The final assignment focuses on the ability to transfer knowledge in an organization. It aims to address; how do we 'learn from BIM' at an organizational level? This is a new component for autumn 2023. For autumn 2023, participants will therefore have to consider how to teach what they have learnt in the process to another group of students. Ideally this would support those that choose Analysis in the 2nd assignment to learn about modelling, or for the ontologists to learn about management. Suggested tools include, short tutorial videos, markdown files, carefully commented code and Jupyter notebooks. Furthermore, there would be a chance for them to develop custom content that could be linked to in the course learning environment that, with the student's permission, could be used in future iterations of the course to support student learning.

5) A future OpenBIM vision

Socio technical transitions, need something to transition towards. In our case it is a vision of an OpenBIM based AEC. However, we have not explicitly defined this vision. Therefore, in this final section, this paper uses the Science Fiction Prototyping (SFP) technique as used in (McGinley, 2015) to forecast a 'OpenBIM Future education' scenario to describe a possible destination for the OpenBIM transition and its effect on the future symbiosis of industry and education.

'She had always wanted to be an engineer, but had found a good job after her undergraduate and not returned for her Master's degree. Going back to Uni now was tough, but she really wanted to finish her education and thought an MSc was the right way to go. She was so excited when the University's digital industrial education (DIE) programme built and validated a customised OpenBIM MSc just for her. DIE had asked Jackie (the ML that ran the show at the engineering company she worked at) to help it develop a tailored programme that seamlessly integrated her upcoming work tasks with more traditional courses and the graduate outcomes. This meant she could see how her daily tasks at work could accumulate university credit to gain her MSc in just six months. Her course plan was calibrated on her old undergrad OpenBIM assignments and the tasks that Jackie thought she needed help with. In the old days it would not have been possible, but the previous government's OpenBIM and FAIR data education legislation meant all built environment data and processes were Open, FAIR and standardised across the AEC industry and in the public sector, including the universities. It was also made possible by the development of standardised intelligent interactive (SII) OpenBIM models for

every known building type. This in turn enabled the first BIM Virtual Learning Environments (VLE)s which changed work into a seamless and gamified educational credit service. Feedback was obviously automated, but the data was so deep, she didn't mind, and felt it really supported her learning goals. Morning updates reminded her of the tasks for the day and resulted in daily certification of her progress. Her colleagues thought she was crazy doing a full MSc, they all did ESMCs (Employer suggested micro credentials) in exchange for extra holiday minutes, but she still wanted her master's degree'.

Discussion

This paper aimed to support the AEC's transition to OpenBIM within the complex context of sustainable, digital and educational transitions, by supporting the transition from student to professional through a BIM course. Traditionally, BIM courses are either stand alone courses about BIM or BIM is integrated into other courses. This paper takes the alternative approach of integrating different disciplines into a standalone BIM course. The challenge with trying to support any transition through education is knowing how fast to pace the transition and how this might change throughout the course lifecycle and that of its students. Furthermore, at a discipline level there are many tradeoffs to be made in the design of a BIM curriculum. For instance, between modelling and analysis. It is important to leave these options 'open' to offer flexibility to the student's learning goals. The previous BIM course described here aimed to support the OpenBIM transition but did not balance the tradeoffs at the student level which demotivated some students. To address this, three principles of OpenBIM were defined here: open, fair and standardized; reusable and maintainable; and agnostic and guiding. The principles were then used to define five OpenBIM roles. There are different interests in BIM and not possible to be 'advanced' in all of them. It is therefore unlikely that a student will be interested in all five roles, so four of these are introduced in parallel, culminating in the OpenBIM Champion role as the validation of the students learning in the course. In this way the students get a chance to dig deeper into 2 roles and then to still learn about the other 2 roles from their peers at the end of the course. The parallel options do not need to be contained on the same course and could for instance provide a link between an undergraduate (OpenBIM Modeller) assignment and a postgraduate (OpenBIM Analyst) assignment. This could also work between the OpenBIM Manager and OpenBIM Ontologist options. In this way the proposed course activities could be thought of as a menu of components that a BIM course responsible could use to support their own course, relative to their own OpenBIM transition journey. Hopefully this will enable more university BIM courses to support the transition to OpenBIM in the AEC. Finally, a vision of a future OpenBIM based AEC was proposed to support future work in this area. The new model (Table 1) will be tested in Autumn 2023. It is hoped that it will inspire the design of OpenBIM courses or the augmentation of existing courses to support the OpenBIM roles defined here. The multiple transitions provide an interesting context for developing OpenBIM courses not least of which working with ChatGPT in the development of the OpenBIM tools. It is our opinion that this should be allowed. It may provide an opportunity to enable students to focus more on learning the OpenBIM roles, IFC and learning from (Open)BIM and less on 'learning python'. In this way the parallel transitions could support the transition to OpenBIM.

Conclusions

This paper is concerned with the dominance of closed BIM tools, it asked what is the role of universities to support this transition? How could we better support the transition and to what extent was university education part of the problem? As university educators, our job is to deliver an education system that provides the foundations for our students when they graduate as well as farther into their future careers in the AEC. Furthermore, we are responsible to empower them to support the change our industry and society is calling for. It would be easier to continue to teach closed BIM software and reinforce, their hold in the industry, relying on the provision of free tools. This paper builds on (McGinley & Krijnen, 2021), to describe an approach to support the AEC's transition to OpenBIM through university BIM education. It includes the principles, roles, a development methodology and support structure as well as a future vision to support the OpenBIM transition. However, the transition cannot happen in one course and needs to be supported in many universities. We hope this will happen and that together we can support the AECs transition to OpenBIM. Future work will be to run the proposed course to explore the possibility of delivering an OpenBIM future for the AEC industry and identify how to measure our progress in the transition to OpenBIM.

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References

Adamu, Z. A., & Thorpe, T. (2016). How universities are teaching BIM: A Review and case study from the UK. https://www.itcon.org/paper/2016/8

Benner, J., & McArthur, J. J. (2019). Data-driven design as a vehicle for BIM and sustainability education. Buildings, 9(5). https://doi.org/10.3390/buildings9050103

Bosch-Sijtsema, P., Claeson-Jonsson, C., Johansson, M., & Roupe, M. (2021). The hype factor of digital technologies in AEC. Construction Innovation, 21(4), 899–916. https://doi.org/10.1108/CI-01-2020-0002/FULL/PDF

Day, M. (2022, September 12). The Open Letter to Autodesk: two years on - AEC Magazine. AECMag. https://aecmag.com/bim/the-open-letter-two-years-on/

Elshani, D., Wortmann, T., & Staab, S. (2022). Towards Better Co-Design with Disciplinary Ontologies: Review and Evaluation of Data Interoperability in the AEC Industry. Proceedings of the 10th Linked Data in Architecture and Construction Workshop Co-Located with 19th European Semantic Web Conference (ESWC 2022), 43–52. https://ceur-ws.org/Vol-3213/

Geels, F. W. (2019). Socio-technical transitions to sustainability: a review of criticisms and elaborations of the Multi-Level Perspective. Current Opinion in Environmental Sustainability, 39, 187–201. https://doi.org/10.1016/J.COSUST.2019.06.009

Ghosh, A., Parrish, K., & Chasey, A. D. (2014). Implementing a Vertically Integrated BIM Curriculum in an Undergraduate Construction Management Program. Https://Doi-Org.Proxy.Findit.Cvt.Dk/10.1080/15578771.2014.965396, 11(2), 121–139. https://doi.org/10.1080/15578771.2014.965396

Jin, R., Adamu, Z., Chohan, N., & Kangwa, J. (2021). A critical analysis of collaborative and disruptive digital-driven built environment education. A Critical Analysis Of Collaborative And Disruptive Digital-Driven Built Environment Education. https://openresearch.lsbu.ac.uk/item/87314

Jolanta, Š., & Pupeikis, D. (2018). Review of BIM implementation in Higher Education. Journal of Sustainable Architecture and Civil Engineering, 22(1). https://doi.org/10.5755/j01.sace.22.1.21116

Karlshøj, J. (2016). Open BIM in course on advanced building design. Proceedings of the International RILEM Conference Materials, Systems and Structures in Civil Engineering 2016, 19–28.

Liao, L., & Ai Lin Teo, E. (2018). Organizational Change Perspective on People Management in BIM Implementation in Building Projects. Journal of Management in Engineering, 34(3), 04018008. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000604

McGinley, T. (2015). A morphogenetic architecture for intelligent buildings. Intelligent Buildings International, 7(1), 4–15. https://doi.org/10.1080/17508975.2014.970120

McGinley, T., & Karlshøj, J. (2022). A Circular Education System for the AEC. EC3.

McGinley, T., & Krijnen, T. (2021). Multi-disciplinary learning from OpenBIM. Proceedings of the 38th International Conference of CIB W78, 703–712. https://itc.scix.net/paper/w78-2021-paper-070

McGinley, T., & Krijnen, T. (2022). A framework for meta-disciplinary building analysis. ECPPM.

Node-RED. (2023). https://nodered.org/

Pauwels, P., & Petrova, E. (2020). Information in Construction. https://research.tue.nl/en/publications/information-in-construction

Rasmussen, M. H., Lefrançois, M., Schneider, G. F., & Pauwels, P. (2020). BOT: the Building Topology Ontology of the W3C Linked Building Data Group | www.semantic-web-journal.net. Semantic Web, 12(1), 143–161. http://www.semantic-web-journal.net/content/bot-building-topology-ontology-w3c-linked-building-data-group-0

Sackey, E., Tuuli, M., & Dainty, A. (2014). Sociotechnical Systems Approach to BIM Implementation in a Multidisciplinary Construction Context. Journal of Management in Engineering, 31(1), A4014005. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000303

Sacks, R., & Barak, R. (2010). Teaching Building Information Modeling as an Integral Part of Freshman Year Civil Engineering Education. Journal of Professional Issues in Engineering Education and Practice, 136(1), 30–38. https://doi.org/10.1061/ASCEEI.1943-5541.0000003

Sacks, R., & Pikas, E. (2013). Building Information Modeling Education for Construction Engineering and Management. I: Industry Requirements, State of the Art, and Gap Analysis. Journal of Construction Engineering and Management, 139(11). https://doi.org/10.1061/(asce)co.1943-7862.0000759

Trevelyan, J. (2019). Transitioning to engineering practice. In European Journal of Engineering Education (Vol. 44, Issue 6, pp. 821–837). Taylor and Francis Ltd. https://doi.org/10.1080/03043797.2019.1681631

Türkeli, S., & Schophuizen, M. (2019). Decomposing the complexity of value: Integration of digital transformation of education with circular economy transition. Social Sciences, 8(8). https://doi.org/10.3390/socsci8080243

Wang Liyuan, Huang Meiping, Zhang Xiaohua, Jin Ruoyu, & Yang Tong. (2020). Review of BIM adoption in the Higher Education of AEC disciplines. Journal of Civil Engineering Education, 146(3), 2643–9107. https://doi.org/10.1061/(ASCE)EI.2643-9115.0000018