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THE CYCLICAL DEVELOPMENT OF BIM AUTHORING TOOLS AND WORKFLOW METHODOLOGIES INTO THE MULTI-VARSITY CURRICULA OF ARCHITECTURAL, ENGINEERING AND CONSTRUCTION PROGRAMMES

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Abstract

This paper explores how the Trivarsity initiative addresses misalignment between AEC education and industry needs and its tangible results in showing the benefits and advantages for both staff and students of incorporating an interdisciplinary, multi-varsity curricular development into their European AEC programmes. Running annually since 2014, the collaborative BIM project has been an action research vehicle for an inter-varsity, interdisciplinary, collaborative design workshop, applying current and nascent digital tools and technologies. The constant re-alignment of AEC sector education to new, effective ways of working may ensure future proofing of educational provision.

Introduction

Background

This paper explores the benefits and advantages for both staff and students of incorporating an interdisciplinary multi-varsity curricular into their European AEC programmes. Effective and conclusive research generally provides evidence of what the curriculum in Higher Education Institutions (HEIs) should be (Emmitt, 2006). Through active participation in the research process, professional educators and students become clearer of the kinds of competence and attitudes which are critical for current and future effective professional performance (Schein, 1972). Businesses require graduates who not only have the skills to do the job, but who can aid the organisation to evolve in the face of continuous and rapid economic and technological change (CBI, 2012; Government of Ireland, 2019). Construction 2025 (Department for Innovation and Skills, 2013) reports on the future aspirations of the Architecture, Engineering, Construction and Owner/operations (AEC) sector, to include it being a world-leader in research and innovation which embraces Information Communication Technologies (ICTs) and smart construction. The NBS BIM report surveys the international adoption of digital tools and technologies (NBS, 2013; NBS, 2023), providing evidence of AEC sector practice now moving from the digital to the machine age. In digital construction, information is required at the level of data across the whole project eco-system. The radical change to the AEC sector disciplinary educational model, is in the application of the basal skills in practice of implementing digital tools, machine learning, and AI, necessitating the ability to design, manipulate and modify the (software) programming of architectural processes (Scheer, 2014, p.124): education needs to explore these innovative and disruptive developments in practice (nascent and emerging fields) to remain future-proof.

Methodological Approach

Research that aims to make projections about the future requires a *prospective* methodological approach (as per Ratcliffe, 2008). Through on-going, collaborative research between academia, industry and the professions, the future (r)evolutionary application of ICTs to professional practice across the disciplines in the AEC sector may be determined (as per *Industry 4.0* (Deloitte 2020)). Technical knowledge and skill are not enough in practice, the participants in a building project must have the necessary social skills to work together effectively and efficiently (Emmitt, 2010). The implementation of an emergent general plan for the integration of Building Information Modelling/Management (BIM/M) authoring tools and workflow methodologies, and soft skills into the curriculum of AEC sector education is challenging - it requires a methodological approach to systematically review forces for, and barriers to, effective change in terms of potential points of entry or intervention into the present educational system (Schein, 1972, p.90).

Action research: the active and interested participation by the researchers in the issue and processes being investigated so that they can identify, appraise and conjecture potential solutions is proposed. The intention of action research is to effect a change: knowledge gained through reflection on action is used to instigate ongoing evolutionary change, and to create knowledge about the process of change, the consequences of this change, and about the nature of the change itself (Fellows and Liu, 2008). Action research is complex and is appropriate for the study of future collaborative practice to inform education.

In the digital age, AEC sector educational evolution may mimic effective development in the I.T. industry, i.e., a *Dev Ops* cycle which is more like a figure of eight ‘cycle’, with continuous improvement of the product through

feedback, reflection, adjustment, and concomitant improvement through the process itself (Kim et al, 2016; Kim, Behr and Spafford, 2018). At any point in time the product is deliverable but in a constant state of flux in terms of the understanding of its development. This is predicated on an approach to learning like 'transformative reflection' (Biggs and Tang, 2011 p.46) which is a multi-stage collaborative process of: reflect-plan-apply-evaluate which is then fed back into the iterative evolutionary development process. In vocational education, a renewed focus on the HEI developer ('Dev') co-creating course devisal/delivery and effective learning mechanisms collaboratively *with* industry operators ('Ops'), presents a symbiotic learning opportunity (see Figure 1 (Robertson, 2022)). All contributors, practitioners, educators, learners, and industry innovators may collectively test out the possible answers to the real world-relevant problems, and interdependently propose solutions, ensuring the alignment and interconnectedness of 'Dev' and 'Ops'. This adventurous type of learning better incubates and develops in students the skills they will need to apply professionally, involving activities with an element of professional, social, and emotional risk. Feedback from activities allow error to be used constructively (Biggs and Tang, 2011 p.65) following Emmitt and Ruikar's (2013) recommendation for through-project and post-project reflection and learning, thus, creating an academic community of reflective practitioners (Schön, 1983) and agile and socio-emotionally intelligent graduates.

HEI's current curricular development is often predicated on a protracted feedback loop. However, AEC sector in-house R&D is 'live' action research - an iterative feedback loop over a continuous two-yearly cycle but with opportunities for shorter term change implementation. Research-informed change in HEIs is challenged by bureaucratic structures and processes, and the reluctance to embrace change. A re-framing of change management in HEIs to the Dev Ops approach successfully adopted by innovatory practices, instigates a revolutionary change in professional education enabling it to remain relevant and travel in alignment with best practice.

The researchers demonstrate an analogous DevOps approach in the re-framing of the quality assurance (QA) mechanisms in their HEIs: the current emphasis on declarative (subject-specific) knowledge and threshold standards is shifted to include achieving 'threshold concepts', i.e., functioning (procedural) knowledge which informs appropriate action by the learner as 'performances of understanding' (Biggs and Tang, 2011, p.81), in order to propose 'satisficing' solutions (Simon, 1996) to industry-relevant problems. Practice problems often involve disciplinary professionals functioning in a 'silo' of specialisation, the research collective aim to bring conflicting 'silos' together to develop collaboratively a solution to the complex problems presented.

This DevOps approach is how that change may be most effectively accomplished in professional AEC sector education: as a partnership between active-research-informed practitioners and up skilled educators. To verify and validate HEI provision the learning mechanisms incorporate how people work, practice in action, patterns in practice, effective methods of action, interpersonal/ inter-professional relationships, and societal influences/events (like Covid-19) as per Seymour and Rooke (1995); Seymour et al (1997).

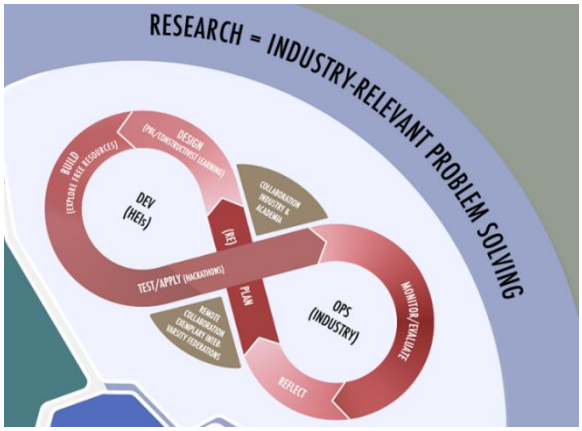

Figure 1: (Produced by Irina Vasiliu) DevOps Approach to Course Development: An on-going, cyclical process of collaborative research and development of the implementation of ICTs between HEIs and the industry (Robertson, 2022).

Reflection on the Cyclical Development of the Workshops (2014-2023)

The workshops started as a vehicle for staff and students to learn about building information modelling that was being mandated in UK, Ireland and Denmark. As educators in AEC, it needed to be addressed, because the curriculum was lagging and falling behind governmental policy. The collaboration outlined below started in 2014 with like-minded *'change agents'* (Schein, p.72, 1972) from academia identifying a *'specific change target'*; a collaborative BIM design project. They then instigated a change process to simulate 21st century, interdisciplinary, professional practice within academia. An inter-varsity, interdisciplinary, collaborative design exercise using industry-standard BIM/M software has evolved within a community of academic experts and practitioners in international HEIs.

In managing this evolutionary change process, the ultimate goals are continuously re-examined: it is a dynamic and cyclical process reinforced by the change agents finding a *'change role model'* (Schein, p.78, 1972). Autodesk, as thought leaders in the evolution of digital technologies in the AEC sector, are an apt change role model. This is a symbiotic relationship between academia and software developers involved in planned change, and the learners are a crucial group in the change-agent collective: their feedback is pivotal to the success of the cyclical development process.

The workshop collaborators from industry/practice (architectural, structural, environmental and MEP), professional education (multi-disciplinary academics and students) and software design and development (Autodesk) collectively review each workshop to identify driving and restraining forces and key barriers to its successful adoption into the existing educational system.

Trivarsity Workshop Development

The genesis for the workshop came through networking during the International Congress on Architectural Technology (ICAT) 2013, hosted at Sheffield Hallam University (SHU). Educators from SHU, England, VIA University, Denmark and Waterford Institute of Technology, Ireland (WIT now SETU Est. 2022). A common goal, with the onset of BIM mandates/legislation across the EU was to collaborate and mimic industry best practice utilising BIM methods and methodologies, upskilling staff and students in understanding and implementation of BIM tools across disciplines. Academia-Industry Partnerships (Thomas, 2013) have been fostered throughout each workshop with guidance, presentations and sponsorship. The first five workshops involved the original three institutes with a mixture of project types, selected to learn software and processes. As the workshop progressed student numbers grew as did the disciplines.

2015 SHU workshop explored authoring the 3D model to ease the downstream pricing/scheduling. The student groups involved Architectural Technology SHU, Derby and Huddersfield and Architectural & BIM Technology WIT.

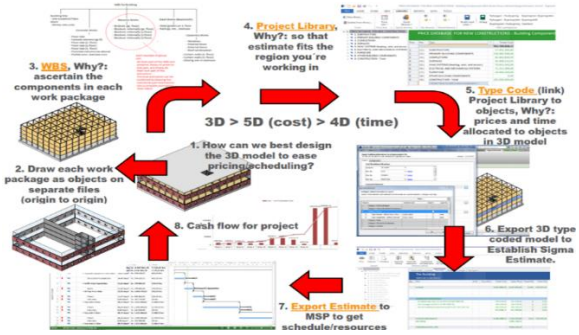

Figure 2: Infographic of Workshop workflow (Muller, 2014)

2015 VIA Horsens workshop introduced the discipline of "Architectural Technology and Construction Management" through the VIA students. This workshop used the same base models as the first workshop and introduced some remodelling aspects to optimise the daylight to the building. Students explored costing, external envelope design and daylight analysis.

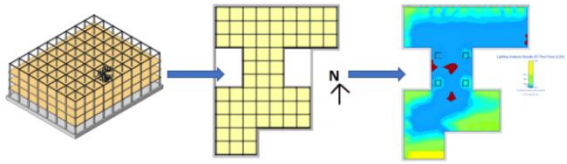

Figure 3: Group 6: Design Development and Analysis (Chisholm, 2024)

2016 WIT workshop introduced two new student disciplines from WIT; Sustainable Energy Engineering who return in 2023 and Quantity Surveying who rejoined in 2019 and have continued to be involved with Trivarsity. A key aspect of the workshops was introduced at this point. "The Prelude" is a period of 2-3 weeks prior to the physical workshop where the project and group members are introduced. The groups set up the CDE, BEP, MIDP, file naming conventions, project programming & roles; communicating through collaborative platforms; at this point it was BIM 360 and later workshops MS Teams. This has since developed to include shared online classes run simultaneously across all participating institutes. The workshop looked at the design of eight mixed use tall buildings to create a new district on Waterford Quay focusing on cost, programming, wind & daylight analysis, structure, architecture and MEP models. Each group had one representative who formed a master planning group to coordinate all groups. Figure 4 below shows them in discussion and the decisions made on the whiteboard.

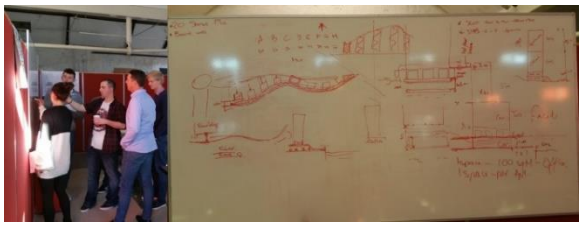

Figure 4: Master Planning Group (Chisholm, 2016)

2017 SHU workshop integrated industry practitioners as a group into the workshop. The principle objective was to explore, gain experience of and optimise the co-ordination of information between the disciplines on a simulated interdisciplinary refurbishment project utilising BIM360 and Autodesk Glue. Preparation work was undertaken during the Prelude. This workshop introduced clash detection and resolution to the students.

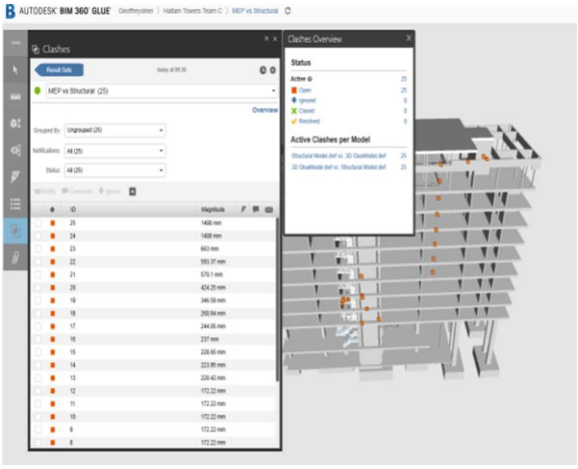

Figure 5: Team C: BIM360 clash analysis (Chisholm, 2024))

2018 VIA Aarhus workshop asked the groups to act as the design team associated with a design & build contractor in a bidding competition against the other teams for the design of a new student union building on the campus. A brief was set for the client requirements, a project programme was to be delivered along with costing packages and overall cost. The assessment of the workshop shifted from formal presentations to an exhibition style which saw each team produce an audio-visual presentation and two A1 posters, displayed in a common area. Refreshments were provided and each student and staff member then marked the projects based on the Most Economically Advantageous Tender criterion set out in the brief. This process has proven to be very successful and has carried on throughout all subsequent workshops. The benefits are seen in the students discussing and reviewing each others work within a social environment at the end of the workshop.

Figure 6: Exhibition & Marking, VIA Aarhus (Chisholm, 2017)

2019 WIT workshop saw VIA exit and Copenhagen School of Design and Technology (KEA) join Trivarsity with their Architectural Technology and Construction Management students. The WIT quantity surveying students took part again. The workshop built upon previous experiences with a design project based on the design and build tender for a tall gateway tower for Waterford Quay. Key aspects of the Trivarsity workshops were now in place: the prelude, multi-disciplinary (to a point) teams, working in the cloud to BIM standards, industry experts presenting, student social event with exhibition and marking to cap the workshop. The collaboration software had matured and the academic staff and students' knowledge had reached a point where the early day set up issues were eradicated.

Throughout all the workshops students could work remotely. This facilitated those who could not travel and added a vital aspect of the cloud collaboration experience.

Figure 7: Group Web call at WIT (Chisholm, 2019)

2020 SHU, the Covid workshop. With the collective experience gained through six Trivarsity workshops in cloud-based collaboration running a workshop during national lockdowns was not an issue. Tools such as Microsoft Teams and Autodesk BIM360 were now integrated into the workshops and our individual programme teaching. The entire genesis of Trivarsity workshops to work to industry best practice was tested with great success. The project dealt with a real SHU campus project, the proposed "Skills Factory". For the first time shared classes ran during the prelude and the workshop. New topics were MEP authoring and integrating Dynamo to size ducts. Both SHU & WIT were in lockdown, KEA were able to attend the classroom which resulted in some interesting dynamics with KEA students working in the one space and connected to the wider student/staff body via MS Teams.

Figure 8: KEA workshop and on the main screen Trivarsity Staff and group members reviewing project work (Sá, 2020)

2021 KEA. Structural engineering staff and students from Instituto Superior de Engenharia do Porto (ISEP) joined the workshop. This made a significant impact on the structural designs and the use of Autodesk Robot within collaboration process. The project was for the design of a new mixed-use district at Refshaleoen and to include building integrated renewables. SHU attended the workshop remotely due to travel restrictions. This was the largest Trivarsity to date with 16 No. groups comprising of 166 students taking part. This was the first Trivarsity workshop to be funded via the Erasmus+ Blended Intensive Programme (BIP). The BIP requirements matched the existing structure of the workshop with a mix of online classes and physical workshop. The length of the workshop increased from three to five days to include cultural aspects such as a river cruise and site visit.

Figure 9: Group 04, poster presentation (Chisholm, 2024)

2022 ISEP, BIP funded. Structural engineering staff and students joined Trivarsity from WUST, bringing more balance to the student disciplines. A comprehensive mix of cultural and workshop events were organised across the five days. The project was the development of a new urban area on the banks of the Douro River. Deliverables were consistent with recent workshops with highlights being the organised cultural events such as the river tour and bridge climb.

Figure 10: Arrábida Bridge arch climb (Chisholm, 2022)

2023 SETU, BIP funded. A return to Waterford and of SETU sustainable energy engineering staff & students, the introduction of Frederick University (FU) architecture & engineering students, and staff from ISCTE School of Technology and Architecture University Institute of Lisbon observing the workshop with a view to joining for the next iteration. The workshop consisted of seven institutes covering eight programmes/disciplines. The project was a revisit to the 2016 project with additional requirements to investigate cross laminated and glulam structure, environmental and embodied carbon analysis with Autodesk Forma and Insight tools. Again, a comprehensive mix of cultural and workshop events were organised.

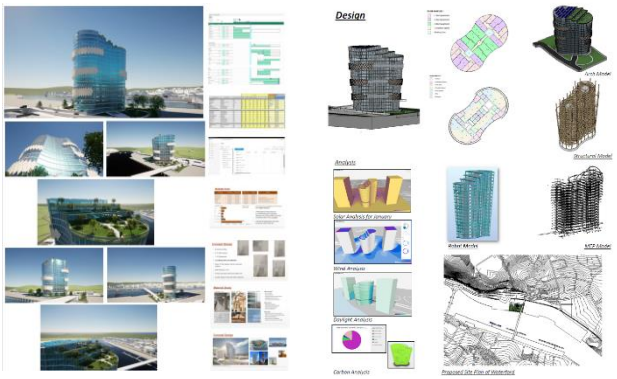

Figure 11: Group 03, poster presentation (Chisholm, 2024)

Trivarsity Impact on Programmes

Across all participating institutions the Trivarsity Workshops have had a positive effect on curriculum and teaching methods. Taking the three longest running members KEA, SHU & SETU, the impact can be seen in:

- the early adoption of BIM authoring tools, management and clash detection tools and the integration of these across years and programmes.
- support by software developers & vendors
- applied knowledge of international standards embedded into curriculum and programmes

- development of multi-disciplinary modules, workshops with their own institutes and locally.
- Senior years mentoring during workshops
- Development of BIM/Digital Construction focused modules building on the knowledge gained through Trivarsity

The impact of participation in Trivarsity for ISEP & WUST institutes who joined later, is similar but enhanced as they have benefitted from the preceding years development and body knowledge gained. Key effects are:

- Rapid amendments to curriculum across bachelor and master's programmes in areas such as, digital modelling & technologies, BIM fundamentals, management, standards & policies, digital surveying, AR/VR, digital twins
- Modifications to course delivery to include collaborative aspects improving teamwork and leadership skills and an uplift in the quality of student work.

Examples of didactical effects achieved in 2023 are presented in Figure 12 from WUST, utilising the software and methodologies from Trivarsity in their Bridge Engineering programme.

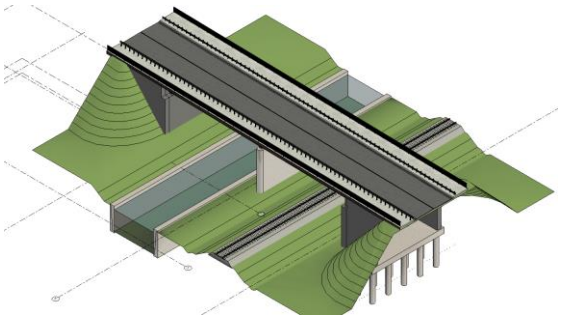

Figure 12: BIM model of a 2-span composite bridge (Hawryszków and Janicki, 2023)

Conclusions and Future Development

The ongoing success of the Trivarsity Workshops demonstrates the importance of interdisciplinary collaborative role-based teaching to allow students practice their discipline specific skillsets whilst gaining soft skills in teamwork and collaboration. Throughout the workshops skills are transferred between students across institutions and disciplines.

Trivarsity students are succeeding through engagement with WorldSkills International Digital Construction competitions, with SHU and SETU students winning medals at both national and international levels.

Staff are collaborating on research projects, studying PhDs at partner universities and the group have been asked to join the recently formed "I Build Sustainable and Smart" group. A European wide collective of educators with aims to broaden collaboration between institutes. One of the aims within the group is to disseminate the findings and knowledge gained through the Trivarsity Workshops to assist others to collaborate in a similar way.

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2015_VIA Horsens:

Ernest Muller VIA, Frances Robertson SHU, Geoff Olner SHU, Liane Duxbury SHU, Jacob Ware SHU, Mark Botham SHU, Brian Dempsey WIT, Gordon Chisholm WIT

2016_WIT:

Ernest Muller VIA, Frances Robertson SHU, Geoff Olner SHU, Brian Dempsey WIT, Robin Stubbs WIT, Gordon Chisholm WIT, Tom O'Brien WIT, John Mernagh WIT

2017_SHU:

Ernest Muller VIA, Frances Robertson SHU, Geoff Olner SHU, Brian Dempsey WIT, Robin Stubbs WIT, Gordon Chisholm WIT

2018_VIA Aarhus:

Ernest Muller VIA, Frances Robertson SHU, Geoff Olner SHU, Brian Dempsey WIT, Gordon Chisholm WIT, Tiberius Gruia Autodesk

2019_WIT:

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2021_KEA:

Joao Pereira de Sá KEA, Gabija Kaltenyte KEA, Frances Robertson SHU, Geoff Olner SHU, Brian Dempsey WIT, Robin Stubbs WIT, Gordon Chisholm WIT, Diogo Rodrigo Ribeiro ISEP, Ricardo Pereira Santos ISEP

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List of Institute Abbreviations:

Copenhagen School of Design & Technology (KEA)

Frederick University (FU)

Instituto Superior de Engenharia do Porto (ISEP)

School of Technology and Architecture University Institute of Lisbon (ISCTE)

Sheffield Hallam University (SHU)

South East Technological University (SETU) formerly Waterford Institute of Technology (WIT)

University of Derby (UoD)

University of Huddersfield (UoH)

VIA University College (VIA)

Wroclaw University of Science & Technology (WUST)

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