Gathering21

Construction Innovations
for Future Generations

TU Dublin — Ollscoil Teicneolaíochta Bhaile Átha Cliath — Technological University Dublin

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CitA BIM Gathering Conference 2021
Preface

This is the 5th edition of the BIM Gathering proceedings. The Gathering conference continues to act as a focal point for all stakeholders, both from home and abroad to come together to share their research, case studies and experiences of working with Building Information Modelling (BIM) and Digital Technologies.

The 5th BIM Gathering conference was hosted virtually due to the continued presence of COVID-19.

The papers presented in these proceedings cover a variety of BIM related topics but collectively have a common theme "Construction Innovations for Future Generations".

Despite the challenges we face with the continued presence of COVID-19 there is positivity with the rollout of vaccines and the response of the Irish Government to fund a Build Digital Project (2021-2026) providing coordination and leadership to deliver increased digital adoption across the entire Irish construction and built environment sector. This year the Gathering will focus on what has hindered digital adoption to date and the innovations and interventions that will be necessary to unlock greater productivity in our sector.

This includes a cultural shift in attitude towards BIM adoption; enabling a digitally enabled safer and healthier work environment; use of BIM collaboration standards as the new norm; getting BIM and off-site production to work and in hand; innovative procurement and contract vehicles; highly skilled workforces; smarter cities, smart buildings, and data; new and emerging technologies; more involvement of women in BIM and construction, and a paradigm shift towards a circular economy.
I would like to thank all of the participating partners, the scientific committee, the organisation committee, the authors, the speakers, the sponsors and most importantly the CitA events team for their fantastic efforts in delivering another high-quality event that will be remembered fondly by all those that attended.

Dr. Alan Hore,
TU Dublin and Co-Founder of CitA

CitA BIM Gathering Conference 2021

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Table of Contents

Digital Construction and BIM Research in Ireland 2016-2020

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As the construction industry opens up post pandemic, new and significant challenges will demand considerable expertise, not least in financial viability, solving the housing crisis and facing the very significant climate change pressures to make the industry less wasteful and less carbon intensive. This presents an excellent opportunity to further inculcate aspects of lean construction, particularly BIM into many aspects of construction not traditionally associated with digital construction, provided the necessary expertise is available and known to exist. Following a well-received recent conference paper summarising BIM-related research published by academics in Ireland's higher education institutions in 2020, this paper will review and identify noteworthy publications in digital technologies, including BIM, by academics of this island's third level institutions in the last five years. Areas of expertise of individuals will be identified to act as a useful directory for both industry and fellow researchers as well as providing a valuable national resource to identify research gaps which need funding if the ambitions of the national plan for the digitisation of the industry are to be realised. Using an already proven methodology, a survey of the 16 academic institutions in Ireland will be conducted through identified representatives in each institution, seeking all conference and journal papers published in the 2016-2020 period. The assembled database will be categorised, sorted and analysed to identify academic individuals in the workforce with extant research strengths in the various themes to establish the available expertise and areas for growth in the next five years.

keywords– Academic publications, BIM, Digital construction

I INTRODUCTION

In 2017 there were three important general BIM publications in Ireland, all undertaken under the auspices of the Construction Information Technology Alliance (CitA), namely, a global BIM review, an Irish BIM review, and the proceedings of the third BIM Gathering [1-3], the latter two as part of the government sponsored BIM Capability Programme [4]. This was followed in 2019 by updates on Ireland's BIM maturity [5] and the fourth BIM Gathering [6] and in 2020 by a review of the BIM publications of academics on the island of Ireland in the five-year period from 2015-to 2019 [7]. This latter has served as a useful guide and national repository identifying who has published what and where in the wide range of areas that BIM now covers.

Subsequently, in the last two years, CitA has added the broad topic of Digital Construction to its interests' themes and has organized a well-attended series of seminars on related topics. It is thus considered timely to conduct a similar review of the publications of Irish academics in digital construction in the broader sense while also updating the previous BIM publications list as a subset of digital construction research.

Digital construction could be described as the application of digital tools to improve the delivery and operation of the built environment. It encompasses many facets of digital technology, including, non-exhaustively, electronic devices and software such as tablets, lasers, drones, visualisation tools, robotics, 3-D printing, BIM, e-commerce, etc. It is primarily data driven and involves a cultural shift towards technological collaborative tools.

Through a survey of learned publications of Irish academics, the aim of this paper is to both act as a repository of knowledge and, hopefully, to provide a stimulus for future research topics and funding.

II Methodology

In total, sixteen academic institutions (Table 1) which teach/research in the construction arena were contacted and asked to submit a list of peer-reviewed conference and journal papers on the topic of digital construction by them and their colleagues in the period 2016-2020 only. While four contacts had none that they knew of, the rest produced 277 titles which were reviewed by the authors. A filter system was used to eliminate papers outside the specified time period and those outside the paper theme (digital construction), taking as broad a perspective as possible. What resulted was a list of some 167 papers that are referenced in this paper. The paper titles were each considered in turn to categorise them in subsequent sub-themes, and from this, the structure of the remainder of this paper was derived. Furthermore, using the 'Find' facility in Excel, an index of the more prolific authors was assembled for inclusion in this paper, as given in the Appendix.

Institution	Contact name	Institution	Contact name
Athlone IT	Finola Deavey	Sligo IT	Trevor McSharry
Carlow IT	Eoin Homan	Technological University of Dublin	Barry McAuley
Munster Technological University	Ted McKenna	Trinity College Dublin	Roger P. West
Dundalk IT	Eamon Cushnahan	University College Cork	Paraic Ryan
Galway-Mayo IT	Mark Kelly	University College Dublin	James O'Donnell
Letterkenny IT	Anne Bonner	University of Limerick	Javier Buran
Limerick IT	Paul Vesey	University of Ulster	David Comiskey
Queens University Belfast	Tara Brooks	Waterford IT	Gordon Chisholm

Table 1: Key contact list for the third level institutions

A cursory analysis of the selected 167 papers reveals that 60% and 32% were conference and journal papers, respectively, the balance being other publications. Of the conference papers, 18% and 23% were published in the 3rd and 4th BIM Gathering proceedings, respectively, the balance of 59% being published in other national and international conferences. This indicates the importance of the BIM Gatherings as a forum nationally for sharing information.

Of the 167 papers submitted on the theme of digital construction, some 50% were on the BIM sub-theme and the next biggest themes were remote sensing (12%) and the digital age (8%). This shows both the disparate nature of digital construction and its universal applicability in many facets of construction.

III Digital Construction

a) Digital age

Throughout the design and construction process, digital construction continues to have an enormous impact. For example, from design [8,9] to quantity surveying [10-12] to site practices [13] to regulations [14] and education [15], digital engineering is making a difference, as is information technology, through the internet of things [16], e-business [17] and ICT [18]. This transformation has also been identified in the roadmap for incorporating digital transition to the construction industry [19], notably through a Centre for Excellence for digital construction [20, 21].

b) Remote sensing

In the areas of photogrammetry, the digitisation of the earth's infrastructure on a macro scale [22], to a more local scale for asset management [23] and building energy performance [24] has come to prominence. Even specific small-scale recording, such as in, say, litter detection [25], building patch repairs [26], and time-lapse videos [27] have received attention. With the advent of unmanned aerial vehicles, such as drones [28], inspection of buildings has become much easier, albeit with data protection issues [29]. Similarly, digital construction has introduced virtual and augmented reality, where architectural [30] and engineering [31,32] features can be visualized and used creatively [33].

Even in a more specialized area, such as in bridge engineering, digitization has become an essential tool for monitoring bridges using computer vision [34] and drive-by monitoring [35] to allow image processing [36] and analysis [37] so that knowledge repositories of Ireland's bridges can be generated for review [38].

In manufacturing in civil engineering, computer vision is also used for assessing pre-stressed concrete elements [39] and micro-computed tomography for characterizing architectural cementitious materials [40]. Furthermore, digitally logged data with mapping can be used to troubleshoot and analyze factory floor data [41,42].

c) Data transfer

An essential element of digitization is the storage and transfer of information. Data sharing platforms have been investigated for practice and education [43,44]. Using dynamic information servers in an attempt to unify construction data has also been investigated [45,46], as has the use of industry foundation classes (IFCs) in design [47].

d) Project and facility management

The development of project management software tools has continued apace and one recent application in the area of trade/contractor performance has been published [48,49]. In the management of public sector procurement and implementing big data to achieve smarter buildings, the facility manager's role has come under the spotlight in two publications [50-52].

e) Building energy performance

Digital technologies are pervasive in evaluating the energy performance of buildings [53], which includes advanced modelling of building energy performance simulation [54-56]. The use of machine learning to minimize uncertainty [57] and optimize performance [58] have been explored. In specific applications, the important emerging needs to model occupant behaviour and to utilize renewable energy systems have been noted [59, 60].

f) Recycling

The role of the life-cycle engineer [61] continues to develop in significance, where whole life cycle costing [62], including recycling of construction waste and demolition waste management [63, 64], have become an essential part of any design.

g) Education

Many of the advances in technology and the use of digitization in the construction industry are taught in the third level institutes and have impacted student learning [65] and collaborative education [66]. Equally importantly, life-long learning provides many opportunities for retraining, for example, as a tool for developing a knowledge of the essence of smart cities [67, 68]. On campus, self-organised laboratories and synergistic partnerships between the academic and administrative functions have both borne fruit [69, 70].

h) General

There were 13 papers on aspects of digital construction that did not fit into one of the themes listed above and so will be dealt with here, briefly and individually:

Leadership in lean construction is complex as it has many facets which have been explained in [71].

Monitoring the displacement of real structures using optical flow methods and vision-based sensors has been described in [72, 73].

In a similar vein, aspects of structural health monitoring and dynamic risk assessment in roads have been published [74, 75].

In the environmental engineering discipline, the use of technology in oil and gas construction projects, environmental modelling and water distribution systems have all been discussed in [76-78].

On the construction materials side, diverse papers have been published on machine learning predictions of geopolymer concrete compressive strength, the use of additive manufacturing of cementitious products and the employment of technology to establish the location of cavity barriers in walls [79-81].

Finally, on a more detailed level, 3D-printing in construction has become a research topic in its own right and its use in printing full-scale concrete structures is gaining momentum [82, 83].

IV BIM

BIM topics are strictly a subset of digital construction, but as it is a well-developed research topic with many authors and papers (50% of this cohort), it was deemed to merit its own section in this paper, recognising that the 2015-2019 BIM papers list has already been published at the Civil Engineering Research in Ireland conference in 2020 [7]. This list updates its predecessor.

a) Lean construction

The relationship between lean construction and BIM has been explored [84], and the introduction of BIM at an early stage in the design process has been recognized as a contribution to lean construction [85]. An analysis of the BIM contribution to lean construction in small to medium enterprises (SME) has also been conducted [86]. More specifically, the application of lean and BIM principles to office fit-outs has also been studied [87].

b) BIM maturity

As already mentioned in the introduction to this paper, the state of BIM maturity in Ireland has been comprehensively evaluated twice in the last four years [2, 5]. Progression and deficiencies in BIM maturity in Ireland can be observed [88-90] and arising from this, as part of the roadmap for BIM adoption in Ireland, an assessment was carried out in 2020 on the state of readiness of Irish construction for the potential imposition of a BIM mandate, as extant elsewhere [91]. A further paper [92] extended the concept of BIM readiness to the SME sector in 2017.

c) Knowledge management

Explorations of the nature of a BIM design model and the demystifying of what BIM data comprises were described previously [93, 94]. BIM-based knowledge management and building information management in construction were reviewed [95-98], as was the transfer of information between parties in construction projects [99-100].

d) Management approaches

The introduction of BIM processes into the industry is a significant challenge in change management. Incorporating existing construction knowledge into a BIM environment is part of that challenge [101, 102], where there is a culture of natural resistance to this change when introducing transformative new technologies and processes [103]. Much can be learnt from international academic collaboration in the process of training a new cohort of construction professionals [104, 105].

e) Public sector

When a mandate is imposed in Ireland, as it will likely be, it is expected that it will impact the public sector initially. Again, by studying trends abroad [1, 106], there are lessons for Ireland which can lead to a strategy for BIM adoption in the public sector [107], based on government policy objectives [108].

f) Facility management

Using a knowledge of the construction and facility management (FM) processes, one can design an approach for incorporating BIM while planning for the maintenance and operation of buildings [109, 110]. BIM can be supplemented by expert systems and FM-designed software to assist in this role [111, 112]. Recently, it has particularly been the focus to establish the benefits of early FM and contractor involvement using the BIM environment to promote more efficient design and construction [113].

g) 5D BIM

Some disparate research work has been undertaken in Irish academic institutions on 5D BIM specifically: The interoperability of costs codes between BIM models [114]; the embedding of life cycle costs in a 5D BIM model [115]; and a review of the Quantity Surveyor's model view definition (MVD) for collaborative engagement [116].

h) Block chain and big data

Two of the key issues in the adoption of blockchain technology, namely how to incentivize its use in procurement and the matter of trust when collaborating, have been addressed in two papers [117, 118]. On the matter of big data, again, two BIM papers address current issues – disaster resilience and spoken dialogue systems [119, 120].

i) Thermal performance and digital twins

The adoption of an MVD can also be applied in thermal comfort analysis [121-123] and building energy performance simulation [124, 125]. Similarly, dynamic building performance evaluation can be conducted post-occupancy using a dynamic digital twin for commercial buildings [126-128]. Given the prevalence of popular dialogue on digital twins, it is surprising there are not more papers published in this emerging topic.

j) GEOBIM and Historic BIM

Subsets of the BIM heading exist, two of which are GEOBIM and Historic BIM (HBIM). A valuable summary of the status of GEOBIM in Europe is given in [129]. Linking geospatial data into BIM is described in [130] while the same data for retrofit projects in discussed in [131]. The role of green BIM is presented in [132].

In HBIM, the current state of the art is described in [133] and useful guidelines for its use in Ireland are given in [134]. Papers on sustainable historic building maintenance and conservation of the Armagh observatory can be found in references [135,136] respectively.

k) Education

This category had the largest number of contributions, perhaps not surprisingly considering how well BIM education in Ireland ranks internationally [2,5]. A summary strategy for BIM education is a good place to start [137]. The importance of pedagogy in teaching is reflected in [138, 139], for example in 6D BIM curricula as presented in [140, 141].

Much can be learned from international studies [1, 142, 143], with specific examples published in [144, 145]. Indeed, international collaborations in Europe have led to a sustainability-based energy BIM-Cert as an example of what can be achieved [146-148].

Academia working more closely with industry has benefits for both through collaborative and knowledge transfer partnerships [149-151]. Furthermore, a BIM toolkit has been developed to assist in training academics involved in BIM-related education [152].

Infusion of BIM into specific programmes has been described for Structural Engineering [153], Quantity Surveying [154] at undergraduate level and a Masters programme at postgraduate level [155].

Finally, an interesting reflection on lessons learned from observing the use of BIM on a campus construction project can be found in [156].

l) Use cases

In the review of the papers on BIM, a number of diverse examples of digital construction in practice emerged, and these shall be mentioned individually here.

A case study highlighting the steep learning curve when introducing BIM in practice is given in [157] and is further extended by reference to BIM being engaged in construction [158], including recording construction details on site [159].

Intelligence assisted design [160] and the automation of compliance checking using BIM [161] have been investigated, including for fire-safe design [162].

Instrumenting new and existing buildings to monitor building performance using BIM has been described in [163] and, by way of interesting examples, the application of structural health monitoring on a historic lighthouse has been described in [164] and using BIM to record information on a listed viaduct in [165].

Many BIM case studies have been conducted by CitA, for example the use of BIM on the National Children's Hospital [166].

Cases are not just restricted to construction, as a study on the impact assessment of green infrastructure using BIM shows [167].

V Conclusions

The last five years has seen much new activity in research in digitization of the construction industry, building on the work on BIM in the last decade. The authors aim was to create a paper which could be widely used to inform students, academics, and all facets of industry as to who has published what and where, so that the rich vein of expertise might become better known. To that end, the names of the many authors mentioned in the list of references below were examined to create an index (Table 2) which it is hoped will also prove helpful when using this focused repository of knowledge. The most prolific academics in publishing in digital construction appear to be Comiskey and McKane in the area of technology, data sharing and education; Motawa in big data and building peeformance; and Hore, McAuley and West in BIM. Areas for significant potential growth include remote and building performance sensing, lean sustainable construction and dynamic digital twins using BIM models.

It is a limitation of this paper that it may be the case that not all academics had the opportunity to submit their publications lists to the authors and so the references here, while manifold, may not be exhaustive. Furthermore, it is recognized that this paper, while lengthy, offers little opportunity for in-depth analysis of the list peer-reviewed papers, as published by academics based in or in collaboration with Irish third level institutions. It is a further limitation of this paper that its original scope was also to compile all MSc and PhD theses titles on relevant topics in the review but the pandemic restrictions ensured that academics did not have ready access to campus to assemble the relevant lists. It is thus recommended that this rich source of knowledge be explored and analysed in future research on digital construction.

Acknowledgment

The authors particularly wish to thank their academic colleagues, as listed in Table 1, for their assistance in compiling the list of references used in this paper.

APPENDIX

An index of the publications of the top 50 most prolific authors is given in Table 2.

Table 2: Index of the publications of the top 50 most prolific authors

Alshehri, F.: 47, 121, 122, 123	Eadie, R.: 17, 66, 112, 138, 140, 141, 157	Lydon, D.: 34, 39, 73	McKenna, T.: 8, 110, 153, 165	Pinheiro, S.: 55, 100, 121, 124
Bazjanac, V.: 54, 55, 56, 100, 124	Frisch, J.: 55, 100, 124	Lydon, M.: 34, 38, 39, 73	Meng, X.: 96, 97, 98, 101, 102, 109, 113	Rebelo, E.: 146, 147, 148
Behan, A.: 130, 146, 147, 148, 156, 160	Hamilton, A.: 146, 147, 148	Lynch, S.: 146, 147, 148	Millar, P.: 12, 23, 25, 81	Rice, M.: 138, 140, 141
Bruton, K.: 41, 42, 57, 128	Hester, D.: 34, 35, 36, 39	Magee, B.: 23, 25, 40, 79, 80, 138	Motawa, I,: 28, 52, 59, 64, 75, 76, 111, 119, 120, 132, 135	Robinson, D.: 34, 39, 73
Cao, J.: 24, 55, 100	Hoare, C.: 45, 46, 47, 53	Maile, T.: 54, 55, 56, 100, 124, 125	Nicholson, G.: 149, 150, 152	Sonebi, M.: 39, 82, 83
Clarke-Hagan, D.: 18, 50, 62, 84, 85	Hore, A.: 1, 2, 3, 4, 5, 6, 7, 19, 20, 21, 88, 89, 90, 91, 107, 108, 142, 143, 155, 166	Matthews, M.: 93, 95, 117, 161	O'Brien, E,: 37, 72, 73, 74	Spillane, J.: 18, 62, 84, 85
Comiskey, D.: 12, 13, 14, 43, 44, 65, 66, 81, 131, 137, 151, 154, 157, 158	Kehily, D.: 10, 11, 114, 115, 139	McAuley, B: 1, 2, 3, 4, 5, 6, 7, 19, 20, 21, 51, 88, 89, 90, 91, 92, 107, 108, 142, 143, 146, 147, 148, 166	O'Connor, J.: 149, 150, 152	Taylor, S.: 34, 38, 39, 48, 49, 72, 73
Corry, E.: 24, 53, 58	Kelly, M.: 86, 149, 150, 152	McCormack, P.: 146, 147, 148	O'Donnell, J.: 24, 45, 46, 53, 55, 56, 58, 99, 100, 121, 122, 123, 124, 125	Van Treeck, C.: 55, 100, 124
Costello, M.: 149, 150, 152	Kenny, P.: 47, 121, 123	McGettrick, P.: 35, 36, 101, 109, 113	O'Kane, E.: 12, 13, 14	Wang, H.: 96, 97, 98, 101, 102, 109, 113
Curran, M.: 18, 50, 62, 84, 85	Kuang, S.: 88, 107, 108, 142	McKane, M.: 43, 44, 66, 131, 151, 154, 157, 158	O'Sullivan, D.: 41, 42, 57, 128, 156	West, R.: 1, 2, 3, 4, 5, 6, 7, 19, 20, 21, 70, 88, 89, 90, 91, 94, 107, 108, 127, 142, 143, 166

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CitA BIM Gathering **Proceedings**

A Cultural Shift in Attitude Towards BIM

An Exploration of Lean and BIM synergies with a focus on SMEs in Construction

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Small and Medium Enterprises (SME) account for 99.7% of the Irish Construction Industry and contribute to 68% of all employment in the sector. These organisations now find themselves facing the challenge of returning to productive business post the Covid 19 shutdown. More than ever, SMEs must modernise and adapt their business models to embrace new ways of working, such as Lean Construction and Building Information Modelling (BIM), in the absence of clear business incentives. It has proved difficult to persuade SMEs to change their ways of working due to limited finances, internal resources and above all, the cultural shift required to embrace new ways of working. The vast bulk of Irish construction SMEs are accustomed to working in a sector that produces low product quality, budget overruns, and substantial construction waste. When partnered with lean construction, BIM can address many of these issues, as the two processes can work together to target and eliminate waste while streamlining the value stream. The primary goals of lean construction are to maximise value and minimise waste. Therefore, BIM can be seen as a lean tool that helps eliminate waste and, at the same time, increases business opportunities and promotes sustainability. This paper will explore the synergies between Lean and BIM in the context of construction SMEs through a literature review. The findings will address a number of barriers to entry for SMEs, focusing on how digital technologies, such as BIM can complement lean construction in targeting major types of wastes. Some of the barriers identified include financial and legal concerns, lack of implementation strategies/guides, knowledge retainment, training impendiments, software and hardware restrictions, as well as employee resistance.

Keywords –LEAN, BIM, SYNERGIES, SMEs

I INTRODUCTION

Small and Medium Enterprises (SME) account for 99.7% of the Irish Construction Industry and contribute to 68% of all employment. These organisations now find themselves facing the challenge of returning to productivity post the Covid 19 shutdown. The economic crisis has put many SMEs in "survival" mode, forcing them to prioritise short-term work over long-term investments [1].

Following the COVID-19 outbreak, it is becoming ever more apparent that digital technologies, such as Building Information Modelling (BIM), will play an increasing role in the recovery and the new normal of the sector. For these digital technologies to be embraced, construction SMEs must overcome several challenges, such as the difficulty of envisioning the potential digitised futures of their business, low digital maturity-level of the employees and the employers, and most importantly, the inherently limited human resources. [2]. As a result, SMEs suffer from many problems, such as low product quality and working efficiency, budget overruns, and substantial construction waste [3].

This paper will explore Lean and BIM synergies with a focus on SMEs. The overarching aim of this research is to establish a lean digital construction innovation framework that SMEs can use to address the critical actions to transition from traditional to digital practices. This paper represents the initial stage of this framework and will provide an exploration on the barriers that SME's encounter and how BIM and Lean synergies can potentially address some of these concerns. Further papers will apply these findings in establishing a lean digital construction innovation framework.

II BIM AND LEAN

BIM is a collaborative process in which all parties involved in a project use three-dimensional design applications. BIM enhances the current communication process, provides a collaborative platform, and supports interoperability between the different business domains [4]. BIM can be applied through the complete lifecycle of a project to evaluate the constructability of designs, visualise construction schedules, provide accurate cost estimates and multiple analyses enabling energy and structural performance predictions that can be applied to compare design alternatives [5-6]. BIM can enable the industry to leverage more value from new software tools and technologies [7]. This can be achieved through the BIM model which can provide accurate information about material resources and subcontractor scheduling. This information can be used to minimise waste by reducing the need for on-site material inventories. The BIM model can also help evaluate the building's function, maintain information and design model integrity, and automate reports [8].

The effective implementation of BIM requires that changes need to be made to almost every aspect of an organisation. For example, for an enterprise to implement BIM, it will require developing BIM guidelines and strategies; otherwise, it may lead to further waste [9].

Furthermore, for an innovation such as BIM to be successful within SMEs, they will need to address several barriers to entry. Barries such as access to finance, cultural change, inadequate communication and information exchange levels, adopting technology, resources, construction project coordination, and bureaucracy [10]. These are all areas that lean construction aims to reduce or eliminate.

The main objectives of lean are to maximise value and at the same time minimise waste [11]. Therefore, the application of lean construction philosophies in SMEs can increase productivity, guarantee better compliance with deadlines, reduce costs associated with waste, and improve quality [12-13].

Lean Construction concentrates on flow and value generation. The flow dimension investigates the tasks' interdependency through the whole project process and reduces waste as a managerial objective. The value generation focuses on customer satisfaction, including internal customers, aiming to improve project participants' integration and information flow [14]. Lean can be attained by combining the following practices, including just-in-time, total quality management, total productive maintenance, continuous improvement, design for manufacturing and assembly, supplier management, and effective human resource management [15].

Lean Construction techniques include daily huddle meetings, last planner system, 5S, first-run studies, just-in-time, pull approach (Kanban), error proofing or fail-saving for quality and safety, value stream mapping, increased visualisation, target value design, partnering, six sigma, total productive maintenance, total quality management and concurrent engineering [16].

BIM and lean construction have been researched independently over the last number of years. However, limited research investigates the positive outcome of combining these two principles and the synergies between them [17]. Although lean construction and BIM have emerged as separate domains in construction IT research, substantial synergies have led to both methods' combined use and implementation [18].

III BIM AND LEAN SYNERGIES

BIM facilitates lean measures through design to construction to occupancy and at the same time contributes directly to lean goals of waste reduction, improved flow, reduction in overall time, improved quality by utilising clash detection, visualisation, and collaborative planning [19-21]. Some of the synergies recorded between both processes include

- Eliminate waste – using the BIM Model to perform suitable design and performance simulation for energy-efficient solutions.
- Amplify learning – positive iteration and client involvement, resulting from BIM using visualisation solutions enabling design and collaborative analysis.
- Decide as late as possible – options-based approach, which is possible with the visualisations permitted through BIM to check for process conflicts.
- Deliver as fast as possible – rapid value flow and iteration of needs, which is again possible with BIM via automated generation of changes and materials schedules.
- Empower the team – facilitate team commitment and rapid feedback through BIM via accurate and complete information sharing.
- Build integrity – conceptual and perceived usefulness over time via BIM through detailed schedules of tasks and materials delivery times.
- See the whole – avoid sub-optimisation via collaboration and concurrent projects by different stakeholders or teams [22].

Lean construction techniques require careful coordination between the general contractor and subcontractors to ensure that work can be performed when the appropriate resources are available on-site. BIM can assist with this as the model provides an accurate model of the design and the material resources required for each segment of the work. In addition, it gives the basis for improved planning and scheduling of subcontractors and helps to ensure the just-in-time arrival of people, equipment, and materials [23].

BIM, in partnership with Augmented and Virtual Reality, can empower Lean Construction Management. A recent pilot project found that Microsoft HoloLens and a webcam can simulate construction progress measurement in real-time. The results showed an improvement in key performance indicators, such as construction time, less time on-site, improved quality, and sustainability by minimising wasted materials [24].

According to Sacks et al., there are 56 synergies between BIM and lean construction. The developed matrix can be seen as an exemplar of the interactions between new information technologies and the production systems they serve [25]. A survey of experimental and practical literature found that 48 of the 56 interactions were beneficial, improving the flow of information and materials. Sacks et al. also developed a prototype BIM-based management information system to support a lean workflow called KanBIM. This system enabled visualisation of the process and the product, and in experiments, a reduction of wasted time spent looking for work was observed.

Other matrices developed include Leite (2012), who presented the benefits of implementing the Last Planner System and BIM, and Clemente and Cachadinha (2013), who applied a BIM-lean matrix approach and found the method improved mechanical, electrical, and plumbing MEP installation works and subcontractor work sequencing. Despite these matrices, there is still a need to clearly evaluate lean principles realised with BIM implementation during the construction phase in a real-world project [26].

For BIM and Lean to be successful, a number of barriers must be addressed, including legal, attitude and market, education, knowledge and learning, technical and software financing issues [27]. There is limited research that has measured the quantitative impact of BIM in improving flow in construction [25]. There is a disconnect between current studies and current practices where BIM-Lean approaches are urgently needed to be integrated with other digital technologies [28]. Increasing BIM and Lean Construction adoption among SMEs is key for achieving the construction industry's transformation [29].

IV BIM AND LEAN FOR SMES

Although Construction SMEs have limited access to investment capital and operate under resource constraints, they are better positioned to innovate than larger firms. SMEs ' flexibility, simple organisational structure, and speed in decision-making are the essential factors that allow them to innovate [30]. SMEs can generate, develop and deliver significant technical innovations due to the level of control that a manager has over decision making. BIM for SMEs has a positive impact over time on project and labour cost [10]. BIM can assist with the lean design process, improved information management, design quality, efficiency, enhanced sub-trades integration, and rework reduction [31].

V BARRIERS

However, there is a lack of focus on BIM implementation and adoption in SMEs despite their contribution to economic growth. This lack occurs due partially to a shortage of experienced staff members and limited technical capacity [32]. The most common barriers are process/people-related and are often the severest for the SMEs. Obstacles such as lack of implementation strategies/guides, lack of clients' demand for BIM, shortage of experts, lack of awareness of the stakeholders, and resistance to change are the most severe for SMEs [31].

Leadership and management strategies, financial capability, employee expertise and skills, and organisational culture are the critical factors that enable SMEs to achieve a successful Lean implementation [32]. In addition, the application of Lean Construction tools for SMEs can increase productivity, guarantee better compliance with deadlines, reduce costs, and increase Quality [12].

One of the key inhibitors related to SMEs and lean is involving suppliers in Lean practices. Other barriers include deficient processes and quality control systems, the transition of current operations or production systems to a Lean system [33]. Further barriers involve control of materials stored at the site, the waste of raw materials, and the lack of management on the productivity of employees and contractors [12].

Given that SMEs struggle to incorporate either Lean or BIM individually, there are significant barriers to adapting both in unison despite the apparent benefits. Research in the domain of BIM and Lean for SMEs is scarce, with the wholesale uptake problematic. Examples of the combined implementation of Lean Construction and BIM at SMEs are virtually non-existent [29]. The research to be conducted over the life of this project will address some of these gaps.

VI CONCLUSIONS

The Economic analysis of productivity in the Irish construction sector Report has called for public contracts to support, value, and reward innovation through BIM, ISO 19650, Lean processes, and Modern Methods of Construction [34]. This recommendation has formed part of the Construction Sector Group's Building Innovation Report, which provided an overview of the Irish construction sector trends [35]. The Build Digital Project is one of the leading actions of this strategy to raise construction productivity levels. This strategy will, in part, focus on both BIM and Lean in the context of raising its profile within SMEs. As evident from the findings of this paper, the synergies gained from partnering both of these processes together can lead to increased productivity and opportunities for SMEs, which is one of the key targets of the Build Digital Project. As part of this study, the research will establish an essential supporting structure to introduce digital construction and lean processes into SMEs. The proposed innovation framework will address the key pillars of innovation required for SMEs by partnering with BIM and lean methodologies concerning the Irish Construction Sector.

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A Critical Appraisal of 4D BIM Technologies for Safety Planning and Site Safety for Temporary Works at the Construction Stage.

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Keywords: PAS 1192-6, Health and Safety Management, 4D BIM, Risk assessment: Temporary Works Design, Scaffolding design: Rules-based checking, VR & Augmented reality

Abstract – The focus of this research is the application and appraisal of Building Information Modelling (BIM) to health and safety and risk management on the construction site with an emphasis on temporary works design. The methodology for this review will be qualitative in nature rather than a quantitative approach. This will include a literature review on BIM application and integration, visualisation, planning, health, safety and risk assessments of construction projects, an appraisal of a case study and as well as other associated works. The knowledge gained from the data will be an extensive appraisal of the literature and which will involve both deductive as well as inductive understanding of the research. In addition, a survey was conducted to gauge responses from participants and evaluate solutions to crucial issues in industry with an overall conclusion.

I. STATISTICS OF CONSTRUCTION RELATED ACCIDENTS

While Ireland's construction activity has increased due to economic growth, a 2020 report from HSA states construction fatalities during 2019 have more than doubled from the previous year, from five (2018) to 12 (2019). [1] [7] The Health and Safety Authority report states that all deaths were from falls from heights. These levels were in decline since 2015 with a recorded 278 non-fatality incidents by the HSA during the same time in 2018. Dermot Carey, Director Safety and Training, CIF commented: *"While safety standards within the Irish construction industry are excellent and improving all the time, complacency is a constant threat.*[8]

Other HSE statistical data on Irish construction accidents reveals that:

- The majority of the victims involved in construction accidents are small contractors and self-employed.
- In 2017, 6 people died as a result of accidents on Irish construction sites.
- There were five fatal falls from height in 2016 and 2 in 2017. All involved small contractors or self-employed construction workers.[1]

Falls, slips and trips were the main cause of non-fatal accidents in construction in 2019, (figure 1) with movements such as lifting, carrying, pushing, pulling, bending and twisting the next most common cause.

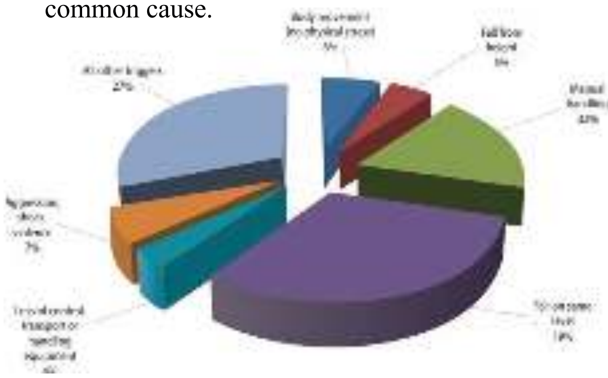

Figure 1. Proportion of reported non-fatal injuries, 2019 [1]

II. BIM FOR HEALTH & SAFETY LITERATURE REVIEW

Workplace injury, illness and fatality data indicate occupational health and safety (OHS) in the construction sector remains a critical issue. Construction deaths in Ireland increased by 140% in 2019, rising from five to 12, according to statistics from the Health and Safety Authority. Falls from heights the primary cause of construction worker deaths, and fatalities are more common in small construction companies with fewer than 10 employees.[7]

Clarke et al. outline the following areas where Health and Safety professionals use BIM technology. These aspects would include:

- Worker safety training and education,
- Design for Safety,
- Safety Planning,
- Hazard assessment and pre-task planning,
- Accident Investigation,
- Facility & Maintenance phase safety. [9]

For these tasks, Health and Safety specialists can use 3D renders and walk-through animations generated from BIM. In addition, a 4D phased simulation focusing on safety procedures, can be generated to demonstrate how temporary safety elements and areas of concern migrate through the duration of a project.

Kassem et al. state that Virtual Environments for BIM are being investigated as an approach to safety training.[10] Despite development of VE research, there is limited information about their effectiveness or benefits for safety training, risk management processes, and limitations. For future research, they recommend requirements to increase real observational studies to provide evidence about comparative performance of learners in VE against those by other methods.

Furthermore, Kassem et al. also state that risk assessment is managed according to the risk management framework of ISO 31000-2009, which is collectively adopted across all industry sectors. They state that Risk Management includes four key phases: identification, evaluation, response/ planning, and risk monitoring/controlling.[10]

Bargstädt et al. concluded that BIM can provide opportunities to identify fall hazards on site through a comparative case study.[11] This was based on automated rule-based checking systems for BIM. The authors compared safety rule applications of site fall/trip identification standards in Germany and the United States. Through their case study, the rule-based checking system in BIM detected potential fall hazards using an Industry Foundation Class (IFC) project model and can recommend safety personal protective equipment using a set of predefined rules.

Similarly, Benjaoran et al. presented a 4D BIM model to integrate safety risk and construction management. Rule-based algorithms for working-at-height risks were formulated, analysed, and visualised into the model. A rule-based system then extracted data from the 4D BIM model to detect working-at-height risks automatically, and predict the necessary actions including safety activities and recommendations.[12]

III. BIM FOR RISK MANAGEMENT

The MacLeamy Curve (figure 2) has been advocated by supporters of integrated project delivery, design performance modelling (DPM) and other frameworks/platforms that adopt an integrative process (figure 3).

Identifying construction hazards at the design stage can be difficult, especially for those personnel who do not have adequate knowledge and experience with respect to construction processes and safety. Several tools have been created to assist design professionals with implementing the concept of prevention through design.[13]

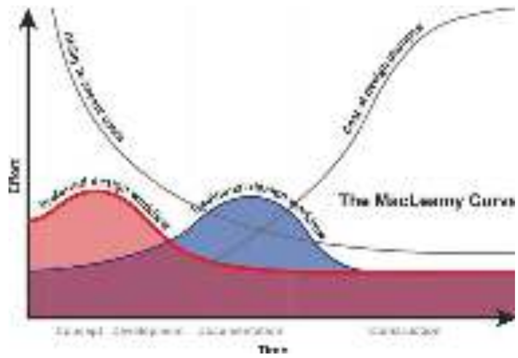

Figure 2. Integrated product delivery (Macleamy curve) [13]

To overcome limitations and inefficiency associated with these tools, BIM and BIM-based tools offer new approaches to design or minimize hazards and risks by integrating 3D models with construction procedures and safety knowledge through iterative design processes. Kasirossafar et al. (2012) confirmed this opportunity through a survey conducted in 2012 revealing that 75% of the participants, who were either university professors or experienced designers and engineers, believed that construction accidents could be predicted and preventable through BIM implementation in the design phase.

For optimal planning and evaluation of temporary works, construction site conditions in 3/4D BIM should be examined with minimum user intervention. Numerous studies manually inspect

BIM to model temporary structure objects and identify potential safety hazards.

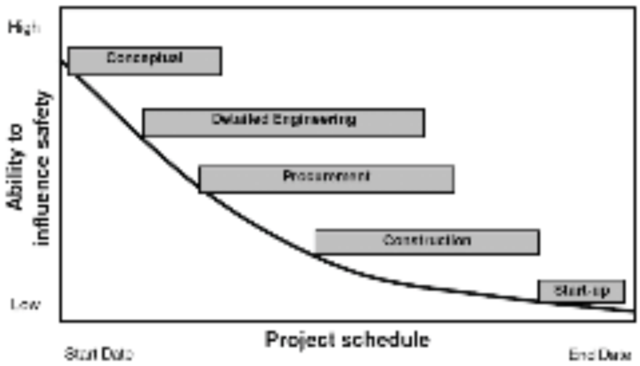

Figure 3. It is at the initial stages of a project that the greatest ability to influence the Health and Safety of a project [3]

VI. CASE STUDY: BIM OPTIMISED FOR TEMPORARY WORKS

The following account outlines a project that employed BIM as a safety management strategy for a major engineering project.

MGF, Wessex Water, is a UK based firm that provides excavation reinforcement for the construction industry and has pioneered the use of visualisation and 4D simulation to convey essential installation and a safe working environment.[14]

The project concerned is the Drax Power Station, the largest renewable generator in the UK and the largest decarbonisation project in Europe. Located near Selby, North Yorkshire, it is connected directly to the national electricity transmission grid, for which it provides a host of system support services.

A series of 3D animations have been developed for use as part of training and toolbox talks. MGF collaborated with Wessex Water to produce a custom-made Safe System of Work for installing temporary excavation support systems in sites such as domestic back gardens, where access was restricted.[14]

Figure 4. Image of cofferdam installation in progress with BIM model of frame [15]

Figure 5. BIM model of cofferdam installation [15]

Outline of Project

MGF provided excavation support for the Ecostore Rail Unload Building as part of the £200m (€223m) biomass project at the Drax Power Station in Selby Yorkshire. MGF were first contacted by Volker Ground Engineering (VGE) to provide financial costs for the design and supply of 3 levels of modular framework for the 18m deep basement in the Rail Unload Building. A financial assessment was calculated, and a welded steel frame was initially thought to be a more inexpensive option.

MGF were able to demonstrate that a BIM modular system presented a significantly shorter lead time of 14 days and offered a substantial time saving of six weeks in setting up and extraction. MGF concluded that the Groundworker would be unable to continue to excavate until the steel frame (figure 4) had been installed in its entirety. By utilising a modular frame this offered considerable time savings reducing install works from over 3 weeks to less than one week.[15]

Due to delays in the existing programme and tight deadlines, the modular option was more favourable as the time and expense saved in programme significantly outweighed the additional cost.

The modular frame system (figure 6), was modelled and analysed in AutoDesk Revit, a software specifically built for BIM, enabling them to demonstrate all aspects of the scheme to Volker Ground Engineering and the Project Team at the pre-construction stage.

Figure 6. BIM frame model with loading calculations [14]

The use of Revit was advantageous due to the technically demanding characteristics of the project. This software allowed MGF to ensure all investors that the design brief had been fully met. Working collaboratively with *Volker Ground Engineering*, the permanent works engineers, the temporary works checker *Saldanha Design* and Management, steel fabricators and principal contractor *Shepherd Construction,* MGF provided design services, installation guidance, supply of equipment and aftercare.[14]

Figure 7. BIM model of temporary framing for excavation [14]

This scheme was originally designed with four stages of temporary framing (figure 7) which was to be fixed in situ. Constraints within the final excavated cofferdam structure, meant that to lower and place the extended steel sections would cause considerable health and safety implications for the lifting and placement operations.[16] The modular system gave a degree of flexibility in this operation which lead to a safer system of work for the operatives and greatly reduced the programme installation time, which was critical to the client.[14]

V. APPRAISAL OF BIM FOR TEMPORARY WORKS DESIGN

Temporary works are utilised to assist in the construction of permanent facilities. Suitable planning of temporary structures is affected by constantly changing construction site conditions and characteristics of the construction activities using the temporary structures.[17]

Despite these impacts, temporary structures used in construction projects have insufficient planning. As a result, there are widespread safety, productivity, constructability, and site coordination issues caused by inefficient temporary works design. Design for safety for scaffolding can be optimised by using BIM. The optimization engine generates multiple alternative scaffolding plans. The safety simulation engine can simulate daily construction site conditions and automatically identifies potential safety hazards related to scaffolding. In a case study using a real-world construction project, the optimization engine generated alternative scaffolding plans and the simulation engine successfully detected potential safety hazards.

The construction and safety managers of a case study project could identify multiple scaffolding plans (figure 8) that were better than the original plan in terms of safety, cost, and duration. The overall results demonstrate that the proposed approach can assist in the creation of safer and more productive plans for scaffolding at a pre-construction stage.

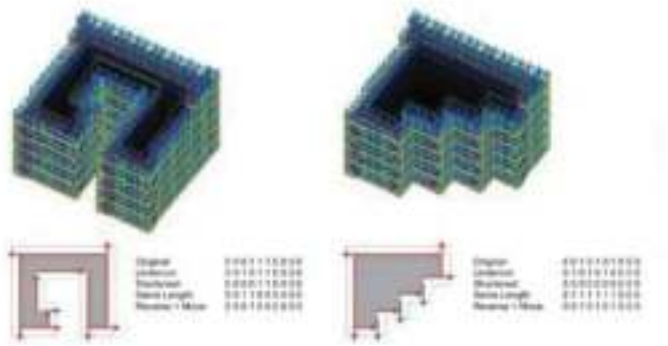

Figure 8. Testing scaffolding systems against various building footprints [20]

VI. APPLICATION OF SAFETY PRACTICES TO SCAFFOLDING DESIGN

In order to ensure the strength and stability of any temporary works structure, there are fundamental aspects that need to be considered which can be simplified as follows:

Foundations – the ability of the ground to carry the loads transmitted from the temporary works structure without failure or excessive deformation or settlement. Structural integrity the ability of the temporary works structure itself to carry and transmit loads to the ground via the foundations without failure of the structural elements, including fixings and connections (e.g. by buckling, bending, shear, tension, torsion), and without excessive deflection.[18]

Stability- the ability of the temporary works structure to withstand horizontal or lateral loading without sway, overturning or sliding failure (stability may be inherent in the temporary works structure itself or provided by the permanent works).

VII. TEMPORARY STRUCTURES: RISK ASSESSMENT

The safety, profitability, speed, and quality of the entire project can be impacted by how the temporary structures are planned and used.

It is apparent that safety planning is more challenging when temporary structures are concerned. Temporary structures, such as formwork, scaffolds, and shoring, are used regularly in almost all construction projects to assist the construction process. Despite the importance, existing safety planning practices fail to effectively address safety problems associated with temporary structures. Most temporary structures do not necessarily appear in drawings, and temporary structures are installed on site often without enough planning and analysis.[19]

Temporary structure drawings, calculations and implementation plans submitted by temporary structure subcontractors are often not reviewed to analyse the impact on construction safety and productivity.

If one was to consider that most construction projects are short of human resources for construction planning, the processes of manually modelling temporary structures in BIM and analysing all possible safety hazards associated with them can be extremely time consuming.[20] Even though there have been successful approaches of using advanced technology to enable effective planning and management of construction safety, few of them presented methods to address safety problems associated with temporary structures.[19]

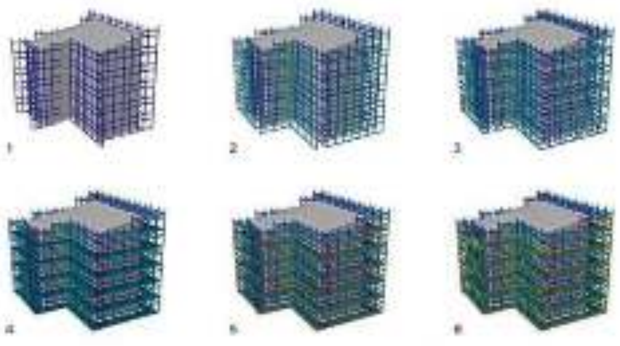

Figure 9. Sequencing of scaffolding structural design[4]

VIII. BIM OPTIMISED FOR CRANE SAFETY OPERATION ON SITE

Many companies in the engineering and construction industry utilise cranes to lift and transport materials.

If installed and used appropriately, these systems make operations easier and safer. But overhead crane accidents cause severe injuries and fatalities every year.[1]

Preventing accidents requires operatives to identify specific hazards that could occur during operation and follow safety procedures to avoid them.

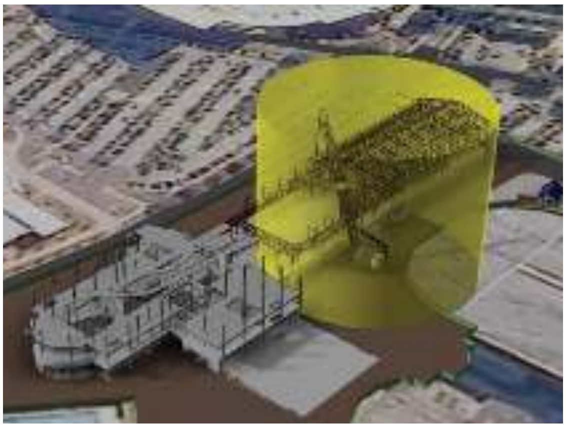

Figure 10. Crane swing work zone (crane management plan)[3]

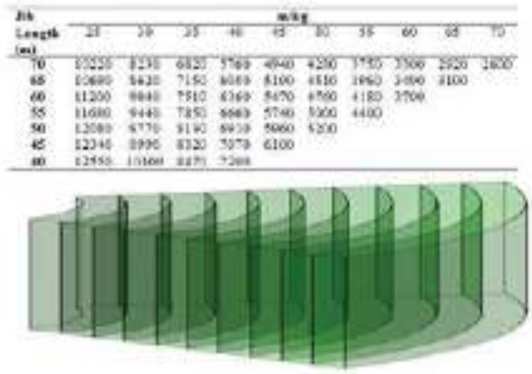

Figure 11. Load information to envelope swing chart [6]

Crane Management Plan using a 4D BIM application

An efficient crane management plan (figure 10,11) in place can identify swing radius of the site cranes and ensure safe distance from any power lines and nearby temporary and permanent structures and identify what personnel will be utilizing crane at a certain instance of time.

Multiple hazards can arise regarding cranes when in use. Most involve large lift systems like tower cranes and mobile cranes.[21] But hazards do exist with all types of systems as well as overhead cranes and with all aspects of ongoing crane management procedures.

Analysis of overhead crane accidents reveals three common safety hazards that every company using overhead lift systems should be aware of to keep operatives safe. The three most common hazards involving overhead cranes include electrical hazards, overloading, and materials falling/slipping from overhead hoists.[6]

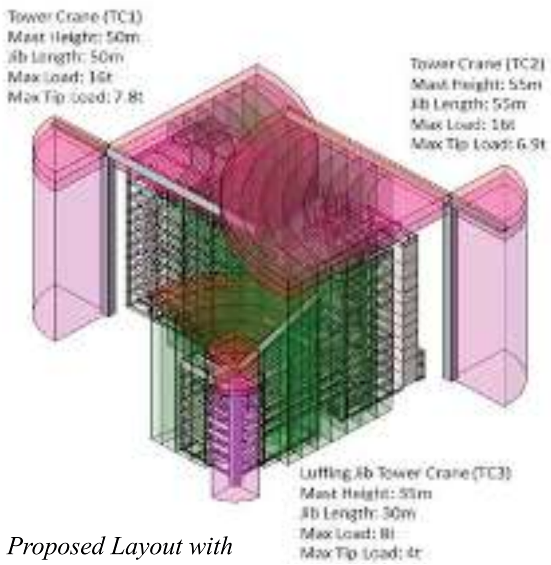

Figure 12. Proposed Layout with Crane information model[6]

BIM can facilitate the automation of Crane Lifting Plan requirements by using the following:

- The site boundary,
- Counter-jib clearance,
- Crane coverage, and
- Load capacity.

From the view (illustrated above), the site boundary has not exceeded the proposed workspace envelopes, or the various clearances required by the crane.

In this case example, the crane positions are satisfactory, with no clashes occurring between counter-jib clearances. Also, the coverage requirement is met, with all elements within the workspace envelopes. The 8-ton deep beam is situated at the intersection of the workspace envelopes of Tower Crane-1 and Tower Crane-2. An inspection of the load capacities of the calculated workspace envelopes reveals that Crane 2 does not have adequate capacity to hoist. However, Crane 1 is found to be adequate.

IX. BIM RULES BASED CHECKING: TEMPORARY SAFETY RAILS

BIM-based Rule Checking is a multi-domain validation framework based on parametric rules [5] and various concepts of BIM-based model checking exist [22].

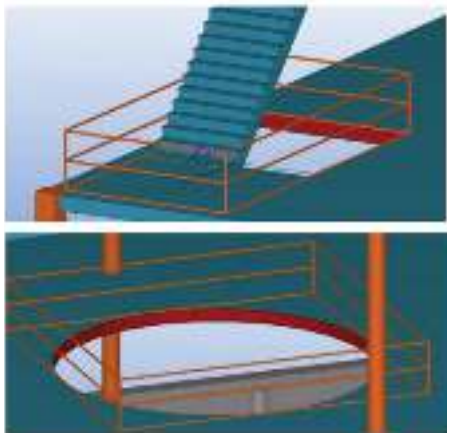

Figure 13. BIM software: Tekla Structures' ability to detect hazardous openings[2]

Moreover, parametric Rule Checking processes can be also applied to validate the compliance of design proposals against codes and regulations (i.e. BIM-based Code Checking) by comparing the parameters: geometric, (figure 13) and text based embedded within the BIM model against standard requirements translated into parametric rule sets. [2]

Other model checking tools can be used for more advanced application of Rule Checking, allowing the user to customize sets of parametric rules as well as quantity and information take-off definitions, for example Solibri Model Checker.[2] Such tools usually apply rules to IFC data representing the design solution to be checked and validated: that is one of the reasons why data interoperability between BIM authoring platforms and BIM tools remains a major issue. [23]

Figure 14. Modelling of Railing System for Fall Protection [2]

Using a conventional approach, construction safety management is grounded on standards, 2D drawings and printouts, so the integration of this information has always been a concern. The following framework (figure 15), for implementing an automated rule-based safety checking in BIM was conducted by Zhang et al [24]

The research conducted was based on BIM model components and it examines the risk factors that may be encountered in building sites, then matches the elements to relevant regulations to establish a framework of applications for BIM in a safety monitoring system.

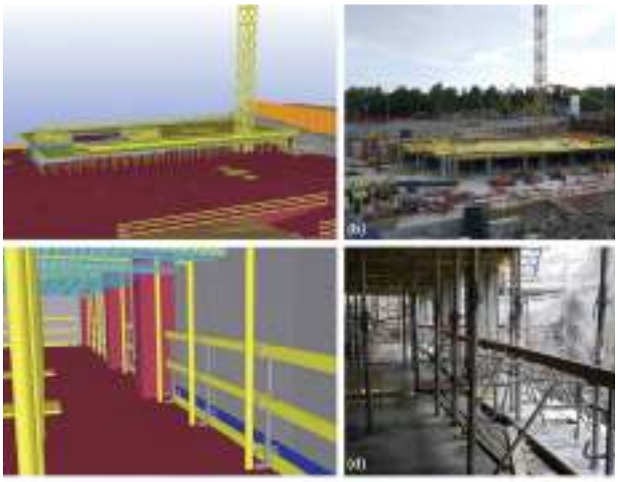

Figure 15. Comparing model and live situation: General view of site during basement construction phase, and at leading slab edge. [5]

Various kinds of regulations can detect hazards from different situations and may describe the same rule in dissimilar format. To aid rule searching, it is essential to reorganize these rules in the same format and same system.[25]
All of these regulations can be classified into safety protection, design calculation and design checking. As the rules are used to prevent safety accidents, the design safety related information is reorganized according to accident-related attributes. A framework of safety rule system is used based on these systematized items:

Safety rule input Hazard type
Accident subject………….Opening
Accident type………………..Fall
Attribute………………….…….Vertical
Parameter (length)………..H=?cm
Safety required……………Safety Rails
Prevention…………………Handrails[25]

X. REVIEW AND ANALYSIS OF SURVEY DATA

An investigation for this research was conducted to gather information, gauge responses from participants and evaluate solutions to crucial issues in industry. This was in the form of a questionnaire and survey concerned with addressing how level 2 BIM enhances and highlights site safety concerns and risk assessment evaluation. An emphasis was applied in determining how BIM assisted technology can be used for the design and planning of temporary works during the construction stage.

The study was confined to 10 BIM professionals related to an ISO19650 compliant AEC company. Anonymity was requisite for participants and the following could be established from the questions put forward.

The questions put to participants were:
1. From experience, are there any advantages/disadvantages by linking the temporary works 3D design model with the permanent works model from a safety and scheduling perspective?

2. The management of site Health and Safety face a number of challenges. Which issues has the most priority in the industry?
- *Cultural attitudes toward safety,*
- *Financial support for training, processes and suitable equipment.*
- *Limitation of qualified BIM specialists*
- *Human behaviour*
- *Project timescales*

3. How will the implementation of BIM affect the role of the Site Safety officer?

4. What level is your familiarity of PAS 1192-6?

5. With the successful adoption of BIM, a new collaborative way of working and sharing of information is expected. Will this achievement experience an initial loss of productivity?

6. Indicate the degree of effectiveness BIM addresses the following risks:
- *Trips/falls*
- *Hazardous building materials*
- *Confined spaces for operatives*
- *Site/machinery plant/crane movements*
- *Site traffic in construction and connecting points*
- *Confining and arranging storage areas while handling materials*

Analysis of data from the survey

The application of BIM to a project has a significant influence on site safety due to an element of prediction in early concept and design. The knowledge among respondents of PAS 1192-6 and imbedded legislation reported was high and was of extreme importance. BIM was very effective in addressing all site safety risks specified in the survey but only partially effected awareness of trips and falls. This may be partially due to the fact of the frequently changing site environment with regards work operatives' movement on site leading to certain degree of unpredictability but nevertheless still effective.

With regards BIM software effectiveness for H&S risk analysis, Solibri model checker and Navisworks were the most effective due to the specialised clash avoidance/detection abilities of same, with Revit, Tekla ArchiCad and MagiCad more suited to modelling and scheduling.

With regards the question of H&S challenges that needed to be addressed, the highest priority was allocated to cultural attitudes toward safety, financial support and project timescales. A medium level priority was the limitation of qualified BIM specialists. This response relates to an increased upward trend of BIM training with continuous professional development programmes for current staff and third level graduate programs specialising in BIM.

When asked about the role of the Health and Safety Officer it was determined to be a redefined one when BIM is considered for a project rather than when a traditional approach is used.

The 4D scheduling capability of BIM for Temporary Works design is used frequently for projects and there is a significant advantage when the Temporary Works design model is linked to the permanent works model for scheduling due to increase of information and predictability leading to better preparation and planning.

XII. OVERALL CONCLUSION

This research concludes that site safety can be significantly improved when level 2 BIM is applied to a construction project rather than a more traditional approach. An implementation of H&S is high on the agenda with responses to survey feedback encouraging.

A new approach to engage site operatives is revealed to be critical for site safety alertness and reduce complacency and lack of awareness that may manifest itself. The positive answers to the questions lead to a clear justification and indeed application of BIM technologies for H&S awareness for site personnel.

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Can the implementation of Building Information Modelling (Digital Construction) improve delivery of Capital Projects (Design and Construction) for the Health Service in association with the development of a new National Estates Information System?

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Abstract−Since November 2017 the Irish public service has been mandated to deliver its investment programme utilising Building Information Modelling (BIM). The Health Service Executive (HSE) is currently engaged in implementing a National Estates Information System (NEIS) to amalgamate current processes and workflows from its various Estates offices around the country. This research is being conducted to help inform the organisation on the benefits of standardisation and to identify the opportunities and pitfalls related to BIM adoption. This paper will review published literature to identify value streams focussing on public sector in general and health systems in particular. The methodology will target where BIM implementation can add value in conjunction with the roll out of the NEIS. This paper examines the benefits and challenges to the HSE in terms of standardisation and BIM adoption and show how these can be implemented to the benefit of the organisation. The benefits of early engagement, particularly in healthcare building design given their additional complexities, will also demonstrate how implementing the BIM programme can add value to the HSE. The findings show that implementing BIM in conjunction with the role out of the NEIS provides an opportunity for meaningful standardisation in the HSE but this will not be without challenge and requires significant resources, investment and engagement with all interested parties.

Keywords – Building Information Modelling, Health, Standardisation, Public Sector.

I Introduction

The Health Service Executive (HSE) was established on 1st January 2005. Prior to the establishment of the HSE health services in Ireland were delivered by eleven independent Health Boards, each responsible for developing, maintaining and managing their own healthcare estate.

Since the establishment of the HSE its Estates function manages the healthcare estate to create high quality physical environments that will enhance wellness for patients and service users. It is responsible for 4,000 property blocks including; acute hospitals, primary care centres, community nursing homes, office accommodation, civil registry offices, laboratories and warehouses.

HSE Estates has an annual capital budget of almost €1 billion in 2021 and the total reinstatement value of the estate is €14 billion. There are 10 local Estates offices spread around the country each delivering similar types of healthcare projects in different ways. There is no integrated system across these offices to communicate and share data. Local areas operate paper based systems and utilise outdated technologies. HSE Estates has identified a need to integrate the business processes and provide one source of information and is currently rolling out a new National Estates Information System (NEIS). The intended key benefits of the NEIS from a Capital Projects and Construction Management perspective are identified as;

- Increased productivity through shared drawings and documentation
- Reduction in contractor claims through accurate real-time data
- Improved quality of projects through global analysis of outcomes
- Alignment with international construction standard Building Information Modelling (BIM)

- Long-term project planning through investment scenario analysis

Fig. 1: NEIS key modules

NEIS is the platform supporting six key modules with Quality & Standards and Business Support at its core [1].

The purpose of this paper is to examine if the implementation of BIM in conjunction with the roll out of this new NEIS can improve the delivery of capital projects and compliance with Government Contracts Committee for Construction (GCCC) position paper 'A Public Sector BIM Adoption Strategy' [2].

II Literature Review

A literature review was carried out by conducting searches of a number of academic databases for journals, conference papers and other publications using key words including 'BIM', 'public works', 'healthcare' and 'hospital'. The papers were then analysed and the observations grouped into a number of themes.

a) *Benefits of Building Information Modelling*

There is a lot of information on the various benefits which can be obtained from using BIM, according to West et al BIM is a collaborative tool and is the single biggest technological change in the last decade [3] and further it is seen as a catalyst for more transparency, tighter integration and increased productivity in the Architectural Engineering and Construction (AEC) industry which mutates, matures and evolves into the future [4].

BIM is the latest revolution in the construction industry and has the ability to significantly alter how projects are delivered McAuley et al quoting Godager, 2011 states that BIM is beginning to change the way we build, the way buildings look, the way they function and are managed, further noting BIM has the ability to promote and encourage each stakeholder, within a project, to play a more prominent role, it cultivates collaboration and promotes a better 'team' ethos [5]. In 2016 a study by Boston Consulting Group established that "By 2025, full-scale digitalization will lead to annual global cost savings of 13% to 21% in the design, engineering and construction phases and 10% to 17% in the operations phase" [6]. Whilst it is an effective process which can improve efficiency and productivity within the construction industry, post construction the public sector can use the model to automate the creation of inventory lists for equipment and populate Facility Management (FM) systems and reduce redundancy of facility data for FM activities [7].

One of the major benefits of BIM is not the tool itself but the associated productivity, standardisation and collaboration the technology encourages. Lin et all noted that whilst the model was a 3D representation of physical and functional characteristics of a building some of the benefits include sharing of knowledge, knowledge integration between users and design professionals, coordinating tasks, improving communication efficiency, time saving and more efficient decision making [8]. BIM reduces the need for full scale mock ups and prototyping provides an opportunity for standardisation [9]. Particularly of benefit in healthcare related projects, according to Manning et al, is that it facilitates development of detailed information much earlier, improves decision making and reduces changes, where designers have the ability to easily develop multiple views, prepare schedules, query accurate information and it enables automatic updates to elevations and sections when considering changes [10]. Digital construction including BIM provides a holistic view of project delivery and helps to integrate parties into a collaborative process, it provides an opportunity for early contribution of all key stakeholders to support evidence based decision making for all stages including managing healthcare facilities [11]. In a recent paper McAuley noted that most value is to be gained in the operational phase because it provides a platform to retrieve, analyse and process building information in a digitalized 3D environment, it's a collaborative platform that supports interoperability between different business demands and with the current Covid 19 crisis organisations are accelerating their digital agendas and beginning to realise the relative benefits that digital tools can offer them [12].

An emerging benefit of BIM is offsite construction, both in terms of entire buildings or fabricating elements which can be incorporated into onsite construction. Detailed prefabrication can be achieved with relative accuracy allowing more time offsite and less impact on healthcare facilities. Quality is also better managed and achieved in an offsite factory / facility environment [13]. The 2019 paper by Dowsett et all noted that the technology provided productivity improvements and increased opportunities for pre-fabrication reducing waste through reduction in rework, improved safety performance and reducing cost as a less skilled workforce is required on site [14].

Other benefits of BIM noted are wide ranging and include; analysis (enabling energy and structural performance analysis [12], benchmarking providing a streamlined process for assessing appropriate lighting, access to daylight, noise reduction even door sizes [15], reduce energy and minimise impact of buildings on environment, encourages reuse of existing buildings making them easier to refurbish and protect/recycle existing space to meet current requirements like air change rates etc [16]. Better 3D visualisation, collaboration improvement, reduced time and cost, clash/collision detection, reducing conflicts, improved accuracy, reduced rework during construction and better construction and cost predictability [17,18], automatic generation of drawings and schedules, change tracking, modelling temporary (e.g. scaffolding) and existing structures, time scheduling and enhanced constructability analysis (health and safety) [11] are other noted benefits. The use of Construction Operations Building Information Exchange (COBie), the international standard for information management in modelling, allows for a formal method of documenting systems and components of a building which helps sort and store information in an easily retrievable format for use with FM systems. Properly maintained, this allows for easily identifying future problems during the building life cycle, linking to location, type of problem, other areas affected and associated documentation including any regulatory requirements [19].

b) Healthcare

Healthcare buildings are highly complex, technically sophisticated, have a lot of regulatory requirements and serve large amounts of people with very complex needs [15]. When assessing healthcare and their buildings in particular there are a number of items to consider.

Designing healthcare facilities is a time consuming and complex task. There are many informed and competent stakeholders (designers experienced in construction and doctors / nurses / allied professionals experienced in healthcare). The required codes and regulations for healthcare buildings contain a large amount of requirements which play a key role in healthcare design [20]. Architects, healthcare experts and users work in a dynamic alliance which provides an opportunity to harness the strength of BIM [4]. A balance is required to address their needs, preferences and requirements, utilise their knowledge and give due consideration for the services and technologies to be delivered [21].

There is an important relationship between the built environment and how it supports healthcare service delivery, which impacts health outcomes. The quality of the built environment impacts directly how patients react and sense the spaces, but it also has a major impact on staff. This is because medical staff tend to stay in these spaces for long shifts, most of the times under pressure [21]. Lucas et al quoting Ulrich et al 2004 has linked the physical environment of a healthcare facility to patient and staff stress, level and quality of care given, and patient recovery time, a hospital is where a sector of the community is more vulnerable to the physical environment [19]. The challenge for healthcare design is that an empathetic sympathetic environment is required to destress patient anxiety whilst functional space is required for healthcare professionals to do their job safely [9].

Hospitals have complex building services accounting for 40-60 % of project value and require geometric coordination. Accurate as-built information is crucial for future renovations [10, 11]. Healthcare systems are dynamic due to the unpredictable, interdependent and evolving tasks. In order to deal with this dynamism and variability, there is a need for flexibility, so that buildings can adapt to changing services and needs [21].

Most existing hospitals are very energy inefficient and are large consumers of energy due to the high level of equipment with significant power demand. Changing need in healthcare technologies demand bigger and better facilities and some hospitals experience continuous refurb whether for patient comfort or technology demands [16].

Facility layout is critical to minimise the potential for disease transfer and a high environmental control is required in terms of air quality, energy control, noise and infection control. Hospital construction renovation and repair activities are identified as the sources of airborne infection from dust generation which can impact patient length of stay. Refurbishment works have to be done in a ‘live’ environment working around sick patients [10, 19].

c) Visualisation

Given the complexities of healthcare buildings and diverse nature of stakeholders, with little or no knowledge or ability to read two dimensional drawings, being able to communicate design is critically important. BIM provides rapid visual creation at feasibility and assessment for alternatives which helps project team members develop shared understanding and the ability to visualise phasing and refurbishment of existing facilities and comprehend complexities in a much shorter time [11]. Given this knowledge gap, effective and active communication results when users are able to visualise the spaces and can provide easy review of furniture, colours, signage etc. reducing consultation time and negating reworks [8]. For the New Children's Hospital project visualisation was a key tool for planning approval. It allowed for visual impact of proposed buildings on surrounding areas to be considered which was enhanced by virtual illustrations and video. Easy visualising of space was a key collaboration tool allowing non specialised users to contribute more at an early stage [18]. Visualisation of service routes and voids is crucial and can add to the coordination process during design [20].

d) Policy

Public sector bodies and governments around the world have recommended or mandated the use of BIM as a strategy for addressing declining productivity with various strategies being adopted (UK 2011, Germany roadmap 2015). The EU BIM Task Handbook launched in 2017 defined a strategic framework that provides a common approach for BIM's introduction to public sector organisations within Europe [7]. The European Parliament voted in 2014 to amend public procurement rules to recommend the use of electronic tools such as BIM for public works contracts [22].

In January 2017 the government launched its action plan for jobs which included a requirement for the Office of Government Procurement (OGP) and Enterprise Ireland to prepare a strategy for the adoption of BIM across the public capital programme and to mandate the manner in which it was to be adopted across the public sector [23]. The OGP responded through a position paper by setting different target dates ranging from 12 - 48 months for projects to adopt BIM. These projects range from Band 1, which are of low complexity, such as low-density housing projects, to Band 5, which are complex projects with a specialist operation and maintenance regime, such as acute hospitals [2]. In a recent paper McAuley et al examined the Irish construction industry's state of readiness for a BIM mandate and noted other key publications including the Roadmap to Digital Transition 2018-2021 launched by the National BIM Council (NBC) in December 2018 with 4 pillars of 'leadership', 'standards', 'education' and 'procurement', and targets or performance indicators which include 20% saving in time, 20% saving in cost and 20% increase in construction exports. In 2019 Project Ireland 2040 established a Construction Sector Working Group (CSG) with part of its remit to investigate how industry and government could take forward proposals on BIM. Mc Auley et al further noted that whilst the Irish construction industry is adequately positioned to respond to a mandate (the education sector has responded to the need for training and appropriate academic qualifications and in the absence of a mandate it could be argued that with the existence of ISO standards, institutional templates and the NBC Roadmap the architecture is largely in place) however a lack of funding, low client demand and the absence of suitable contractual frameworks are chronic barriers [12].

There have been a number of papers produced around the adoption of BIM in Ireland, Ireland's readiness and focus on the public sector in particular [3, 5, 7, 12, 17, 22, 24, 25]. Ireland is well placed to support adoption with the NBC roadmap, champions within in industry such as the Construction IT Alliance (CitA) [26] who have been advocating the use of ICT and BIM since 2011 and BIMIreland.ie [27], a flagship website established as a key source of information on BIM and digital construction for Irish enthusiasts [12].

For BIM and digital construction to be adopted it must be mandated and as noted by Kuang et al the BIM adoption cycle as published by the World Economic Forum (WEF) in 2018 is a useful graphic to support the effective adoption of the National BIM roadmap [17].

Fig. 2: The BIM Adoption Cycle (WEF, 2018)

e) Education / Training

As with almost any technology, education and training must be at the centre of its adoption and this is evident in the NBC Roadmap where education and leadership are two of the four pillars [28]. West et al notes that BIM education and training supports BIM maturity, and research and industry in Ireland have been well served by a series of BIM gathering conferences organised every two years by CitA. Further noting that Irish education ranks amongst the best in the world for the adaption of its construction related programmes for BIM, from inclusion in undergraduate modules to full MSc and industry training programmes [3].

It is noted that significant upskilling is required for the public sector [5]and whilst project teams need people who can display a willingness to adapt and acquire new skills, education is key and important for government representatives and senior people in industry [25]. Education will evolve and industry will experience incremental benefit as designers and users become more familiar with their abilities and confident in the use of the technology [10]. Learning is a transferrable knowledge from one project to another and through time provides positive implications for design quality [4].

Since 2016 the CitA BIM Inovation Capability Programme (BICP) has captured the capability of construction and education response to the increased requirement for BIM. Educational institutes are seen as key partners and have responded rapidly to industry requirements despite the absence of a national mandate. The focus of public bodies should be on client requirements with staff upskilled in software and processes to empower BIM ready staff to take up leadership roles [12].

f) Technology

Many teams struggle with new technology and collaborative BIM is a change in traditional institutional practices [4]. Industry are now embracing BIM as the norm and incorporating emerging technologies like rule checking which can be particularly productive in healthcare where solutions like *Solibri* can confirm room types and number of gas outlets in correct configurations. This provides opportunities for reducing/minimising waste during the design process and increases the overall quality of the project [20]. Use of BIM based tools supports the identification of client requirements and stores information (using *dRufus*) to support decision making. It ensures needs are fulfilled and building compliance with regulations and standards is achieved negating repetitive tasks. This can also be particularly useful in healthcare for the creation of room data sheets and equipment lists making amendments required during design much easier [14, 21].

The BICP case study on the New Children's Hospital highlighted a number of the technologies used including; "google cardboard" as a visualising tool to help communicate design to non-technical users, "Dynamo" to reduce repetitive and tedious work and "Navisworks" for clash detection. The team employed "Cost X" for quantity take off, "TEKLA Structural Designer" and "SCIA Engineer 16" for structural analysis and "Codebook" was used to manage room data sheets, equipment requirements and coordination [18].

g) Client

BIM can facilitate the integration of project and asset management services [12] but information exchange through the lifecycle of a building, from conception through design development, the construction phase and into the operational phase needs to be properly managed to support facility management and maintenance and ultimately patient safety and reduced down time in hospitals [9]. Healthcare is a complex and critical AEC market segment with many challenges; BIM and its associated tools can increase the effectiveness with which owners, designer, and builders effectively and efficiently develop and execute these projects [10]. For BIM adoption to be successful the client must be invested, leading and the initiative must come from the top to enable early involvement of all key stakeholders [11]. Clients need to take an active role and support this with the necessary expertise and resources including individual, environmental, management and technological [4].

The first iteration of BIM implementation will not provide the desired results and every iteration has cost implications which must be realised by clients, implementation requires time and money to bed in and this needs to be recognised before the start of the BIM journey [14]. Setting requirements or aspirations at the start of a project is crucial for success (start with the end in mind) [9]. Investing in suitable resources is key for clients and it is noted that the role of BIM manager is a high priority and will deliver real benefits [25] and in a survey almost half of respondents considered that project managers should be BIM proficient [13].

It is important that the public sector recognise the benefits that BIM can bring but the process of adoption requires leadership [24], the role of public bodies is absolutely critical if BIM implementation is to become a reality [5]. The current suite of public works contracts are seen as combative but the role of information within construction needs to be seen as an agent for collaboration rather than and agent for dispute and control. The successful implementation of BIM in Ireland will require money in the form of additional design fees and investment in infrastructure and the public sector must demand its use and be willing to fund the change accordingly [25].

h) Industry

Kuang et al explains that construction is one of the last large industries to significantly embrace technology and leverage the opportunities that this transformation change can bring. The principal reason for the slow pace of change is the various internal and external challenges, such as, poor collaboration within the supply chain, outdated regulatory practice and monitoring and the difficulty of recruiting and retaining diverse talent in the sector [17]. The construction industry is fragmented and often polluted with duplication of effort but each participant has unique and valuable knowledge and skills, however the challenge is to bring these knowledge bases together and carry information from one stage to the next [10].

Foreign direct investment companies in Ireland have promoted the use of BIM leading to contractor upskilling. Public works contracts have become the lifeline for struggling contractors post-recession, however it is noted that the introduction of GCCC contracts met resistance from AEC sector and some small and medium sized businesses will no longer compete for government projects [5]. Large and progressive contractors claim the cost benefit to budget alone justifies the implementation of BIM, but there is a requirement to promote consistency of approach across all project types so that industry does not have to keep reinventing itself for each government project [24].

Ireland has become one of the global technology hubs, it is quite mature with regards to applying technology for modelling and collaboration purposes, as well as the integration of network-based disparate systems but despite this the construction industry is struggling to adopt the required ICT skills needed to fully drive the digital agenda. The very nature of Irish construction industry is one of adversity amongst its working members, information is closely guarded and information is power. This confrontational behaviour must come to an end if the potential of BIM is to be realised, information technology in construction has taken centre stage in Europe and industry has to keep up. The construction industry needs BIM in order to shift away from redundant work practices [25].

McAuley et all asserts BIM is now seen as the centrepiece of the construction industry's digitalisation and digital transformation, and if the industry is to attract the next generation of professionals to disrupt the way the construction industry works then government and industry must continue to embrace the change. Industry is still pushing the BIM agenda with policy makers mostly seen as passive. In the same paper McAuley et al suggest that Ireland was mature for modelling process and workflow but weak in terms of collaboration processes and policies. A public sector mandate would also help drive BIM through the private sector but also noted that industry is well placed to conform to emerging standards including ISO 19650.

i) Public Works Contracts

The Irish government introduced the Capital Works Management Framework (CWMF) in 2007 with a suite of new forms of contracts; the stated aim of the CWMF was to provide an integrated methodology and a consistent approach to the planning, management and delivery of capital works with the objectives of greater cost certainty, better value for money and efficient project delivery. These new contracts were heavily weighted towards the employer, coupled with poor project management on the client side has led to an oppressive environment for struggling contractors [5]. These contracts were conceived and drafted in a completely different economic environment and on the basis of appropriate risk transfer. McAuley et al notes that the experience was actually reduced fees, increased responsibilities and higher client expectations. The contracts were founded on the principle that a high level of quality information should allow for a high level of risk to be transferred however as the nature of the Irish construction industry is one of adversity where information is closely guarded and information is seen as power this appropriate risk transfer in many cases has not happened. In 2014 an Irish Government agency review called for the public works contracts to be revised to include a more collaborative and co-operative approach [24].

The 2014 review found that risk was not being adequately priced and recognised BIM as a powerful risk management tool [12]. The format of the current contracts do not support the collaborative nature required for design teams to deliver projects using BIM who experience duplication of work between disciplines where currently BIM implementation is being overlaid on traditional programmes leading to unrealistic expectations. Clear protocols are required to define who models what aspect of the building and at what stage, these protocols are required at the start of the project to ensure design teams price requirements correctly and correct resources are allocated to the project for each discipline at the correct time [14]. Further work is required to develop the legal wording of a BIM amendment to the existing public works contracts and it is recommended that the Irish Government prepare a protocol similar to the CIC BIM Protocol as used in the UK or adopt same for use with the CWMF [24].

j) Implementation / Information Management

Research shows that BIM is an information management tool that goes way beyond its design functions. Two of the main key performance indicators identified in the use of BIM leading to better integration of project teams and better collaboration are communications and coordination, there is also a need to move away from document model to integrated project database model for delivery of projects [13]. BIM implementation requires more than simply technology adoption, failure rarely results from the technical characteristics of the technology but more on how the social aspects have been addressed during implementation which is defined as reconfiguration of a complex set of actors, technologies and activities into an information system that can facilitate collaborative working [14]. While using BIM information becomes the fundamental asset, there is a need to make information more explicit to support better decision making. In healthcare, 'requirement management' is critical across all stages of a project as requirements change, evolve and are refined. Design and information management is complex but crucial to enable efficient management of expectations and requirements [21].

k) Restrictions / Roadblocks / Barriers

There is significant literature about the challenges faced in adopting BIM including fear of low success and failure, lack of support from senior leadership in companies and time to learn [7]. The lack of clear and consistent standards and new contract provisions which embrace collaboration is a clear barrier, as is reluctance to move to new forms of delivery including Integrated Project Delivery (IPD), adequate legal protocols and policies around design liability, design delegation and ownership of data [5, 12]. Available skills and ability are a major factor which results in additional time and cost in upskilling, implementation can be challenging, especially without previous experience together with reluctance to adapt to new ways with too much reliance on CAD and 2D drawings [11].

Many construction firms operate in silos instead of encouraging a more collaborative culture and AEC organisations struggle to develop new forms of organising and change [4]. For BIM to be successful all confrontational behaviour must end. Current designs are often weak, with risk not being identified or allocated properly, leading to dispute and conciliation [24].

A major factor in the widespread deployment of BIM is adequate training and investment in technology which can be significant for smaller design firms and may preclude them from tendering [13]. McAuley et al notes that financial assistance may be required for hardware and software resources and allowances for training of staff, there should also be a programme of training for public bodies in BIM awareness with a focus on client requirements. A key finding is the upskilling of staff in BIM software and processes should be coupled with a call for BIM-ready staff to take leadership roles [12].

III Engagement

As the NEIS project is being implemented a number of information engagements have been organised with senior managers and interested groups within HSE Estates. Feedback has been collated where participants feel the introduction of the NEIS and implementation of BIM will provide;

- Standardisation of work practices
- Consistent approach
- Enhanced levels of cohesion and compliance (with existing protocols)
- Greater efficiencies in local offices
- Better visibility across the organisation

The organisation is already well engaged in the transformation to digital systems with the strengths identified in the existing team to enable the change including; expertise, experience, team work and structure (see figure 3).

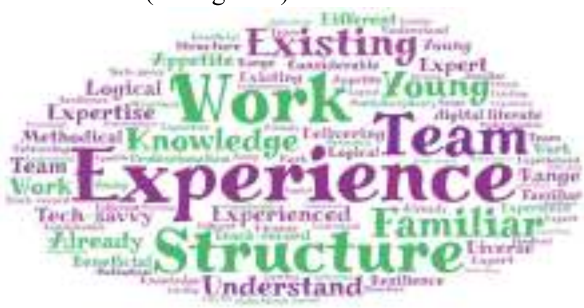

Fig. 3: Infographic of feedback identifying strengths of existing team to enable change to digital technologies

A key question is what is required to help the teams in the various offices adopt and implement BIM and utilise the NEIS. The pertinent issues have been categorised with emphasis on effective training, communication and engagement. The end users have also identified the need for additional resources and simple design where possible.

Fig. 3: Key issues to make implementation a success

The HSE has also commenced engagement with other public sector organisations including the Office of Public Works (OPW) to share experiences and learn from each other as well as ensuring consistency for partnering designers and contractors. A programme of planned engagement with professional bodies and construction representatives has also been developed to ensure effective engagement before and after roll out of the NEIS.

The implementation of the NEIS has already provided the opportunity for standardisation, with the chosen platform utilising a naming convention based the recently released national annex to ISO 19650:2. The project has engaged with Estates colleagues through demonstrations of the system and workshops on defining the role of local "Champions". The local offices have in turn responded by nominating a representative to actively engage in the configuration of the system which will aide the transformation to the new system and promote buy-in. In conjunction with the development of the NEIS a National BIM Working Group has been established to set a strategic direction and draft policy for BIM implementation across the various offices and provide standard documentation for future projects and partner engagements.

IV Conclusions and Findings

The research shows the benefits of BIM are wide ranging for the construction industry but specifically for health related projects because of their additional intricacies, regulatory requirements, technically complex systems and the wide range of stakeholders involved in healthcare design and use. BIM provides for development of detailed information which presents the opportunity to communicate with non-technical clients and provide visual representations much earlier in the design process.

Innovation around the use of digital technologies is advancing at pace, which industry is embracing, including rule checking software, laser scanning and importantly management of room data sheets, equipment requirements and coordination which are crucial in healthcare projects. Whilst BIM is used as an analytical tool to provide more effective buildings and promote more efficient use of space the real benefit of utilising BIM is the associated productivity, standardisation and collaboration that the technology encourages. The benefits include sharing of knowledge and more efficient decision making, which are key aspirations of the HSE in implementing BIM in conjunction with the role out of the NEIS.

The construction industry is fragmented and full of adversity where information is closely guarded and seen as power. BIM is now seen as the centrepiece of the construction industry's digitalisation and digital transformation to encourage collaboration processes and policies. In a lot of instances BIM implementation is being overlaid on traditional contract methods and programmes leading to unrealistic expectations on design team members and risk is not being appropriately transferred, as envisaged at the introduction of the Construction Works Management Frameworks (CWMF). The existing suite of public works contracts need to be reviewed in the context of emerging digital technologies to promote a culture of collaboration rather than the current adversarial approach.

Numerous papers have been written on the state of readiness of the Irish construction industry and the need for a national mandate which must be led by the public service. The existence of the ISO standards and the National BIM Councils' Roadmap to Digital Transformation is an indication that the infrastructure is largely in place, but this must be supported by adequate funding, revised contractual frameworks and adoption across the public sector which will also encourage use in the private sector. The HSE is well placed to become a leader in this digital transformation of the public service and have adequate structure, technical ability and knowledge to deliver this new way of working. HSE Estates have a young team who are digital literate, professional and have experience in delivering change with a willingness to embrace new technology.

For BIM to be successful clients need to be invested, take an active role and support it with the necessary expertise and resources including technical and financial. Clients must realise that the successful adoption of BIM will require money in the form of additional design fees and investment in infrastructure. However, given the many benefits of implementing the technology, clients will quickly recoup a return on this investment followed by further savings in the longer term from increased productivity and collaboration. For this to be successful in Ireland the public sector must demand its use and be willing to fund the change accordingly. BIM is an information management tool leading to better integration of project teams, there is a need to make information more explicit to support better decision making. The adoption of BIM, coupled with the launch of the NEIS brings a new focus on the importance of having the right information in the right place at the right time.

Education and training is one of the four pillars on which the NBC roadmap is founded. BIM education and training supports BIM maturity, significant upskilling is required for the public sector, especially on client requirements but the education sector is well placed to address this need. Effective training for all personnel has been identified as a key requirement for successful roll out of BIM and NEIS and this will need to be funded accordingly. Adequate investment in training and upgrading of technology are seen as potential barriers to widespread BIM implementation together with support from senior leadership, lack of clear and consistent standards and fear of something new. It is imperative that public sector organisations recognise the real benefits available from BIM adoption and address the potential risks with training and funding, especially to smaller design firms or contractors who may rule themselves out of tendering for public works contracts because of potential cost and risk.

The implementation of BIM in conjunction with the role out of the NEIS provides an opportunity for meaningful standardisation in the HSE but this will not be without challenge and requires significant resources, investment and engagement with all interested parties. Leadership, another pillar of the NBC roadmap, will be instrumental in ensuring the successful adoption of both BIM and NEIS for the health service. This leadership must come from the top and BIM proficient staff should be encouraged to take leadership roles in the implementation and role out of NEIS and BIM for the organisation.

IV Future Research

This paper has considered the benefits of BIM implementation in the context of design and construction for healthcare projects, however, further research should be considered to examine the benefits to the HSE in the commissioning and handover phase of capital projects and the operational phase where substantial efficiencies may be achieved by adoption and use of BIM technologies and processes.

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From Building Simulation Software to Ontology Language: Using a Calibrated HVAC Model as the Core of a Digital Twin Platform

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Integrated analytics and control applications, such as monitoring-based commissioning, Automated Fault Detection and Diagnostics (AFDD), Predictive Maintenance (PdM), Measurement and Verification (M&V), operational optimisation and demand response, can benefit from the use of building energy simulation (BES) models as virtual testbeds for the evaluation of control strategies and improved energy performance assessments. Hence, the ideal Digital Twin Platform (DTP) solution should enable cross-domain information exchange between virtual and physical assets. However, no solution aiming to integrate a BES model using a standardised convention was found.

This paper introduces a Python-based tool that maps the components and variables contained in the Apache Data Model (ADM) to BRICK entities and relationships. The script allows an IES-VE model to be exported as a BRICK model, giving applications access to simulated variables with the same query language as the one used in their existing domains. Two examples where IES-VE models with various systems, equipment and variables being exported as BRICK models are presented. Future research considers a similar solution for other ontology languages such as Project Haystack and RealEstateCore.

Keywords – BRICK, IES-VE, Ontology, Standard, Project Haystack, Smart Buildings.

I Introduction

In 2017, building stock accounted for 36% of the energy used globally and was responsible for 39% of the total CO2 emissions [1]. In the UK, building-related industries accounted for 20% of the total annual greenhouse gas emissions in 2018 [2]. The country has set the goal of achieving an 80% reduction in greenhouse gas (GHG) emissions by 2050 against a 1990 baseline [3].

It has been shown that adequate hardware across the building, including submetering, sensors, actuators, and integrated analytics and control software, can save energy by influencing user behaviour, operations optimisation and uncovering inefficiencies only detected when combining multiple data sources [4]. Lawrence Berkeley National Laboratory (LBNL) documented energy analytics enabled primary energy savings ranging from 12 to 30% [5].

Analytics solutions include monitoring-based commissioning [6], Automated Fault Detection and Diagnostics (AFDD) [7], Predictive Maintenance (PdM) [8], Measurement and Verification (M&V) [9], operational optimisation, demand response electricity supply [10], among others.

Building energy simulation (BES) can support these analytics-based solutions through baseline modelling for energy-saving estimations in M&V [9], enabling quantitative model-based AFFD [7], and model-based PdM [8]. Additionally, building energy simulation can be used as a virtual testbed for the evaluation of individual [11] and grid [12] level operational optimisation and demand response strategies. Finally, research shows that cross-domain information, e.g. the integration of simulated and metered datasets, is essential for building energy performance assessment [13].

Hence, there is a growing effort for seamlessly integrating building simulated data into the analytics domain. These solutions can be packaged into Digital

Twin Platform (DTP) solutions which can be cloud-based, e.g. Azure Digital Twins [14] or edge-based, e.g. Volttron [15].

In order to support a cost-effective real-world and virtual assets integration, it is necessary to ensure that physical and virtual assets have a similar vocabulary and structure, e.g. that all Building Management System (BMS) points have a corresponding model variable. It was identified that there was a lack of research in this field, as a result, this paper explores a solution for translating building energy simulation model variables to an ontology language typically used for classifying BMS points, heating, ventilation, and air conditioning (HVAC) equipment and spaces within a building.

The following section briefly describes the Apache Data Model (ADM) architecture, followed by an overview of standard ontologies. The proposed solution is to export a subset of the ADM variables as a standard ontology model and presents two examples of IES-VE models that were exported as BRICK models. Finally, a conclusion of the approach is discussed in conjunction with the future research directions.

II Apache Data Model

The IES-VE is a BES software composed of several modules intended for advanced analysis. These modules support geometry creation, profile modulation management, natural ventilation assessments, solar radiation analysis, thermal templates and HVAC network modelling. Altogether, provide a holistic overview of the performance of a virtual building.

When an IES-VE model of an actual building asset includes accurate information about the geometry, actual building fabric properties, real internal gains, a HVAC network that reflects the actual systems - with the error between simulated and measured data being minimised, and its uncertainty being acceptable - we say that it has been calibrated.

The IES-VE software allows users to export all the information from a model into an Apache data model (ADM) file. The ADM contains information required to run a simulation and has been conceived for co-simulation with third-party integrations via a Python-based library. Figure 1 shows the information contained in the ADM.

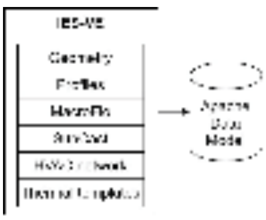

Fig. 1: The ADM contains critical simulation information contained in the IES-VE model.

The HVAC network is modelled using components (coils, heat sources, water loops, etc.) linked to variables (temperature, airflow, modulation, etc.) and HVAC zones through well-defined relationships. At a high level, components are divided into airside, waterside and plant equipment. Figure 2 shows the sub-categories of components for each category.

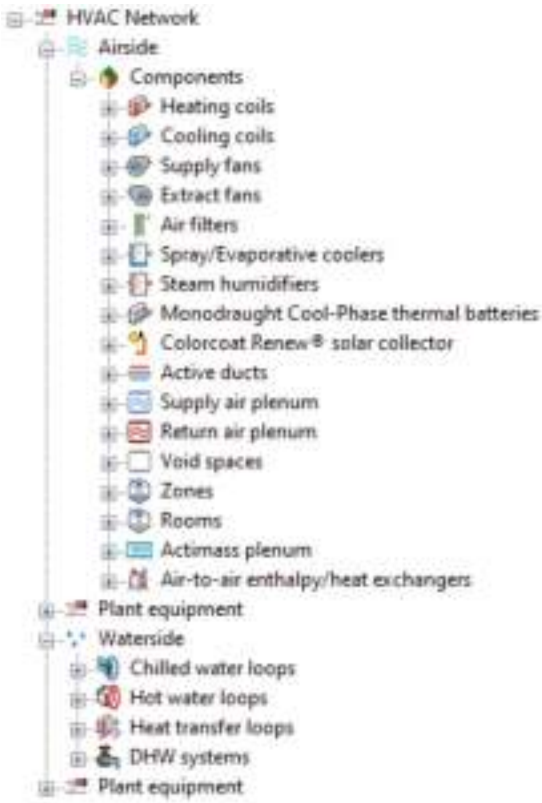

Fig. 2: The HVAC network architecture in the ADM.

Building spaces can be conditioned or unconditioned, where a group of conditioned spaces is known as a "HVAC zone". Each room and component contain a comprehensive set of variables available upon request before starting the co-simulation job.

Model variables are classified into read and write. Read variables are outputs from the simulation, and examples are air temperature, relative humidity, comfort metrics, heating and cooling loads, and CO2 concentration. On the other hand, write variables include internal gains breakdown, number of people, setpoints, and HVAC controller variables.

III Standard Ontologies

During the design, construction and commissioning stages of the building life-cycle, a Building Information Model (BIM) focuses on the 3D aspect of the building assets enabling functionality like clash detection, 3D visualisation, and gamification, among other benefits. Examples of formats in this category include the Industry Foundation Class (IFC) and green building XML (gbXML). However, Structured BIM formats lack descriptions of how the constituent equipment and points work together, have limited query mechanisms and cannot be extended by users. These drawbacks restrict their use during the operations, maintenance and audit stages of the building life-cycle.

Recent literature reviews and surveys from the industry show that, during the operational phase, each asset-building represents a unique challenge in terms of available data, business model, goals, type of building assets and budget. Unstructured (schema-less) models are more suitable due to their flexibility, ability to describe relationships across components of any nature and the possibility of data integration. Figure 3 shows a building metadata life-cycle and the commonly used open BIM formats for each stage.

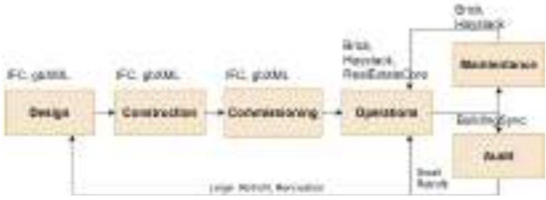

Fig. 3: Building metadata life-cycle and standard ontologies commonly used. Adapted from [16].

Standard ontologies have emerged to promote the implementation of a single vocabulary and access to multiple sources of data. In general, an ontology ensures that any application can interact with any equipment and device without having to deal directly with their underlying communication protocol, e.g. BACnet [17], LonWorks [18], Modbus [19], Niagara [20], web APIs, etc.; or the physical location of the data source, e.g. cloud or edge platforms.

The ideal ontology should have the following characteristics:

- Represents "things" in buildings. A "thing" could be a physical, virtual or logical asset.
- Represents relationships between things.
- Extensible classification of things.
- Portability and consistency.
- Relationships and classifications should be generalisable to new situations.
- Support implementing advanced control and analytics applications (FDD, supervisory control, energy optimisation, etc.).
- Includes actors relevant for the business model.

There is a growing number of standardised schemes. Notable tagging schemes include BASont [21], Smart Appliances Reference (SAREF) [22] and RealEstateCore (REC) [23]. Full building ontologies examples are Project Haystack [24], BRICK schema [25], ASHRAE Standard 223P [26] and Quantum ontology [27]. In addition, Microsoft introduced the Digital Twin Developer Language (DTDL) for Azure Digital Twins [28]. Despite DTDL not being an ontology itself, it is capable of adapting to an existing one. Documentation for importing from IFC, REC and BRICK models is available [29].

Using a standard ontology model as the core for data integration alongside analytics and visualisation is a recommended practice for Digital Twin Platform (DTP) as it allows holistic system integration, enabling what we know as a Smart Building. The following section briefly presents the main characteristics of each of the full ontologies that are already available for public use.

a) RealEstateCore (REC)

Developed by Real Estate companies from Northern Europe in 2019, REC is an OWL 2 Web Ontology Language for smart buildings integration. It describes buildings using the *BuildingStructure*, *BuildingStructureComponent*, *VirtualComponent*, *Premises*, *StoreyLevel* and *Room* entities and describes HVAC components and point using the *Device*, *Sensor* and *Actuator* entities. REC introduces the concept of *Agents*, where people, organisations, groups, and any stakeholder related to the buildings' assets can be included as part of the model. Also, the *VirtualComponent* is an entity that can be used to identify a simulated variable.

REC features modularity, highly customisable and free to use under the MIT license. REC allows imports from existing IFC and BRICK models.

b) Project Haystack V4

Project Haystack was developed by industry actors in 2014. Haystack uses a series of tags (individual or composite) to describe entities, relationships, and hierarchies.

Haystack tags can be categorised in markers (e.g. zone, temp, sensor), value (date:2018-01-01), and reference (e.g. id:HC00001).

The relationship between tags is expressed using special reference tags that link a point to a piece of equipment (equipRef), to a specific space (spaceRef), equipment to a site (siteRef), and a site to a weather station (weatherStationRef), among many others.

Haystack is considered a flexible and human-interpretable ontology, however it is a limited machine-readable format [30].

c) BRICK Schema

BRICK is specialised in technical assets such as systems (HVAC, lighting safety, electrical, gas), building locations (spaces, floors, outdoors), points (sensor, command, setpoints, status) and the relationships between them. BRICK takes advantage of the Resource Description Framework (RDF). The schema is based on triplets with descriptive tags using the subject-predicate-object RDF standard. A triplet can describe a point, equipment, location or resource. BRICK entities are organised in classes with expected tags and relationships.

Tags are derived from the entities, and they can be combined to create higher-level entities, e.g. all entities with the *tag: Air*, *tag: Temperature*, *tag: Sensor* and *tag: Point* will be instantiated as members of the *brick: Air_Temperature_Sensor* class. The relationships between entities are specified as *isLocationOf*, *controls*, *hasPart*, *hasPoint*, and *feeds.* Inverse relationships, tags and tagsets are also included and can be generated automatically using the provided BRICK schema package [31]. A BRICK model can be deployed in a BRICK server linked to an RDF database and queried using the "SPARQL" language.

It is also possible to embed within the model entity (e.g. a sensor) a pointer to the location of historic time-series data using unique IDs of the sensor. Similarly, BACnet object IDs can be used to access current BMS values in the BMS controllers. Bespoke specifications on how to read and write data from data sources can be included in a BRICK server in the form of connectors, i.e. protocol specifications. Hence, queries across all buildings in a portfolio become possible. For example:

- List all fan coils currently on.
- List all spaces that have no occupants and are being supplied with external fresh air.

Documented drawbacks of the BRICK schema are the limited ability to create custom tags and relationships and the relatively high effort to create the BRICK models in the first place [30].

The following section documents the steps to enable the export of an IES-VE model in the form of an ADM file which is then exported as a BRICK model. We chose the BRICK schema due to the amount of available documentation and tools online. However, the conversion approach should be applicable to other full building ontologies, specially REC and Project Haystack.

IV Proposed Solution

The solution in this work assumes that knowledge embedded in any IES-VE calibrated model can be used to create a BRICK model with zero or minimal intervention. The benefits of this solution are that:

- It enables access to read and write model variables with queries, effectively turning the calibrated model into a virtual testbed.
- For new buildings, it provides the initial BRICK model that can be used as reference for the tagging of the real assets (e.g. equipment and points), reducing its adoption barriers and making the process less error-prone and more efficient.

Figure 4 shows a sample architecture that integrates real and virtual assets in the context of a simple Digital Twin Platform (DTP). Elements in blue show the features required to achieve the model export: (1) a points list of model variables that are relevant for the applications, (2) a calibrated model in the form of ADM and (3) Apache to BRICK script. Notice that it is possible to export all variables from the ADM; however, we prefer to avoid the export of model variables that are not relevant. Besides, it is more often the case that a subset of variables, and not all of them, are relevant for any given scenario.

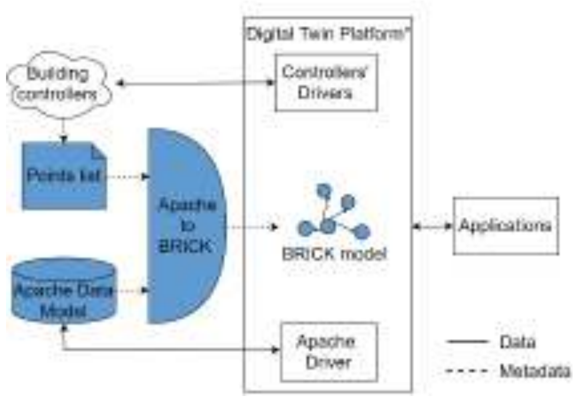

Fig. 4: Apache to BRICK solution architecture. Elements in blue show the elements required to achieve the model export.

As described in the diagram, the Apache to BRICK script uses the knowledge from the ADM to map the points lists using BRICK identities. The current version uses BRICK ontology version 1.0.3. The script is written in Python, as the support libraries for BRICK and the ADM are available in this language.

In the following subsection, examples of the mapping for components, equipment and relationships are presented.

a) Components

In the ADM, components are represented with a combination of two to four letters followed by six digits, creating unique IDs e.g. HC000001. The letters represent the type of component, e.g. HC is a heating coil, which in BRICK is defined as a *Heating_Coil*. Table 1 shows more examples of component mapping between ADM and BRICK.

Table 1: Examples of Apache to BRICK component

Component ID	BRICK equipment
HC******	Heating_Coil
CC******	Cooling_Coil
SF******	Supply_Fan
HWDL******	Hot_Water_System
PR******	AHU
CD******	Condenser
IN******	Outside_Air_Damper

A HVAC component in the ADM is called "multiplex", it does not have a BRICK equivalent. A multiplex does not represent any physical component, it is used to group components that are part of a single HVAC zone. However, we use the multiplex information to assign the subset list of components that feed each HVAC zone.

b) Points

The ADM has a list of more than 1,200 read variables and several write variables. These were mapped to their closest BRICK point equivalent. Table 2 shows an example of the point mapping.

Table 2: Example of Apache variables to BRICK points

Apache Variable	BRICK point
airTemperature	Room_Temperature_Sensor
roomCO2Concentration	CO2_Sensor
boilersLeavingTemperature	Leaving_Water_Temperature_Sensor
boilersEnteringTemperature	Entering_Water_Temperature_Sensor
primaryTargetSupplyTemperature	Supply_Water_Temperature_Setpoint

It is worth mentioning that not all variables have a BRICK point equivalent, and they have to be expressed as custom entities. An example is a COP (efficiency) variable, available in various components that exchange heat from the water to air substances.

c) Relationships

Finally, relationships between spaces, air side, water side, and plant equipment components are represented as described in Figure 5.

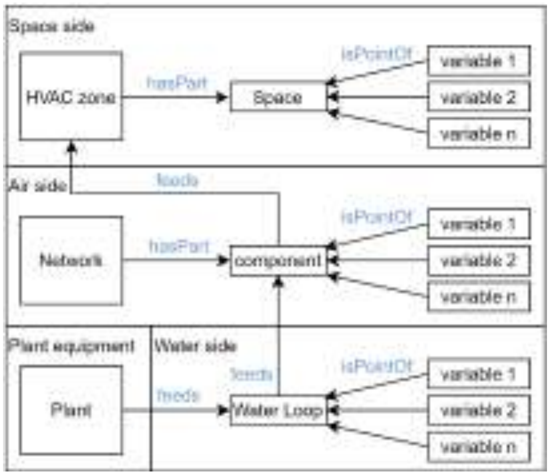

Fig. 5: Relationships map between Apache HVAC and BRICK relationships.

V Case Studies

Two case studies are presented in this example. One is a simple two-room model with a simple HVAC network and the second example corresponds to a calibrated model of an office building located in France.

a) Simple Two-room Model

The model contains a HVAC system with an air handling unit (AHU) with constant air volume (CAV) feeding two HVAC zones with terminal reheat coils. Figure 6 shows the simple geometry of the model and Figure 7 is a graphic representation of the HVAC model in the IES-VE software. The model is then exported as an ADM file.

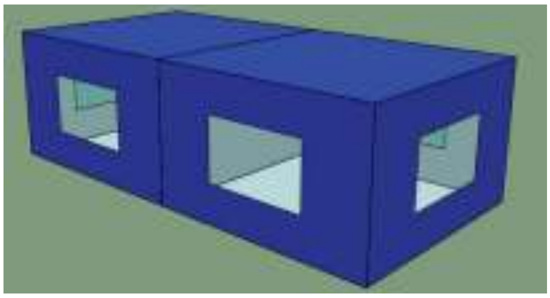

Fig. 6: Simple two-room case study.

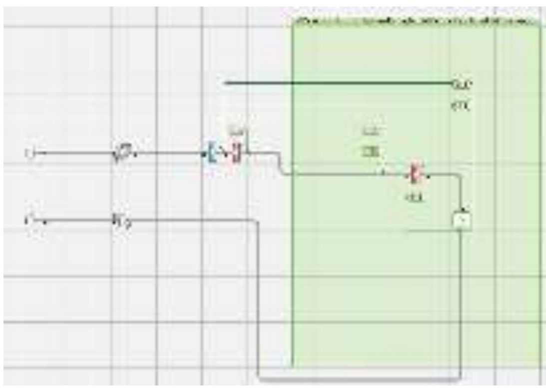

Fig. 7: The Airside HVAC network of the simple two-room model.

The list of points includes the variables described in Table 3. Only variables from the Space and Air side are selected for simplicity.

Table 3: Point list of the two-zone model

Level	ID	Variable
HVAC Component	SF000330	airflow power
HVAC Component	EF001301	airflow power
HVAC Component	HC002832	sensibleLoad
HVAC Component	CC000780	totalLoad
Space	RM000000	numberOfPeople roomCO2Concentration airTemperature lightingGain

Using the Apache to BRICK script, the resulting model is presented in Figure 8.

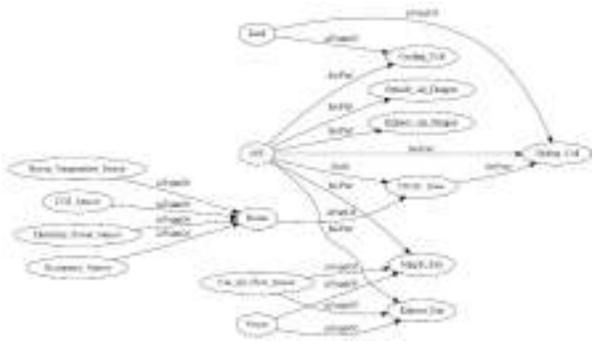

Fig. 8: BRICK network of the simple two-room model.

After the model is expanded, e.g. inverse relationships and tags are automatically added, the model is ready for queries directly from any application able to execute SPARQL queries. Figure 9 shows an example of a query that links the number of people in a given space (in reality, it would be a motion sensor) with the AHU supply fans that feed this space.

```
select  ?occupancy_uuid  ?airflow_uuid where {
?airflow_sensor rdf:type brick:Fan_Air_Flow_Sensor ;
      brick:hasUuid ?airflow_uuid .
?fan rdf:type brick:Supply_Fan ;
      bf:hasPoint ?airflow_sensor .
?ahu rdf:type brick:AHU ;
      bf:hasPart ?fan .
?zone rdf:type brick:HVAC_Zone ;
      bf:isFedBy ?ahu .
?room rdf:type brick:Room ;
      bf:isPartOf ?zone .
?occupancy_sensor rdf:type brick:Occupancy_Sensor ;
      bf:isPointOf ?room ;
      brick:hasUuid ?occupancy_uuid .       }
```

Fig. 9: SPARQL query example.

An unoccupied space that is being fed with fresh air represents an energy-saving opportunity. Figure 10 shows an example of a plot that uses the result of the previous query to highlight energy saving opportunities in the IES-VE model. The query would be identical in the real building, provided that the IES-VE model represents the actual building.

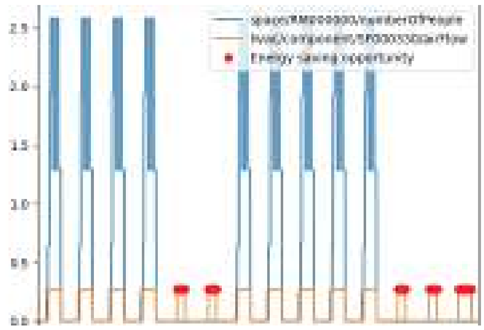

Fig. 10: Example plot from variables resulted from a query.

b) Complex Office Building Model

An IES-VE model representing an office building in France was tested. The model has 1120 rooms and 1974 HVAC components across 45 systems. A high-level view of the air side network is displayed in Figure 11. 120 variables from the air side and room level were deemed as relevant. The resulting BRICK model is presented in Figure 12. Notice that the network has been extended to cover the inverse relationships.

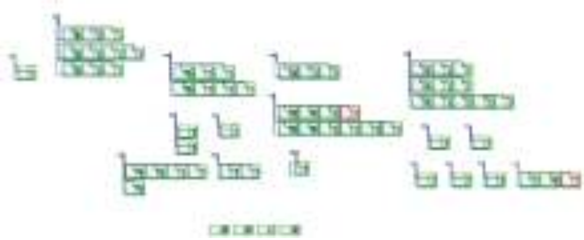

Fig. 11: Air side HVAC network in the IES-VE model.

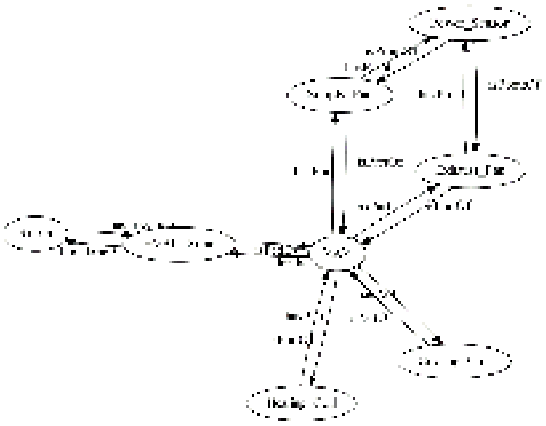

Fig. 12: Air side BRICK network of the office building model.

VI Conclusions

This paper introduces a script that exports an IES-VE model in the form of an Apache Data Model into a BRICK model with no intervention. We identified only two instances of variables with no direct mapping between the Apache and BRICK ontologies, suggesting that the process can be achieved with minimal supervision.

Two model examples are provided; one is a simple two-space building with a simple AHU. We also show a sample query for fault detection using simulated data. A second example is a complex office building in France. In the future, a similar approach for other ontology languages, such as Project Haystack and RealEstatecore, will be explored.

VII Acknowledgements

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OPW Revit Template – an enabler to increase the implementation of BIM on OPW projects

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Abstract – The Office of Public Works (OPW) is a government office responsible for matters concerned with flood management and property services, with responsibility for delivering and managing over 2000 buildings within the state property portfolio [1]. With a full in-house multi-disciplinary design team, members of the OPW are present throughout a building's lifecycle, which gives the OPW a great opportunity to make the most of BIM. However, while a growing number of OPW projects are delivered using Revit, the overall number of projects using formal BIM processes is small. Arising from a desire to increase the number of projects using Revit and BIM, the OPW submitted a successful funding proposal to the Our Public Service 2020 Innovation Fund [3] to create a multidisciplinary Revit Template for the organisation. Drawing on expertise from across OPW, an in-house "Template Team" was formed to lead the development of the Template under the guidance of an experienced BIM Consultant. Following formal Revit training for the Template Team, Digital Built Consultants (DBC) were appointed to assist the team to develop the Template. Over six hackathon sessions, DBC provided guidance to the team on what to include in this first OPW template file. OPW architects, engineers and draughtspeople collaborated, using a single Revit Central Model, to create the OPW Revit Template. In August 2020, the first version of the Template was successfully completed and has since been made available to staff. It holds common styles, annotations, view types and schedules for use across the organisation; it is also supported by a number of "resource templates" holding discipline-specific information. Since the launch, the file has been used to create single-discipline Revit models on OPW projects on a number of projects and has been further updated in 2021 to include revisions to align with the 2021 National Annex to I.S. EN ISO 19650-2 [7] and a number of other updates following feedback from colleagues. The Template provides a starting point for OPW architectural or engineering Revit models. It is hoped that the tool will increase the adoption of BIM processes on OPW projects in the coming years, acting as an enabler to assist colleagues moving towards the further implementation of Revit / BIM on OPW projects.

Keywords – BIM, Revit, Revit Template, Multi-disciplinary, Our Public Service Innovation Fund, OPS 2020

I Introduction

The Office of Public Works (OPW) is a government office responsible for matters concerned with flood management and property services; its remit also includes the responsibility for delivering and managing over 2000 buildings within the state property portfolio [1]. Properties under the remit of OPW include buildings of national significance such as Dublin Castle, Leinster House and Áras an Uachtaráin, UNESCO world heritage sites Brú na Bóinne and Skellig Michael and many other heritage sites throughout Ireland.

As designers, OPW teams are responsible for delivering new construction, refurbishment, conservation and major maintenance projects throughout the country. These range in scale from one-off buildings for organisations such as the Irish Coast Guard or An Garda Síochána to large, complex projects including the Forensic Science Laboratory at the Backweston campus, maintenance/ refurbishment projects on existing buildings such as Leinster House and international projects such as the Irish Pavilion at Dubai Expo 2020.

In-house teams of architects, engineers and quantity surveyors, working alongside other civil servants, lead the design and manage delivery of these projects. Acting as a client, OPW projects are also supported by external consultant architects, engineers or quantity surveyors, as necessary during the design phase; the organisation also appoints Contractors for the construction phase of new projects, and for maintenance and upgrading works to existing assets.

With parts of the organisation acting as client, designer, owner and tenant throughout the design life of a building, the influence that the OPW has on construction projects is unique in Ireland. This reach also gives the OPW a great opportunity to make the most of BIM.

II BIM AT OPW

At a Government level, the mandate to use BIM on public projects is currently being reviewed as part of changes to the Capital Works Management Framework (CWMF); it is expected that "opportunities to further deploy digital technologies, such as BIM" will be included in this next iteration of the CWMF [2].

In parallel with this, the OPW have been transitioning to working using BIM processes over the past number of years, and significant investment has been made in both hardware and software to support this.

Over the past two years, there has been a renewed effort to increase both awareness of BIM within the organisation and the implementation of BIM processes on OPW-led projects. Initiatives have included the formation of an internal BIM Committee, led by the Office of the State Architect, which includes representatives from each of the OPW design disciplines involved in project delivery; development of an OPW BIM Implementation Strategy which was reviewed by OPW Management Board; training on use of BIM technologies and workflows; development of common standards for use on OPW buildings projects; and, implementation of 3D modelling on a number of OPW projects.

Fig. 1: Westport Coast Guard Station structural model

At a project level, the adoption of BIM is most visible through the use of Revit models to generate project information at all projects stages, particularly at tender and construction stage as shown in Fig. 1 and Fig. 2.

Fig. 2: Sample architectural model showing design intent

However, while a growing number of OPW projects are delivered using Revit, the adoption of Revit to deliver project information varies across teams and disciplines. Overall, the number of OPW-led projects mandated to use formal BIM processes, or where Revit is adopted by multiple members of the design team, either in-house designers or consultants working for OPW, is small.

As a complex organisation spanning multiple design disciplines, where projects are often delivered by a combination of OPW in-house designers and external consultants and with individuals representing a myriad of project roles, the need to increase implementation of BIM on projects to deliver efficiencies in the design, construction and management of assets is clear.

III OPS 2020 FUNDING

Arising from a desire to increase the number of projects using Revit, and ultimately to increase the adoption of BIM processes on projects, the OPW submitted a proposal to the *Our Public Service 2020 Innovation Fund* (OPS 2020) [3] in February 2020.

The proposal centred on the creation of an OPW multi-disciplinary Revit template file, to assist in-house design teams making the transition to delivering BIM projects through Revit.

Along with a desire within OPW to increase the adoption of BIM on projects, this project also aligned with the *Government Strategy to increase the use of Digital Technology in Key Public Works Projects* [4] and a number of the OPS 2020 strategic actions.

It was proposed that this Template – the first developed specifically for OPW – would provide much of standard 'set-up' for models, reducing the set-up time on each project. As a multi-disciplinary template, stored centrally on the OPW network and accessible to all staff, this could also be maintained centrally into the future and provide visual consistency to OPW drawings and models created by different parts of the organisation.

In order to deliver this project, it was proposed that an internal team of OPW architects, engineers and draughtspeople would be formed to design and develop the Template file, under the guidance of an experienced BIM Consultant.

Following review by OPS 2020, this project was one of 34 projects, out of 364 submitted from across the wider civil and public service, selected for funding in 2020. Once funding, totalling €10,970, had been confirmed, work began immediately to deliver the project.

IV Covid-19

Almost immediately after the project started, the global Covid-19 pandemic began to take hold in Ireland. As with many organisations, OPW staff immediately began working remotely and this required a change to the method of implementing the Revit Template project.

It had originally been envisaged that once the project Template Team had been established, meetings, training sessions and template development sessions would take place in person.

However, given the developing nature of the pandemic in Ireland, all communications within the project team and all in-person meetings would need to move to a virtual environment. The key impact of this on the project was the change from supervised template ‘development sessions’ with the Consultant to a presentation and workshop style session, with the Template Team working more independently on elements of the Template in advance of follow-on meetings with the Consultant.

The impacts of Covid-19 meant that the Template Team never met in person, the Team attended all training sessions virtually, no physical meetings took place with the Consultant, and the project was completed whilst all members of the team were working remotely.

V Project Setup

A simple project structure was put in place – the project was led by Michael Day, and in his absence Lennart Sobiecki, with the team reporting to Ger Harvey, chairperson of the OPW BIM Committee.

a) Baseline Survey

In advance of commencing template development, a short questionnaire was created in order to identify existing Revit projects completed throughout OPW, the particular Revit Template (if any) used to deliver these projects and to identify any perceived barriers to the use of Revit on OPW projects.

In May/June 2020, the survey was circulated to architects and building engineers throughout the organisation and 76 responses were received.

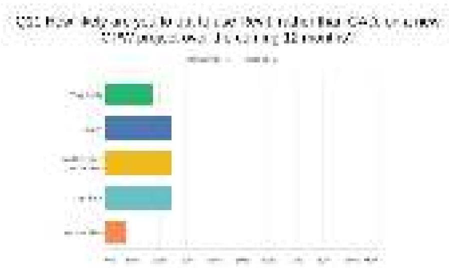


Fig. 3: Sample of Survey Responses

The survey results provided a good insight into the use of Revit throughout the organisation at that time and the potential usefulness of this Revit Template once completed. Some of the key findings included:

- Revit proficiency throughout the OPW is variable, with a limited number of Expert (<2%) or Advanced Users (11%).
- The majority of users are at a basic level of proficiency: Beginner (31% - I can open the 3D view, I can draw detail lines, I can edit project information) or Newbie (43% - I am aware of Revit, and have opened it once or twice).
- Two-thirds of respondents have received formal Revit training, either at university/college (12%) or a subsequent training course (54%). A number of respondents received training a number of years ago, but “haven’t used Revit since”
- Three-quarters of respondents have never used Revit to deliver project information at OPW
- Of those who have used Revit on projects, most have only used it on a small number of projects
- Respondents most frequently describe the Revit Template used on their projects as ‘I created it as I went’ (47%) or ‘I used a template from someone else in the organisation’ (24%). Two respondents also noted that the template used on their projects was ‘Started from First Principles’.
- All of those surveyed said they would be ‘Very Likely’ (88%) or ‘Likely’ (12%) to use a Revit Template developed for the OPW
- Approximately 42% of respondents noted that they are ‘Very Likely’ or ‘Likely’ to use Revit on a new OPW project over coming 12 months as shown in Fig. 3
- Respondents noted Training, assistance from a BIM Manager, an OPW BIM Execution Plan, use of Revit ‘as standard’ and a Management decision to use Revit / BIM as drivers to increasing the use of Revit at OPW.

b) Template Team

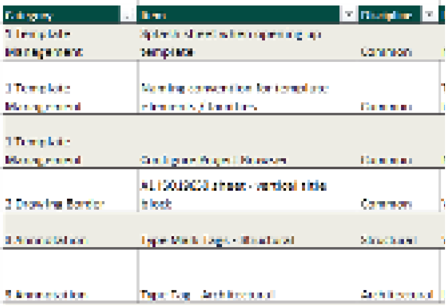
Drawing on expertise from across OPW, a multi-disciplinary in-house 'Template Team' of 11 individuals was formed; this team would lead the development of the Revit template file under the guidance of an appointed BIM Consultant.

Although prior knowledge of Revit was desirable for Template Team members, the most important factors in determining membership of the team was that it would span across the OPW, with representatives from OPW's main design offices in Dublin and Trim, and would include members from the three main building design disciplines – architects, civil/structural (C&S) engineers and mechanical/electrical (M&E) engineers.

c) Working Collaboratively

As part of the initial project set up, an 'Alfresco' sharing site was set up for the project. This allowed the Template Team members, who would not ordinarily have access to a common Network Folder, to share ideas and resources throughout the project.

This site hosted an Excel-based list of 'ideas' for inclusion in the Template, a sample of which is shown in Fig. 4; this comprehensive list of ideas was collaboratively generated by the Template Team and was used as a 'wish list' to inform the brief for the Consultant and direction for the project.



[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Common
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Common
[illegible]	[illegible]	Structural
[illegible]	[illegible]	Architectural

Fig. 4: Revit Template 'ideas' (extract)

Given the multi-disciplinary nature of the team, whose members would not be in frequent contact otherwise, an internal 'StarLeaf' messaging group was also created at the outset of the project to promote more interaction between members of the team.

d) Revit Training

In order to provide the Template Team with sufficient knowledge to commence development of the template, part of the project budget had been set aside for Revit training.

A series of training courses were organised for the team. Due to Covid-19 restrictions, these all took place using Microsoft Teams. All of the Template Team completed training in Revit Advanced – BIM Management and Revit Advanced – Families, and a number of less-proficient users also completed 'Revit Refresher/Upgrade' courses. Where additional places were available on the courses funded by this project, a number of other OPW colleagues with an awareness of Revit were invited to join.

e) Consultant Appointment

Based on colleagues' responses to the baseline survey, individual ideas from the Template Team and following a number of team video-conference sessions, the Template Team developed a 'Scope' for prospective consultants to assist them to deliver the project.

The Scope was sent to a number of potential consultants in May 2020 and following a competitive tender process, Digital Built Consultants (DBC) were appointed to assist the Template Team to complete the project.

VI Development, Review and Issue

a) Hackathon sessions

Over the following three months, six hackathon sessions were held between OPW and DBC. These interactive sessions were primarily led by Digital Built Consultants and generally involved a presentation followed by an informal discussion and questions and answer session. The use of 'screen sharing' functionality allowed members of the team to regularly share their screens to talk through an area of particular interest or challenge as shown in Fig. 5.

Fig. 5: Template Team 'hackathon' with DBC

The first workshop was of an introductory nature, with DBC trainers providing examples of templates used by other organisations, why a Revit template is important, hints and tips for what should be included in the OPW Template and advice on next steps for the Template Team.

The following three sessions were 'discipline specific', focussed on items of an architectural, C&S and M&E nature; this was followed by two review sessions with DBC.

b) Overarching Template Strategy

In advance of commencing template development, DBC stressed that a key decision on the overall ‘template strategy’ was required by the Template Team. In the original proposal, it was envisaged that one multi-disciplinary template would be created for the organisation, to streamline implementation of future template updates and to give a consistency to the visual appearance of OPW drawings, regardless of design discipline.

DBC presented three approaches to the Team, as follows, based on the idea of having one/many ‘main template(s)’, complemented by one/many ‘resource templates’; the ‘main template’ would contain items used on a majority of projects (text styles, drawing borders, standard schedules, etc.) and the ‘resource template’ would include the less frequently used items (a particular architectural door family, structural standard details etc.).

- Option 1: Four independent ‘main templates’ (architectural, structural, mechanical, electrical) complemented by four ‘resource templates’ (one for each discipline)
- Option 2: Four independent ‘main templates’ complemented by one multi-disciplinary resource template’, as shown in Fig. 6
- Option 3: One multi-disciplinary ‘main template’ complemented by one ‘resource template’

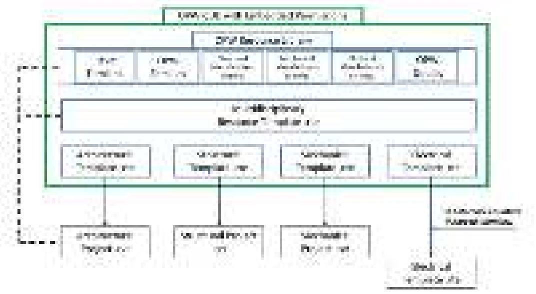


Fig. 6: One possible approach for multi-dis. template file

Based on the advice from DBC, it was agreed that splitting the ‘main’ and ‘resource’ templates would be a logical idea. However, after discussion between DBC and the Template Team, it was agreed that one multi-disciplinary ‘main template’ would be suitable for the OPW (as originally envisaged), but that this would be supported by four discipline-specific ‘resource templates’ to contain the less commonly-used items relevant to individual disciplines; this was a fourth option.

c) Template Development

Following the first workshop session, the Template Team met virtually to ‘divide up’ the elements of the templates that they would take ownership of delivering; this was based on i) the time individuals could give to the project alongside their other work (i.e. those with less time would complete more straightforward tasks) ii) the complexity of the task and their personal Revit proficiency (i.e. those with less experience would deliver more straightforward items) and iii) the discipline of the Template Team member and the element to be developed (i.e. architects generally developed architecturally-specific items, etc.).

A single Revit Central Model was created on the Alfresco sharing site to allow the Template Team to start collaboratively develop the OPW Template. However, due to technical issues with the Alfresco site, it was subsequently necessary to relocate the Revit Central Model to an alternative location. With the assistance of the ICT Team at OPW, a new ‘OPW Standards’ shared drive was created, both to provide a common location where the team could develop the template and, since release, where the OPW Template is hosted.

Over a period of about eight weeks, the team collaboratively developed the template. The idea to use a single ‘Revit Central Model’ worked well, and allowed members of the team to simultaneously work on the same file, synchronising their individual changes back to the shared Central Model. At one stage during the development, up to six individuals were working on the Central Model at the same time.

By the end of August 2020, the Team had developed a sufficiently good template file to allow it to be reviewed by DBC.

d) Review and Issue

Over two review sessions, Digital Built Consultants provided feedback on the work that the Team had done and, along with in-house tests by the Template Team, tested the template for usability.

Following completion, the template was made available as a ‘read-only’ file to all OPW colleagues working in the building design disciplines, through the shared ‘OPW Standards’ drive. A copy of the template file was also shared with public sector colleagues at Dublin City Council for their comments.

In addition to the template and the four supporting resource templates, a number of supporting files were also created to assist those using the template. These include:

- A number of short training videos showing how to use basic elements of the template
- A Template Feedback Form as shown in Fig. 7

- A Revit 'Family Request Form'

Fig. 7: Revit Template feedback form

VII OPW Revit Template

The first version of the template was successfully completed in August 2020; it was developed in Revit 2020 and holds common styles, annotations, view types and schedules for use across the organisation.

The OPW Template was designed to give enough 'set up' information to allow an architect, C&S or M&E team to develop their own discipline model using the same starting template; it is envisaged that any embedded information that is not relevant to a particular discipline can be purged from the model at an appropriate time.

The following items were incorporated into the first version:

- An agreed naming convention for template elements, adopting the ISO 19650 [5] discipline identifier at the start, i.e. 'A_Door Schedule', 'S_Foul Drain [linetype]' 'Z_2.0mm General Text'
- An agreed naming convention for Families, adopting the NBS-approach to include the originator of the family has been defined, i.e. 'Z_OPW_TB_...' for a Title Block Family, generated by OPW and common to multiple disciplines
- Defined Line Patterns
- Defined Line Styles
- Defined Filled Region colours, based on the Government Visual Identity Guidelines [6] , shown in Fig. 8
- Defined Filled Region colours for materials
- Defined Text Styles using Arial, in a range of sizes and colours, based on the Government Visual Identity Guidelines [6] , shown in Fig. 8
- Project Browser layout has been defined to include both a 'Standard' set up (sorted by Role, and Sub-Category) and an 'Alternative' set up (sorted by Role and National Building Elements identifier)
- View Types for each discipline
- View Templates to accompany each View Types
- Annotation Symbols – North Arrow, Scale Bar, Revision Symbol
- Pre-defined Architectural Schedules – Casework, Ceilings, Doors, Furniture, Rooms, Windows
- Pre-defined Structural Schedules – Beams, Columns, Floors, Foundations, Walls
- Pre-defined Common Schedules – Views, Sheet
- A limited Material Library has been added
- A 'Report Cover' matching the latest OPW branding has been added
- A 'Template User Notes', set as the starting view, an extract of which is shown in Fig. 9

Fig. 8: Sample standard items in OPW Template (extract)

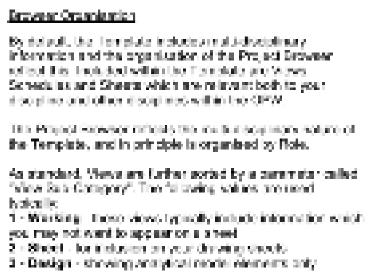


Fig. 9 OPW: Template user notes (extract)

Fig. 10: OPW drawing border guidance notes (extract)

In addition, the first OPW cross-discipline drawing borders were created as part of this project; these were embedded in the OPW Template and also exported for use in AutoCAD format. The drawing borders are available in a range of page sizes (A0, A1, A2 and A3) with horizontal and vertical title blocks, and in English or Irish.

Development and implementation of this common drawing border was a fundamental part of this project. Following a review with Senior Managers from across the organisation, these new borders have since been adopted as standard and replace the numerous different drawing borders previously in use across the organisation. User Notes to outline how to use the Drawing Borders have been included within the OPW Template as shown in Fig. 10.

VIII Template Adoption

Since the release of the template, it has been used to develop single-discipline Revit models on projects including Bunmahon Coast Guard Station (structures) as shown in Fig. 11, Tallaght Garda Station development (architectural), Ring Garda Station refurbishment (architectural) and the Kilcairn Government Offices project (architectural).

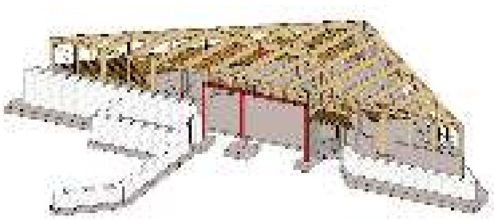


Fig. 11: Bunmahon Coast Guard Station structural model

Feedback on the template is generally positive, with many welcoming the approach to standardise and streamline workflows within the organisation.

IX Updates

From the beginning of this project, it has been acknowledged that the first release of this OPW Template was the 'start of a journey' and that work on the file would need to continue over the coming weeks, months and years as Revit proficiency across the disciplines, and more widely across the organisation, increases.

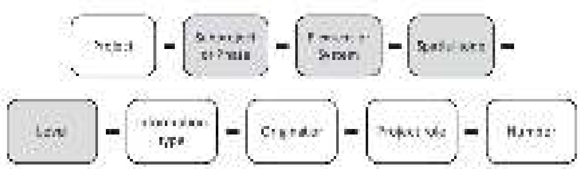


Fig. 12: Figure NA.1 from I.S. EN ISO 19650-2, split for clarity. Shaded fields apply "as applicable"

In order to reflect the changes arising from the release of the new *National Annex to ISO 19650-2* [7] in early 2021, a second version of the OPW Template was release in June 2021. This includes:

- Discipline IDs updated to align with the new National Annex ('A' becomes 'AR', 'S' becomes 'SE' etc.)
- Additional brand colours have been added to reflect OPW Brand Guidelines April 2021
- Default drawing borders, as shown in Fig. 12, have been updated to align with *IS EN ISO 19650-2* conventions [7], including the information contained identification field as shown in Fig. 12

Fig. 13: Title block, NA:2021 to I.S. EN ISO 19650-2

X Further Work

While a lot of work has been done on the template, the nature of Revit templates is that they need continued maintenance, updating and management. It is anticipated that, in time, this will be under the remit of an OPW BIM Manager, but in the interim the Template Team will continue to manage and update this tool. A StarLeaf user group for OPW Revit Users has been set up, and colleagues are encouraged to use this forum or the dedicated email address revittemplate@opw.ie to submit ideas or suggestions for consideration by the Template Team in future versions of the Template.

A follow-on survey to establish use of both this Template and Revit on OPW projects is planned for late 2021/early 2022.

Whilst this project focussed on the creation of a Template to increase the use of Revit by OPW architects and engineers in the first instance, further consideration may be given in future to how this Template could be used by i) other external designers working on OPW projects, ii) in-house and external Quantity Surveyors, iii) Contractors working for OPW, iv) OPW Facilities Managers / Property Managers managing these buildings on behalf of the state and v) other Government Departments, Agencies and Local Authorities.

XI Conclusions

The use of BIM at OPW continues to increase, with individual teams, disciplines and projects implementing varying levels of BIM, many of which focus on the use of Revit to generate 3D models.

The original intention of the Revit Template Project was to create a file to i) enable the transition towards using Revit on projects, ii) simplify and standardise the setup of OPW models, iii) provide consistency in the appearance of OPW drawings, and iv) allow changes to be updated centrally in one location, common to all disciplines. The first of these objectives will be measured through a follow up survey in due course, while the other objectives have been achieved through the work to date. In addition, this project provided a great opportunity for individuals from across the OPW to improve their Revit skills and to test the capability of people and systems for collaboratively creating Revit models on future projects.

At Government level, there is a renewed desire to increase the level of innovation, and adoption of digital tools in the construction sector [8]. As an organisation, the OPW have made a strong commitment to the increased adoption of BIM on OPW projects – both on internal projects, and for those where OPW acts as Client.

The OPW Statement of Strategy 2021-2024 [1] states "…for example, the introduction of appropriate BIM deliverables into OPW procurement processes – both for design services, in the appointment of contractors and in the acquisition/leasing of State Property – has the potential to reduce direct building costs, mitigate construction risk and reduce potential contractual conflicts, providing improved outcomes on public works projects".

Aligning strongly with these objectives, it is anticipated that work on the Template, as one element of a wider OPW BIM Implementation Strategy, will continue into the future; it is hoped that this tool will encourage more colleagues to move towards working in a 3D environment, acting as an enabler to the implementation of more formal BIM processes on their projects.

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The application of BIM processes and standards in the context of the façade manufacturing industry.

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Abstract—In recent years, the adoption rate of BIM throughout the construction industry has risen significantly amongst architectural practices, engineering consultants (Structural, Civil, Mechanical, Electrical) and main contractors. However, there is evidence to indicate the façade industry currently shows little interest in actively participating in a BIM process on construction projects. Frequently façade BIM models are produced after the fact, if at all. Typically, the façade contractor has no role in the BIM process, this research paper sets out to identify the obstacles experienced in the façade industry and propose a viable solution which enables façade contractors to be compliant with current BIM processes. A comprehensive literature review of currently available published literature was critically appraised to identify common barriers experienced with BIM adoption throughout the construction industry. Through semi-structured interviews with experts from the façade industry, main contractors and specialist subcontractors, qualitative data was obtained and analysed for common themes and patterns to identify barriers for adoption of BIM within the façade design and manufacturing process. The data obtained was used to examine current practice and workflows of façade subcontractors. Results indicate a consensus from façade contractors that current BIM processes are not well suited to the development and manufacture of façade elements.

The aim of the research is to examine the gathered data and develop a workflow applicable to the facade industry's processes capable of meeting current BIM processes and standards while also exploring if BIM authoring tools, such as Revit and Dynamo, can generate suitable documentation for the approval stages of a design during the construction stage. In addition, it is acknowledged that current BIM processes need to be reviewed for its suitability and application to the façade manufacturing process, through discussion with industry stakeholders.

Keywords—Building Information Modelling (BIM) Process, Façade Design & Manufacture, Construction Process, BIM Technologies, Barriers to Implementation

I INTRODUCTION

Throughout the Architecture, Engineering and Construction (AEC) industry the implementation and use of Building Information Modelling (BIM) has steadily increased. Figures published by the National Building Specification (NBS) indicate a rise in awareness and use of BIM from 13% in 2011 to 73% in 2020 [1].Despite an awareness and increase in BIM adoption throughout the AEC industry, evidence indicates these trends are less apparent in the façade manufacturing industry.

Following a comprehensive review of existing literature, an abundance of research was found to be primarily focused on overcoming resistance to BIM and implementation of BIM processes in the AEC sector. The literature review identifies common barriers to BIM adoption experienced throughout the AEC industry, which has largely retained the same linear structure [2]. A lack of research was identified relevant to the façade manufacturing industry.

This research aims to investigate the current state of BIM adoption in the façade industry and to evaluate a possible workflow to satisfy all stakeholders of a construction project. To gain insight into the current state of readiness of digital workflows a qualitative interview method was employed as a means of data collection. Using thematic analysis two main themes and four sub-themes were identified and reported on in section V. Using action research, a proposal for recommended changes for the implementation of BIM processes and technologies are proposed as a concept solution for discussion with interview candidates of the façade industry.

II LITERATURE REVIEW

The scope of the published literature in the context of façade design and fabrication and BIM adoption in Ireland is limited and research from other countries has been included in this study.

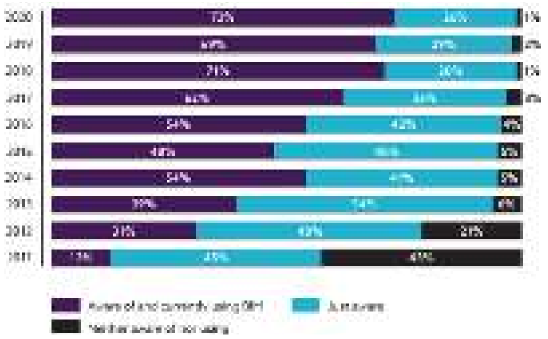

Fig. 1: BIM Adoption over time [1]

Survey data collated by the UK's National Building Specification (NBS) between 2011 and 2020 indicates a rise in BIM adoption from its respondents [1]. Survey results published in 2019 in collaboration with CitA [3] indicate a broadly similar trend in the Irish construction industry.

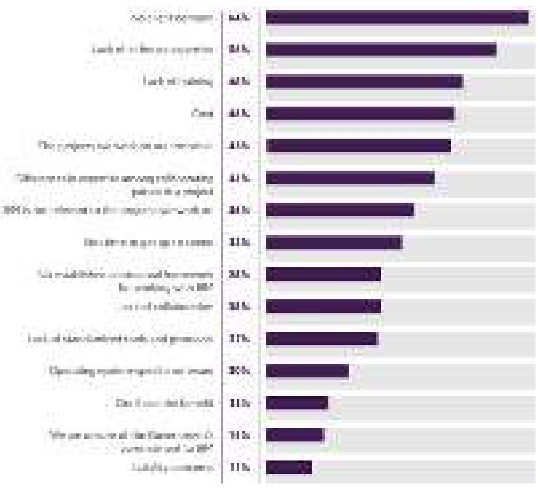

Fig. 2: What are the main barriers to using BIM [1]

The survey results illustrated in Fig. 2 compare with common barriers identified throughout the vast amounts of research literature available concerning barriers to BIM adoption in the construction industry. In order to determine the common barriers to BIM adoption within the façade industry research was focused on the following 5 areas:

1. Barriers Associated with BIM,
2. Technology Barriers,
3. People / Human Factors,
4. Business Associated Factors, and
5. External Barriers.

Barriers Associated with BIM

Research indicates one of greatest barriers to BIM adoption is related to a lack of understanding on how to use BIM in an effective and fluent manner, which is predominantly attributed with an unfamiliarity of the process and the belief that BIM is a software program [4].

In order to avoid increased frustration and conflict in collaborative environments it is critical to standardise the process and provide appropriate guidelines for the adoption of BIM [5]. Research by Awwad [6] found this only to be possible by ensuring management, with the help of consultants, were responsible for controlling the performance of employees during the adoption stage to ensure effective implementation methods and avoid poor project management [5].

Evidence indicates BIM processes and technologies are underutilised in the process of façade design and fabrication where integration of BIM can facilitate improved communication and collaboration across multi-discipline environments [7]. Where BIM is applied at the design & engineering stage of prefabrication projects, design changes or alterations can rapidly be communicated when necessary before the manufacturing stage without compromising the duration or quality of a project or product [7], [8]. Further barriers associated with BIM can be identified as technology barriers which is discussed in the following section.

Technology Barrier

A great deal of research suggests interoperability between different software vendors and future legacy issues as a point of contention for the adoption of BIM processes. These barriers which are imposed through BIM technologies are described as a cause for resistance in the workplace to change practices.

Table 1: Brief Summary of Six Basic Information Exchange Standards [9]

Name	What it does
IFC: Industry Foundation Classes	Transports information or data
IDM: Information Delivery Manual	Describes processes
MVD: Model View Definitions	Translates processes into technical requirements
BCF: BIM Collaboration Format	Exchange coordination
bsDD: buildingSMART Data Dictionary	Defines BIM objects and their attributes
IFD: International Framework for Dictionaries	Specifies what the exchanged information means

International standards such as Industry Foundation Classes (IFC) exist to provide a standardized vendor-neutral format for the exchange of BIM model data across the industry. While standard such as IFC, and those illustrated in table 1, have been developed to overcome the issue of interoperability it is widely acknowledged that further optimisation is required to improve the quality and reliability of data when exporting models in order to avoid data loss [10].

Applying written standards and process to new technologies often requires upskilling of employees or intervention/assistance from consultancies to adapt their workflows to BIM capable processes [11]. International research suggests costs associated with adopting these new processes and technologies pose significant challenges to organisations and require substantial investment from organisations. In the context of the Irish construction industry research by Miuri [4] suggests there would be more incentives to adopt BIM processes and technologies if these costs could be reduced. Furthermore, a recent survey by Mcauley et al. [12] in 2020 found that respondents from over 50 organisations, emphasized cost associated with digital workflows pose significant barriers to businesses. It was suggested funding is made available, through grants, to offer financial assistance associated with the high purchase cost of software, hardware and upskilling of staff, raising awareness of digital workflow with all stakeholders of a construction project.

People / Human Factors

Although BIM is a technical process, it's success is dependent on individuals within companies who use it. Research by Siebelink [13] identifies the importance of people in terms of adopting innovative technologies and promoting organizational changes. Individual discomfort is attributed to the disruption of day-to-day activities by the adoption of BIM technologies, a need to use BIM must be created for people to embrace it [13]. Therefore it is vital to train people on BIM technologies and open up new ways of thinking and working while carefully managing this process to avoid unintentionally strengthening resistance through to rapid a transition [13], [14].

Sun et al [15] and Muirí [4] highlight a concern regarding a lack of professionals educated in BIM technologies and processes. While a recent study by Mcauley et al [12] indicates educational institutes have responded rapidly to the industry demand for BIM-related education providing expertise and knowledge, considered vital for breaking down barriers and promoting the implementation and adoption of BIM within organisations.

Business Associated Factors

Decision makers in organisations experience major challenges in the development of appropriate strategies for successful implementation of BIM processes and technologies [16] which are highly dependent on cost considerations [5] and a fear of experiencing downtime [4].

There is a requirement for management to change and re-evaluate the traditional collaboration process, people at all levels of an organisation need to be educated about BIM and the available tools. This is especially true for organisations who lack knowledge and experience within the project teams and organisation, research by Eadie et al. [17] cite a lack of knowledge and experience within the project teams and organisation as being a contributing factors for not implementing BIM. A more recent study by Mcauley et al [12] found there has been an increased push in implementing digital technologies in Ireland, 60% see these as crucial to their future business model and increased value within their organisation [12].

Further research suggests companies would benefit from a clearer vision and individual understanding of what is being worked towards to deliver BIM across all projects within their organisation [18]. Careful consideration is required in defining new BIM roles and responsibilities to avoid confusion and competition between new and traditional roles within an organisation requiring a tailored approach for BIM adoption dependant on the specific sector [19].

Despite an increase in external pressure from clients mandating BIM and an increased reliance on digital technologies some organisations do not see value in adopting BIM processes and have made little advancements in this area [12].

External Barriers

Among the external barriers cited in literature, both client awareness and government mandate feature frequently. Research by MacLoughlin [18] found 57% of those surveyed felt there was a need to implement BIM due to client demand, while only 14% implemented BIM due to the requirement for working on government contract jobs.

Despite an uptake in requests over the previous 12-18 months [20] research suggests clients do not fully understand what BIM is and question who experiences the benefits and where real savings are gained from a BIM process [21]. Rarely do they capitalise on the benefits which can be gained from BIM implementation through model interrogation (clash detection) and mitigate costly overruns on site due to reworks [22].

Research by Turner [20] suggests the demand for an Irish BIM mandate could greatly assist in driving BIM engagement. Further research suggests that government support for a mandate has rated highly for a number of years [4]. Moore [23] recommends a simpler BIM mandate could be implemented in a shorter time frame which follows the principals of BIM Level 1 (information delivery), ensuring investment in necessary resources prior to a digital transformation to a more complicated BIM Stage 2 mandate. McAuley et al [12] suggests that the Irish construction industry is already adequately positioned to respond to such a mandate, highlighting the multitude of training solutions, roadmaps, CPD events, conferences, certification routes as well as guidance documentation and templates. Furthermore, in light of the current Covid-19 pandemic, Irish business have accelerated their digital construction agenda [12] further strengthening the position of the industry to respond to a BIM mandate. Lessons can be learned from mandates in the UK (in effect since 2016) and other countries to enable the realisation of support for a successful BIM program through the provision of education and training [12].

The following section explores literature relevant to the process in construction and design and fabrication.

a) Process

Typical Construction Process

The process involved in realising a construction project from initial concept design to construction has, for the last 100 years, largely remained the same, the linear structure of this process has developed into one consisting of many disciplines and specialties [2]. An increase in regulatory requirements and initiatives, such as Nearly Zero Energy Building (NZEB) and Leadership in Energy and Environmental Design (LEED) respectively, have led to more complex and sophisticated building façades and services.

For successful project outcomes, it is vital that all disciplines work together with a multitude of façade consultants, specialists and engineers who have in depth knowledge of structural engineering, building physics and advanced modelling techniques [2]. Typically, the architectural discipline is nominated to coordinate the construction project, or stages thereof, Table 2 outlines the typical stages of a construction project (left) and compares these to the RIAI Work Stages (right).

Table 2: Project stages, Typical vs RIAI [2], [24]

Typical Stages	RIAI Work Stages
1. Concept System Design	1. Inception & General Services
2. Outline Design	2. Outline Proposals
3. Detailed Design Proposal	3. Scheme Design
4. Tender Documentation/ Execution Design	4. Detail Design/Building Regulations
5. Manufacturing	5. Production Information
6. Assembly	6. Tender Action
7. Use and Maintenance	7. Project Planning
8. End of service life	8. Operations on Site and Completion

In relation to facades, the extent of the construction process ranges from the initial concept design, through the development and fabrication process, installation and finally its end of service life. Depending on procurement methods the construction process ties in with BIM process in different ways, each with individual challenges. Sacks, et al [25] states that Design-BID-Build (DBB) excludes the contractor from participating in the design process, therefore they must build a new model after design is completed. While Design-Build (DB) enables a single entity to be responsible for design and construction and poses a great opportunity to exploit BIM, similarly Construction Management at Risk (CM@R) and Integrated Project Delivery (IPD) enable early involvement and collaboration with the contractor in the design process.

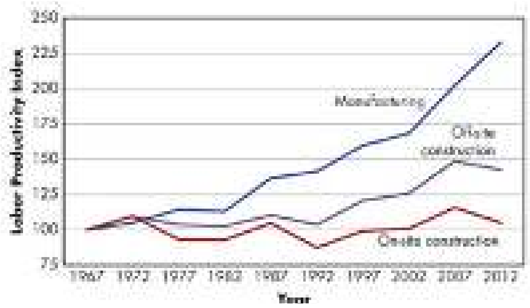

Fig. 3: Labour Productivity 1967 – 2015 [25]

Studies show construction productivity has remained relatively unchanged over a period of 45 years (1967 – 2015), stagnating behind Agriculture, Forestry, Fishing and Hunting [26], [27], in contrast manufacturing industry productivity has more than doubled. Crowley [28] states that construction is a craft-based industry which is incapable of a mass production process, in contrast the automotive industry (revolutionised twice in the last century) has moved from being a craft-based process to a mass production process over a century ago.

A comprehensive literature review of barriers to BIM adoption within the construction industry was undertaken with a focus on five main areas identified as applicable in the context of the façade industry. Furthermore, research was undertaken relevant to current processes and lean principles pertaining to the construction industry to ascertain their relevance to the façade industry. This body of knowledge is used to gain a better understanding of the current state of the façade industries readiness for BIM adoption through a semi-structured interview process.

III Research Objective & Aligned Methodology

Objective 1: Identify common barriers to BIM adoption in construction, evaluate their relevance to façade industry.

Research Methodology: Undertake a comprehensive review of currently available primary and secondary literature including recently published academic papers, industry standards and publications. Critically appraise the body of work and identify current issues concerning BIM adoption barriers and processes concerning the AEC Industry.

Objective 2: Critically appraise the current state of BIM adoption and integration in the façade industry.
Research Methodology: A qualitative interview method (semi-structured interviews) will be employed as a means of data collection. Interviewees will be asked scripted open-ended questions, responses will be probed in order to collect the best data possible and explore issues not previously considered [29]. Interview topics comprise issues relating to the construction process and barriers to BIM adoption in the façade industry. The data is analysed to identify and report on patterns (themes) using thematic analysis [30].
Objective 3: Develop & appraise a proposal for effective implementation and adoption of BIM processes and technologies for the façade industry.
Research Methodology: Undertake action research to identify problems found in current practice within the façade industry following analysis of interview data, use the data obtained to propose recommended changes to current practice to implement BIM processes and technologies for effective information flow, and evaluate the effectiveness of the proposed changes [31].
Objective 4: Critically evaluate (triangulate) the proposed solutions through testing & discussion with industry experts.

IV Questionnaire Design and Method of Analysis

The overall aim of this research was to investigate the current state of BIM adoption in the façade industry and to evaluate a possible workflow to satisfy all stakeholders of a construction project by fulfilling the contract BIM requirements.

To gain a better understanding of barriers for BIM adoption and the processes relevant to the façade industry semi-structured interviews were undertaken. Based on barriers identified through the literature review and research relating to the typical construction process, interviews broadly comprised the following 6 areas for discussion.
Process – identification of typical processes undertaken by the façade subcontractors in their day-to-day operation.
Familiarity of BIM processes – establish how familiar each interviewee is with BIM processes and technologies as well as their organisation.
BIM Technologies – determine which software and technologies are used as well as interoperability issues experienced with BIM software.
People Barriers – assess people's perception of BIM processes and technologies and the impact this has made on individuals and company structure.
Business Factors – has a lack of BIM awareness and business strategy hindered the adoption of BIM within or by an organisation.
External Barriers – asses if interviewees have experienced external pressure to adopt BIM processes and their view on government BIM mandates.

The research sample comprised 10 individuals actively involved in the construction and façade industry, the main criteria for participation were:

- Active Participation in the Construction Industry.
- Relevant experience with facades on construction projects.
- Exposure to BIM on projects, BIM adoption or in-depth knowledge were not essential.

Interview data was analysed for the identification and reporting of patterns (themes) using thematic analysis [30], the process of thematic analysis comprises 6 phases:

- Phase 1 – Data familiarisation
- Phase 2 – Generate initial codes
- Phase 3 – Search for themes
- Phase 4 – Review Themes
- Phase 5 – Define and name themes
- Phase 6 – Produce the report

An initial list of ideas was generated following thorough examination of the data, the essence of each theme is defined, and detailed analysis written to identify the 'story' of each theme and reported on in the following section.

V Qualitative Analysis & Synthesis of Interview Findings

To determine the level of BIM adoption in the context of the façade industry 10 semi-structured interviews were completed. The aim of the interviews was to investigate common barriers for the adoption of BIM in facade the industry. Consideration was given to the level of participation in the façade industry. Both façade subcontractors (Sub) and specialist (Spec) have extensive experience within in the façade industry, while the former are suppliers and manufacturers of facades. The later predominantly deal with both main contractors and subcontractors in the façade industry. Interviewee_03 has extensive knowledge dealing with subcontractors both as a BIM Manager and in their previous role, while Interviewee_06 is the senior engineer responsible for coordinating the façade subcontractors on site. Research participants had different levels of BIM maturity, both main and sub-contractors had extensive BIM knowledge, while only one façade subcontractor has begun adopting BIM in their day-to-day processes. The remainder of façade subcontractors at present did not utilize BIM in their day-to-day operations.

Through analysis of interview data, two main themes and four sub-themes have been identified and reported on under the following headings:

a) Process & Common Practice.

b) Barriers Associated to BIM.
- Knowledge & Understanding.
- Business & External Barriers.
- Technology Barriers.

a) Process & Common Practice

Typically, all interviewees are involved post main contract award at the subcontractor appointment stage and remain involved throughout the construction process. Interviewee 01 notes, occasionally they assist the subcontractors with production of information and may be involved later in the construction process all the way through to handover.

The typical process relevant to the façade industry comprise 3 main stages from tender to site assembly a tender preparation and proposal stage (1), a 2D detailed design stage (2) and a subsequent production and manufacturing stage (3).

Façade subcontractors were found to use traditional methods for production of drawings and information, using 2D AutoCAD and MS Excel. While one façade sub-contractors, Interviewee 8, expressed they are in the early stages of implementing a BIM capable workflow for their day-to-day operation using Solidworks (by Dassault Systèmes).

From the outset of the project Solibri was used to develop a BIM model for detail design drawings which are intended to be progressed further for manufacturing drawings in one continuous process, while also satisfying the project and contract requirements. Early indications suggest their day-to-day processes have been disrupted and a slowdown has been experienced when compared to using 2D AutoCAD methods. However, they are confident BIM software will enable them to become more efficient on subsequent projects and foresee halving time spend at production when compared to 2D AutoCAD methods.

b) Barriers Associated to BIM

Research indicates an increased awareness and adoption of BIM processes and technologies throughout the construction industry calling for a revaluation of traditional collaboration processes and management to change at all levels of organisations [1], [11]. Interview data indicates that both the main-contractors and façade specialists use BIM processes and standards in their day-to-day operation. Despite an awareness of BIM, the adoption rate of façade subcontractors interviewed remains low, a sentiment shared by the main-contractors and façade-specialist.

Individual Knowledge & Understanding

On the topic of individual resistance towards BIM adoption, the consensus from the façade subcontractors was one where no resistance was perceived by interviewees. Both the main-contractor and façade specialist have experienced a reluctance to change within their organisation, Interviewee 01 attributes resistance towards BIM to a lack of knowledge and understanding of what is required when engaged in a BIM process.

Fig. 4: People Resistance to BIM

Adoption of BIM technologies can lead to individual discomfort and resistance attributed to a disruption of day-to-day activities [13]. Interviewee 03 notes the importance of being able to empathise with individuals in different roles when implementing a framework which expands the individual's knowledge to illustrate the day-to-day benefits a BIM process can provide. While Interviewee 9 notes individual knowledge of BIM may not be relevant across the entire demographic of a company, expressing fabricators could not make use of a BIM model for machining as they require 2D drawings and materials to perform their job.

As contractual obligations for a BIM process become more prevalent, a requirement to influence people perception of BIM will be required, new ways of thinking about innovation are brought on by those willing to train and adopt to industry demands. The following section explores the interviewees experiences associated to adopting BIM processes in the context of business and external barriers.

Business & External Barriers

The consensus amongst the façade subcontractors was that BIM provides no added value to their current practice or influence on business decisions, which may in part stem from a lack of knowledge or understanding of BIM processes and technologies.

Fig. 5: Business Value in Adoption

When asked about the companies view on adopting BIM processes and technologies Interviewee 4 commented BIM is viewed as an asset towards the end of a project where a BIM model is produced as a bolt-on/additional service only when required, not as part of their design process. With no requirement for mandated BIM deliverables, façade subcontractors remain hesitant to adopt BIM practices unless pressured to do so by contractors as part of their BIM process.

Where façade sub-contractors predominantly experienced external pressure from the main contractors, who in turn have experienced increased pressure from clients in the public sector. In response to pressure from the main contractor, Interviewee 8 have begun a trial using Solidworks to meet the requirement to deliver weekly Data-Drops of WIP BIM models.

Interviewees typically found the requirements for BIM processes were dropped in favour of cost savings, provided all documents shared on the Common Data Environment (CDE) follow the BIM naming protocols.

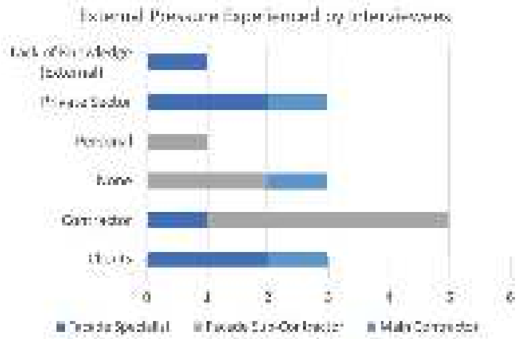

Fig. 6: External Pressure Experienced by Interviewees

Interviewees expressed mixed opinions when asked if the government should be the driving force behind a BIM mandate. Interviewee 3 states that they (the government) do not have the expertise to be able to deliver a BIM mandate, and a lot of that responsibility falls on to contractors. Interviewee 3 also notes that companies who do not adopt BIM, or digital processes may struggle to remain competitive in the future. As long as BIM deliverables are not mandated, façade subcontractors remain hesitant to adopt BIM practices.

Technology Barriers

Analysis of interview data indicates the use of AutoCAD remains prevalent with Revit following closely. However, there was a clear divide between façade subcontractors and other interviewees in software used in their day-to-day operation, the former predominantly utilising AutoCAD and bespoke manufacturer software such as Wictop, ReynaPro and Logikal throughout their process.

There was a consensus from façade subcontractors doubting Revit's capabilities as a tool for the production of detail design drawings. One notable exception to this, Interviewee 10 believed a Revit model could be utilised for more than presenting a model to the contractor and can be used for detailing and fabrication drawings. Interviewee 8 in their trial did not consider Revit for drawing production, instead relying on Solidworks which enabled exporting directly to their fabrication machines.

When contractually obligated to deliver a BIM model, the façade subcontractors typically outsourced the procurement to a 3rd party at a very late stage of the project, Interviewee 5 expressed concerns regarding the disconnect between 2D CAD drawings and a 3D model and whether the 2D drawings are correctly interpreted during the creation of a 3D model.

Fig. 7: Revit use by Discipline

All interviewees expressed concern about interoperability between their software suite and applications used throughout a BIM process.

VI Discussion

It is acknowledged this study comprised of a small data sample of 10 interviewees, 6 of which are active in the industry as façade subcontractors. Findings from the interview data set suggest barriers around BIM adoption in the construction industry remain prevalent with respect to participants active as façade subcontractors.

As the research progressed it became apparent that façade subcontractors are willing to engage in BIM processes, however, they are reluctant to adopt BIM as no added benefit to their day-to-day operation is perceived as well as a lack of trust in BIM processes and technologies. This section discusses 4 topics for areas of improvement.

a) Change Requirement

As BIM increasingly becomes more prevalent in the construction industry it is vital for façade subcontractors to be able to respond to and meet their contractual obligation where BIM Stage 2 (Level 2) processes are mandated by the client.

Post-interview stage conversation with interviewees indicate they would consider adopting BIM processes if this would enable better coordination between façade and other specialist. To enable a change of practice is vital to promote training on BIM processes and technologies, and encourage new ways of thinking to enable business owners and employees alike to make informed decisions around BIM adoption.

b) Process Changes

At presently BIM models are frequently created after the fact, integrating BIM into current process would enable increased coordination between the façade subcontractor, the main contractor, and the design team.

For the current process to undergo change and integrate with BIM technologies and software, companies will be required to re-evaluate current practice and identify how BIM technologies can be integrated into a new process to meet their day to day needs and fabricate a façade.

Using Autodesk Revit, a widely adopted industry model authoring tool, this research explored the feasibility of creating a BIM model capable of producing a document set typically generated by a façade subcontractor for a typical curtain wall. 3D objects (Revit families) were created for all elements of a curtain wall façade, from the BIM drawings comprising typical general arrangement plans, elevations and sections were generated as well as a 3D isometric view and schedules of quantities/sizes.

c) Further Process Improvements

Further process improvements are possible through utilising sample models which contain preconfigured curtain wall systems, these can be easily copied into new projects inclusive of model data used for scheduling and annotating.

Further efficiencies can be achieved through using BIM software with tools such as Dynamo, a visual programming environment which aims to give users the ability to visually script automation tasks [32]. Placement of structural supports, parameter population, mundane tasks such as tagging elements can aid with QA/QC control.

d) Open Discussion Forum

Throughout the AEC industry there exist several outlets such as the CitA Technology Trends series and annual BIM Gathering which provide an open forum to all members. Interviewees expressed a lack of open forums specifically catering to the façade industry, suggesting they all exist in their own silos with little interaction between competitors.

An open discussion forum could enable the closure of a disconnect between the façade manufacturing and the design side of the industry. Opening an opportunity for all disciplines to converge and openly discuss their expectations of one another, identify potential problems and discuss solutions based on other industry stakeholder experiences.

VII Conclusion & Recommendation For Further Research

This research primarily focused on the early stages of the facade production process from tender through to generation of shop drawings for approval.

The overall aim was to investigate the current state of BIM adoption and to identify obstacles experienced by façade design and fabrication industry and propose a viable solution to enable BIM adoption and Compliance while satisfying all stakeholders of a project.

Common barriers for BIM adoption and process inefficiencies were identified and their relevance to the façade industry was assessed throughout the literature review process. Despite increased awareness of digital technologies, façade manufacturers, at present, are reluctant to adopt BIM processes and technologies due to a lack of trust and perceived benefit to their current processes.

With widespread adoption of Autodesk Revit across the AEC industry, Revit models natively support a great deal of interoperability with other stakeholder models for coordination purposes and inclusion of the AIM. Findings suggest BIM software, such as Revit, is adequately capable of producing façade drawings for the purposes of the approval's stage and site coordination.

Evidence also suggest BIM adoption by façade manufacturers can be facilitated by indicating the competitive advantages brought on by being BIM capable. Government, client, or main-contractor BIM mandates further reinforce the likelihood of BIM adoption by façade manufacturers.

Further research into implementing BIM for fabrication utilizing software such as Revit is encouraged, methods and workflows are necessary to further progress a BIM model to advance this from being suitable for generating shop drawings to being capable of being used in the manufacturing and fabrication stage of façade projects.

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Work Breakdown Structure (WBS) Applied in Building Information Modelling (BIM) Framework in Construction Project (The Case Study: La Rotonda of Verona)

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Abstract：Building Information Modelling is revolutionizing the construction industry and the roles of the professions that work within the industry. Work Breakdown Structure is one of the delivery-oriented tasks carried out by the project management allowing for the breakdown of the project into small components as tasks, guaranteeing more successful project outcomes, in particular for large projects. WBS applied into a BIM project can provide additional benefits in comparison to more traditional 2D paper-based design data use. This paper will focus on the "La Rotonda project in the city of Verona in northern Italy where a WBS was deployed to support a project managed BIM environment. Here, the segregated tasks and objects must be translated into parametric information. To achieve this goal, the definition and procedure of a traditional WBS are investigated and translated into non-geometrical parametric data that is readable by the BIM tools. Thereby, a new attitude is created to digitalize the work breakdown components, attached to related BIM objects and models.

Keywords： Building Information Modelling, Work Breakdown Structure, Parametric, Functional Restoration, Project Management, Construction Management..

I INTRODUCTION

Building Information Modeling (BIM) is gaining increased uptake in the built environment. Related to the progress of new technologies in information and software developments, BIM supports the management of the whole life cycle of buildings. Increasingly BIM is seen as a new revolution in construction tools and approaches. The affected platform of this revolution is both procedure of building and the production as an architectural outcome (1). Four main sectors in Building production chain are subjected to BIM as the AEC-FM (2), abbreviations for:

- Architecture
- Engineering
- Construction
- Facility Management

One of the advantages of the usage of BIM is to have a multidimensional built object. It can be completed by providing an interdisciplinary vision through the building procedure. As the production of a building is a complex result of various efforts in different platforms. During the project lifecycle, many kinds of information in a different context are created and contributed to the model of the building. BIM supports and considers the high range of this information (3).

Project management should be considered as the critically involved sector in construction which is attributing with BIM, sharing its theories and practical tools. As a result, the association of Project Management with BIM creates new information and data related to construction projects that enhances the overall project management experience.

Project management guarantees coordination and monitoring during the different stages of a project, according to the available resource (4). The theoretical features and methodologies of project management have been used by the construction industry for many years. In particular, using progress management (5) has a high value for architects and construction parties. Hence new development in the construction industry required developments in Project management frameworks and elements. BIM as a revolution in construction and architecture, calls project management's traditional concepts and tools to be updated due to digital progress in information and communication technology (ICT).

This research focused on attitudes towards WBS which are increasingly important features of project management body utilized in construction management. The goal of the research is to present an adaptation of WBS into a BIM environment. To reach this goal firstly WBS will be presented and its traditional definition will be adopted to be able to enter BIM platforms. Project managers segregate each project into its components to breakdown the whole body into smaller elements. The aim of this exercise is to make the project more feasible and more understandable. Project breakdown can occur in various aspects which are outlined in table 1, namely Cost Breakdown and Risk breakdown. Table 1 will present different breakdown structures.

Table 1: disciplines in breakdown structure

Abbreviation	Name
GBS	Geometry Breakdown Structure
WBS	Work Breakdown Structure
CBS	Cost Breakdown Structure
EBS	Equipment Breakdown Structure
OBS	Organization Breakdown Structure
RBS	Risk Breakdown Structure
MBS	Measurement Method Breakdown Structure
SBS	Specification Breakdown Structure
DBS	Drawing Breakdown Structure
PBS	Physical Breakdown Structure
FBS	Functional Breakdown Structure

WBS in traditional project management has been developed over the course of time. The fundamental purpose of using a WBS framework in a BIM environment is to translate the traditional methods and theories into the intelligent and digital language of BIM. To execute such development, the theories and procedures of WBS must be clarified and extracted. The methodology must be translated into the BIM usable language. Hence, it is possible to create a link between the project management and BIM model of the building.

The current research focused to revolutionize a traditional project management towards the digitization of WBS methodologies.

II WORK BREAKDOWN STRUCTURE

Work Breakdown Structure (WBS), for the first time, was used by the U.S Department of defense for one of its rockets project in 1960(6). In the course of time, the argument has been developed in theory and methods and had permeated into other disciplines. The main area in which WBS could be used is the large projects in all majors.

As the construction industry can involve highly complex large project it make sense to breakdown a project into more manageable bit sized elements to ensure more project success.

Regarding the subject of the research, it must be declared the difference between project management and construction management. Project management involves organizing associated features over the whole project regarding the resources like budget and time, while construction management organizes the management of operation section within all sections of a project. following it can be considered also as

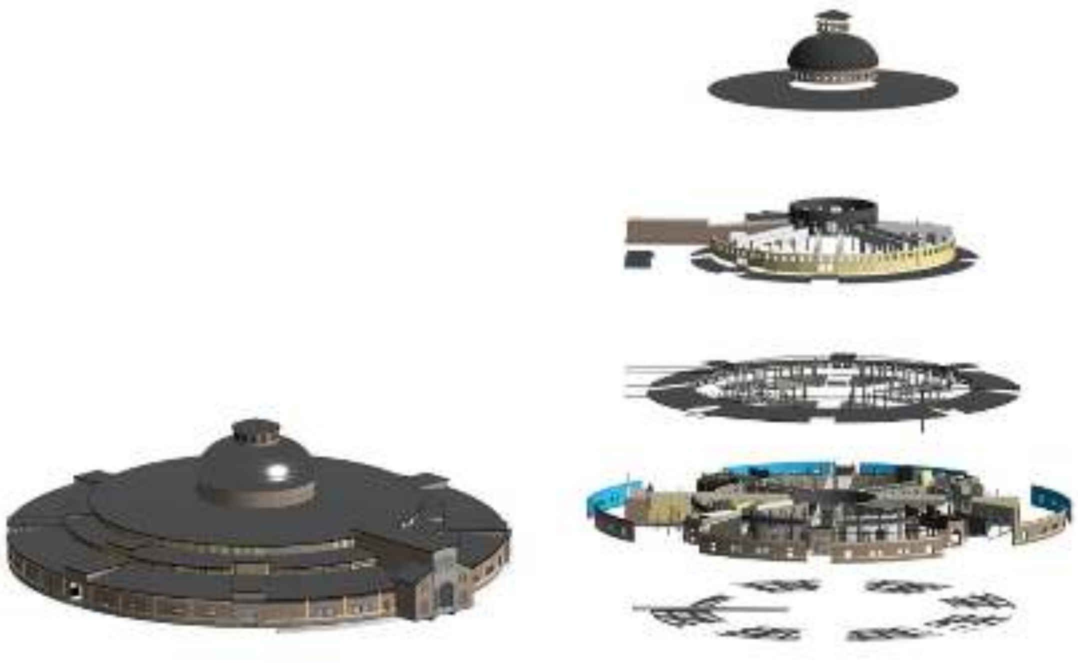

Figura 1:The vision of the whole main building "La Rotonda", and its dissociated components

"Operation management". (7). According to the requirement of the stakeholder, it became necessary to focused on construction management rather than project management. The presented work breakdown contains activities on the construction site.

An important advantage of applying BIM in a project management's framework is to digitalize its traditional methods and meanings (8). In this research we used the WBS fundamentals to breakdown the tasks during the construction phase of the La Rotanda project in the city of Verona in northern Italy, considering that the methodology could be developed to other gates of the projects, namely maintenance and demolishment.

III CASE STUDY

The research is established on the "La Rotonda" in the city of Verona, north Italy. The building previously was used as the refrigeration station. A storehouse to keep the ice. Mainly developed between two world wars inside the industrial zone of the city. The round shape of the building was adopted useful regarding its destination. As charge and discharge of the merchandises were possible. Due to this geometry the whole building is divided into galleries by main axis. The project is a site composed of several secondary buildings and a main circular building. "La Rotonda" (Circular in Italian) shown in the figure 1, under title of use change of the building. To a commercial complex of Eataly chain. Studio Mario Botta is the designer of the project. The level of complexity and dimension of the project made it necessary to apply Building Information Modelling on the project procedure in particular construction management.

IV METHODOLOGY

To support the methodology of this paper, the whole construction site is divided into small components and elements. The measurements that divide and breakdown the project are a list of features of elements in different aspects. Each aspect divides the whole entity of the project according to its value into several subdivisions as demonstrated in the figure 2.

a) Building

The site is composed of several buildings gathered together as a whole industrial complex. The current project addressed only four main buildings. The main building is La Rotonda, however as other buildings have their own construction procedures, they must be taken into account as well as the main building. Building Number 10, building number 11, building number 18, and external built elements are introduced to this level of breakdown.

b) Slice

Regarding the shape of the main building this is an orderly geometrical circle, with component parts like the slices of a circle. The axes of the structure are also based on this division. Hence, in this level of breakdown, the building is divided into 16 geometric similar slices composed of galleries and halls between galleries, a main central dome and external zones. As a result, 19 parts are recognized.

Note: elements in the border of the slices have two code options, depending on the side that activity carries on.

c) Level

The levels of the building are contributed to breakdown procedure. As a result the foundation level, ground level, mezzanine level, first level, and cover level are introduced. Furthermore, regarding the spatial distribution of the mezzanine level, as its surface is located in different height, this level, in particular, is divided into two majors. Internal pieces of this level (which are located inside halls) are lower than external pieces.

d) Macro Activity

According to the list of activities, particularly associated with these projects, it is possible to consider three main activity groups. Structural, architectural operations, and security interventions. Macro activities are imposed on elements, in single action or a combination of actions. For example, a column could be expected to pass both architectural and structural operations. On the contrary, a series of elements, to say a range of beams could be targeted for a single macro activity.

e) Micro Activities

Going in-depth on macro activities, a list of precise works and operations can be extracted. The list of accurate activities can be modified and customized from the Category of expenses by the society of construction, registered in the management system. The whole list is imported and categorized into the work breakdown, but only the ones which are related to the case of construction are considered and calculated to the building model.

f) Cost List

In the next breakdown step, the list of costs is imposed to elements and works. The list consists of detailed activities with material and quantity of work's unit.

WBS 7: A further step could be added regarding the advance description of works. This step is the key that explains the work method and how the specific operation must be carried on.

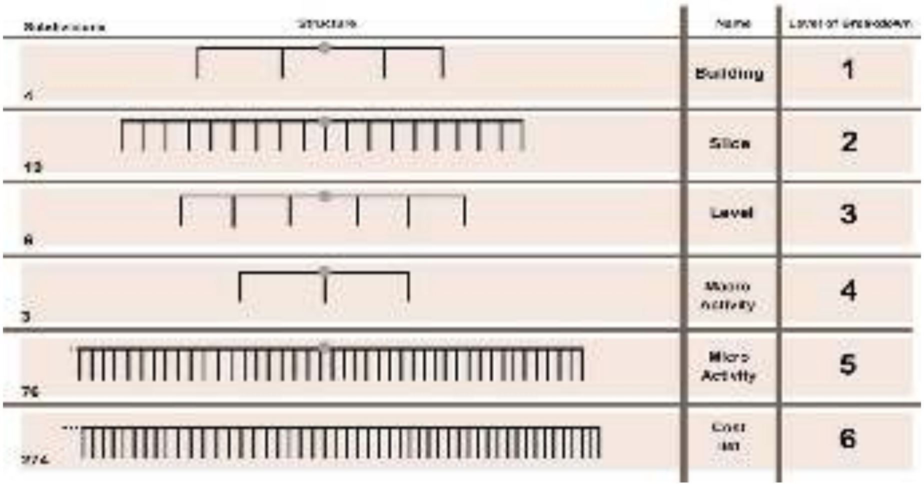

Figura 2:The structure of breakdown of activities through different locations in the construction site

V THE COMBINED CODE OF WBS

The construction of a building is a composition of many various activities with different characteristics. Those activities are distributed in the different zones of the building and different phases. As it is explained, after the breakdown of the entire work structure, each step introduces a single code. To give an example, as the figure 3 illustrates, the activity of Demolizioni (Demolitions), imposed as a structural work on a beam located in the first floor, in the A2 slice, and the main building (building number 10), should contain the code of [1.2.5.3.3]. The sixth part of the WBS code will refer to the cost of exact activity , the precise amount and material information. Each step of WBS creates a part of the general code of single activity. In practice, for an element the three first parts of code must be the same as they refer to the location of the element rather than work. Exceptions are the elements on the boundaries of the slices that could contain the code of the slice in both sides, depending on the operation's side of the wall.

The combined codes are inserted into the project as the shared parameters that are attached to the related object as its information. in such a way all codes will be project parameters that could contribute to other information in the schedule of data. WBS could assign a particular number to every single element regarding a single activity. Inside the environment of BIM, this particular number can be translated into parametric information. The procedure can be applied due to the possibility of BIM to combine Geometric and non-geometric information of the construction's elements (10).

VI CONCLUSION

Using the Work Breakdown Structure inside the BIM environment, requires to digitalize the breakdown components. To achieve the goal of the project, firstly the definition and methods of WBS in traditional project management are investigated. Secondly, the way that dissociated elements can be translated into BIM language is explained. As a result of the research, it can be argued that each step of breakdown creates a part of parametric information that contains the specific number of the work. The resulted number demonstrates the specific area and work that every single element has. The parametric information can be utilized in the BIM model attached to the element's model. It can contribute and associate with other information and data related to elements and the whole model of the building.

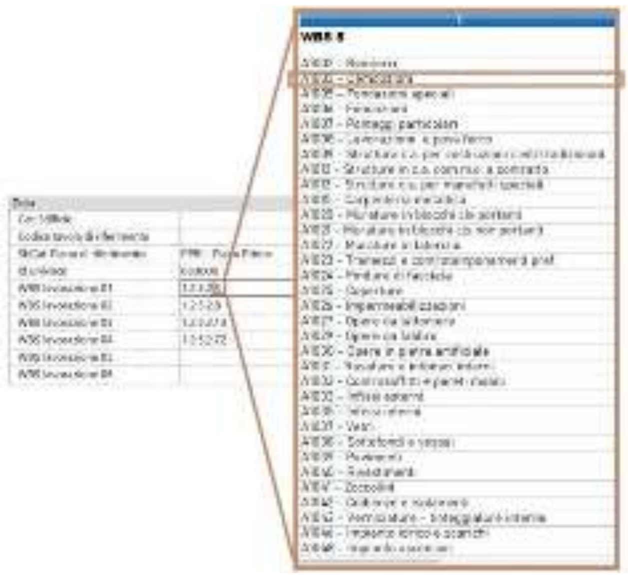

Figura 3: WBS creates parts of elements data

Figura 4:Each element is associated with its data alike its WBS information

VII ACKNOWLEDMENT

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Innovative Procurement and Contract Vehicles

Innovation and Transformation of Multi-Project Management practices in the AEC sector in Ireland

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Abstract − Projects are becoming increasingly complex and data-heavy within the Architectural, Engineering and Construction (AEC) sector and the need to analyse workflows and streamline processes in order to be more efficient is key to organisations being more competitive. The adoption of digital tools, automation, information sharing and communication technology has been envisaged as the main concept of the fourth Industrial Revolution (IR) 4.0, due mainly to demand in the industries to increase efficiency. Ultimately Big Data and Knowledge/Information Management collection within AEC organisations is used to leverage better decision-making, increase productivity, and reduce costs across all levels of a multi-project environments. The research aim was to examine the current extent to which the AEC organisations use digitalised data and the critical drivers to innovation. A mixed-method research through qualitative and quantitative data collection was adopted for the purpose of this exploratory research, examining the perceptions of innovation and transformation to digitalisation and the use of Big Data within multi-project organisations in the AEC sector in Ireland. The organisational culture within AEC organisations has led to resistance in the adoption of digital tools due to them being poorly understood by senior management. Digital transformation needs to form part of the strategic plan of organisations. The construction companies have demonstrated their investments in the adoption of digital tools to streamline processes in comparison to other organisations in the AEC sector. The relationship between digital adoption and performance is widely unknown at the moment in the AEC sector, and strong leadership is required within the industry to drive digital adoption. This will lead to the creation of better processes, enabling organisations to be more efficient, reducing risks, and increasing quality for clients.

Keywords − Multi-Project Management, Digitisation, Big Data, Knowledge Management, Information sharing

I Introduction

AEC is a project-driven industry; each project is unique and requires particular forms of professional inputs and management. Each project can generate a wide range of knowledge and data stemming from the complexities and nature of the project. This constitutes a classic learning cycle and streams of knowledge transfer within organisations [1]. Deloitte, a leading professional services organisation, has recognized the evolution in the Project Portfolio Management sphere, suggesting that "Digital disruption has resulted in profound changes to organizations and continues to do so. As the disciplines of technology and business have become more closely interconnected, each has profited from the practices and priorities of the other" [2]. The objective of the research is to gain a level of understanding with regards to multi project management and to establish if software tools are being implemented in AEC organisations.

Many companies in the AEC sector have multiple projects ongoing at the same time. Projects are becoming increasingly complex and data-heavy and the need to streamline processes to be more efficient is key to being more competitive. The ever-growing digitalisation will propel companies to pursue efficiencies in the AEC sector. The relationship between digital adoption and performance is widely unknown at the moment and strong leadership is required in the industry to drive digital adoption. This research objective is to examine data culture and how data can enable knowledge management and influence better decision making to benefit AEC organisations and ultimately the client.

II Literature Review

This literature review identifies Multi-Project Management (MPM), also known as Project Portfolio Management (PPM) in organizations broadly, with a focus on the emergence and importance of data management in line with the transformation of the digitalisation within the AEC multi-project environment.

This literature review focuses on the innovation of multi-project management practices in the construction industry, which is characterised by high uncertainty, culture, fragmentation, complex decisions, dynamic changes, turbulence, and communication.

A thematic literature review was carried out for this research to discuss the existing literature based on key themes (Fig. 1) that relate back to the objectives of the research.

Fig. 1: Literature Review - Themes (created by Author)

a) Multi-Project Management

Multi-project management is managing multiple project environments simultaneously, where projects could have shared resources, deadlines, and complexity. Recent evidence suggested Project Portfolio Management is transitioning and evolving like many disciplines. The move towards automation, Internet of Things, Big Data, and information sharing is rapidly changing the landscape of organizations to focus on digitalization. Companies are looking at how the PPM role and processes will change focusing on "operational excellence and continues innovation" [2]. The Central Statistics Office (CSO) Ireland shows micro enterprises account for 91.9% (Fig. 2) of all enterprises in 2018.

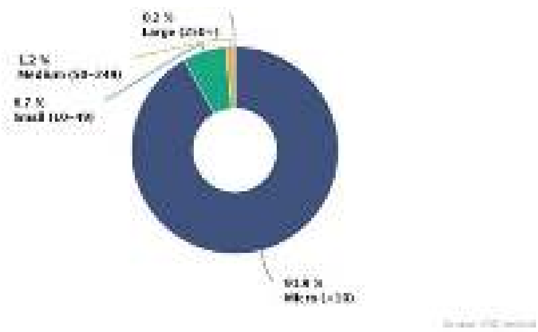

Fig. 2: Business in Ireland - SME (source: CSO Ireland)

Furthermore, the construction sector had the largest share of persons engaged in Small, Medium Enterprises (SME's) at 92.7% in 2018 (Fig. 3). These figures show that SME's make up the majority of the AEC companies in Ireland. Therefore, with the majority of companies being micro enterprises, as seen above in Fig. 2, this will inevitably lead to some managers focusing on management process, adaptability, and innovation within the digital transformation world of the organisation today.

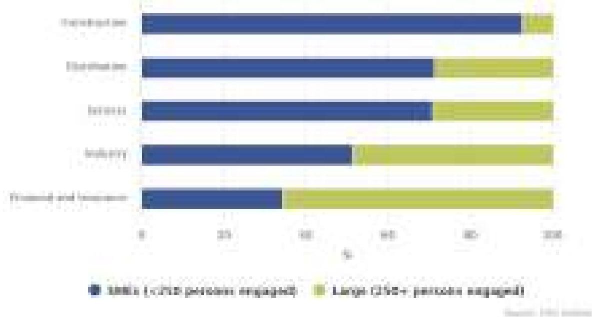

Fig. 3: Business in Ireland - SME (source: CSO Ireland)

Leaders of digitalisation within multi-project environments will need to be able to appraise organisations and industry professionals of the value digital adoption will have on the organisation and its processes.

b) The Role of PMO

The PMO gained prominence within project-based organizations coinciding with the project management momentum in the 1990s. Organizations were searching for more efficient ways to manage an increasing number of projects under the one organisation. The need to coordinate and standardize the approach supports the principles and procedures of managing projects utilised by PMOs today [3].

The Irish Government recognizes the progress of project management and the need to be more responsive with standardizing the project management approach, Action 10 "strengthening programme and project management is critical to the successful achievement of Government priorities, the management of public finances and the delivery of public services. Project management facilitates the identification of priorities and the effective allocation of resources, monitoring of progress and delivery of results" [4] Many of the Irish public sector bodies including Tusla; Department of Defence; Technological University Dublin; Health Service Executive; have set up PMOs with the objective to support project and programme management. The key challenge is the implementation of a digital PMO within existing platforms and organisations.

c) Big Data

The definition of "Big Data" is described by Gartner leading technology research and advisory company. "Big data is high-volume, high-velocity and/or high-variety information assets that demand cost-effective, innovative forms of information processing that enable enhanced insight, decision making, and process automation. The vast amount of data collected in any form and shape has intrinsic value to the performance of organisations in industries" [5]. Data has always been collected, the trend now with the array of data types in the form of structured, numeric data in traditional databases to unstructured text documents, emails, videos, audios, and financial transactions, is the analysis of the data has advanced so much, the data can provide answers in almost real-time, allowing organisations to reduce costs and smart decision making.

Large amounts of information is collected within the AEC sector, especially if organisations are working on multiple projects. However, the data has traditionally been siloed and strictly used within the department or division of the organisation [6].
Big Data provides companies with large amounts of knowledge, which can then be used to improve the planning process. The trend of Big Data is relatively new, and the literature is limited. A more systematic approach for future literature would be needed to identify the critical data required to employ Big Data effectively within each discipline in the construction industry.

d) Knowledge Management

Different studies have considered Knowledge Management through organisations, humans, technological aspects, processes to support business innovation, information to create competitive advantage [7] [8].

Previous studies around Knowledge Management identify the architecture, engineering, and construction (AEC) industries to be problematic in the sharing of information and communication within multi project environments, largely because of the industry's fragmented structures, complexities of projects and project-driven nature [1]. Vaz-Serra et al, (2020) [1] findings exhibited the level of confidence in decision making and retaining knowledge served as great value to the construction companies involved in the recent research.

e) Project Management Tools

The introduction of software tools to improve data collection and inform decision-making processes in multi-project environments needs to have a clear purpose within organisations. The recent Industrial Revolution 4.0 (IR 4.0) we are experiencing is fundamentally changing the way we live, work and relate to each other. The majority of AEC organisations and other sectors are turning to software to support operations and project management practices. Previous studies have reported on the utilization of software for supporting project management and project portfolio management [9].

III Methodology

This research aims to produce findings established through exploration of the opinions, perspectives, and experiences of leading industry personnel working within different disciplines of the AEC sector. The methodology approach of the proposed research is concerned with reducing the area of investigation to concentrate on understanding and interpretation of perceived experiences and knowledge within industry professionals in the AEC sector, largely focusing on transformational change within organisations regarding digitalisation and a large amount of data been created on each project and whether these can make companies more efficient through better decision-making processes.

The methods considered for the research is exploratory sequential mixed methods in the form of qualitative and quantitative data collection. The rationale for choosing the mixed method was to develop a richer theoretical understanding and heighten knowledge to answer the researcher's questions through the qualitative data approach via five number interviews selected from a list of industry experts through the researchers own contacts and who are relative to the research study in regard to their knowledge and experience of the AEC sector. Supplemented by the quantitative data via a questionnaire with 55 responses providing the best theoretical proposition for the outcome of the research.

The research is conducted under an inductive-sequential design, with qualitative research as the core component to the theoretical drive by using semi-structured interviewees. The 30 – 40-minute interviews commenced with open-ended questions based on four main themes extracted and developed through the literature review. The reason for selecting a qualitative research approach was to gain an understanding of the views of the participants. These participants could directly be involved in helping companies make decisions on the implementation of tools and practices to help AEC organisations become more efficient through the digitalisation revolution.

The questionnaire was circulated to over 45 respondents employed in the AEC sector throughout the Republic of Ireland via email. The researcher invited those 45 respondents to forward the questionnaire and circulate within their organisations.

Thematic analysis approach (Braun & Clarke) was adopted for the findings. The rationale for choosing a thematic analysis was to identify patterns across the data set and provide a sense of commonalities across the data set with quotes from the interviewees to support the pattern or interpretations.

Table 1: Interviewees' Participants

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
P1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
P2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
P3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
P4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
P5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
P6	[illegible]	[illegible]	[illegible]			

IV FINDINGS

The subsequent findings are presented under the research objectives with the primary data collection the interviews as the source of the findings, with additional findings for objectives supplemented by the quantitative analysis.

a) Research Objective 1

Investigate the levels of understanding and use of multi-project management within companies in the AEC sector in Ireland.

The shared theme between all the interviewees regarding their understanding of multi-project management was defined as "*Several projects going on at the same time*". In addition to the main theme the additional subtheme of Geographical location was coded from the interviewees, providing an insight to the impact it has on multi-project environments. Participant 2 located in the West of Ireland gave a detailed response to the geographical location exhibit key response below.

Participant 2 (P2) **-** "*depending on the scale of architectural practice that you operate, and geographically where you're located. So the realities of let's say, an architectural practice operating in the west of Ireland, is that you don't have the same natural hinterland to pick from. Let's say, we were inside the M50 in County Dublin, you will see contractors and architects who basically will pretty much not venture beyond the M50."*

The geographical location of organisations is very important, as can be seen from the participants based in the West of Ireland. The view of the participant was that companies based around Dublin would have greater access to projects. In the researchers' experience companies in the West of Ireland would travel great distances in order to procure projects at a considerable cost and time.

Participant 4 (P4) provided a theme around information sharing as an important factor to methods of multi-project environments, setting out from the start of a project the policies and procedures required of all internal staff or external collaborators was key by creating one line distribution and a single source of information.

Participant 4 (P4) **-** *"You also need a method of sharing and collaborating externally and obviously in a Common Data Environment (CDE). These CDE's really help multi-project management because if you have common data environments that have your standards and methods of sharing information, methods of communicating with staff and taking away a lot of the kind of email functions and creating one line distribution, that you have more collaboration and more cooperation between parties on common data environments."*

b) Research Objective 2

To establish which project software tools are being implemented in AEC multi-project organisations.

Both interviewees from construction companies (P4 & P5) outlined the adoption of construction software packages was used to manage projects in their relevant organisation. Participant 5 (P5) outlined the use of this all-in-one construction software tool will ultimately replace a lot of functions in the workplace for their organisation.

Participant 5 (P5) **-** *"Last year a specific Construction software package, Procore, was adopted for all new projects. This software will replace a lot of the functions of the Workplace as it has document storage but also has a suite of tools specifically developed for the construction industry. The tools are split into two types - Core tools and Project Management tools."*

The questionnaire revealed over 54% of respondents used software to manage individual or multiple projects (Fig. 4). The respondents affiliated with construction companies named all dedicated all-in-one construction management software tools such as Viewpoint, Procore, and Abm. The number of Architectural, Engineer, Project Management and Quantity Surveyors organisations, noted using a range of software tools such as Excel, BIM 360, Sharepoint, Archtech pro, MS Project, Buildsoft, Cubit, AutoCAD, and Revit. There was only one respondent from an Architectural organisation that used Monday.com to manage projects.

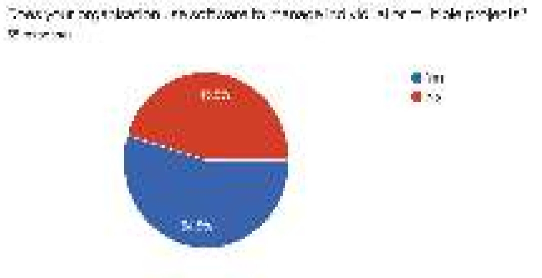

Fig. 4: Software to Manage Projects

c) Research Objective 3

Examine which Big Data is currently being collected to benefit the organisation on future projects.

The majority of interviewees were not aware of the term “Big Data”. The term had a greater sense of understanding from the construction companies' interviewees, who were able to express their knowledge and understanding. The common theme that emerged from both Participant 4 (P4) and Participant 5 (P5) regarding “Big Data” was the large amount of digital data that is being processed and acquired in a single project alone, notwithstanding a multi-project environment acquiring data on all projects. Both interviewees alluded to be the task of analysing and getting the correct information to the right audience in real time was the biggest challenge currently.

Participant 5 (P5) - *“Big Data I suppose is just the amount of digital data we're trying to deal with now, and. it's one thing just collecting the data and that has to be done as easily as possible. But then you have to try and analyse it and make sense of it, and target it to the right audience that needs to know about it. There's just too much data there now for individual people to keep on top of it all. You needed sorters, you needed to analyse to a certain degree, before humans can barely get a hold of it and see what the issues that are coming out of it”.*

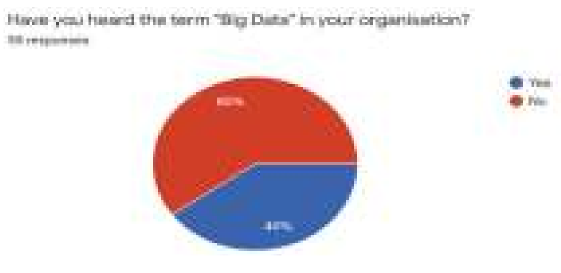

Fig. 5: Big Data

The questionnaire showed (Fig. 5) 60% had never heard of the term “Big Data” and 40% were aware of it. Within the 40% that had heard of the term 18.1% of the respondents were from the Engineering discipline, 18.1% from the Architectural discipline, 22.7% from the Construction companies, 27.2% from a Project Management discipline, and 13.6% from Quantity surveyor’s organisation.

The questionnaire outlined 51.8% of respondents used digital software tools to collect data and 48.2% did not. Further analysis from the questionnaire showed how respondents consider the different types of key data collected on projects for future decision-making excluding timesheets varied from each discipline.

The majority (57%) of respondents to the questionnaire strongly agreed (Fig. 6) that the analysis of previous project data would lead to greater efficiencies and improve strategic decision making within multi-project organisations.

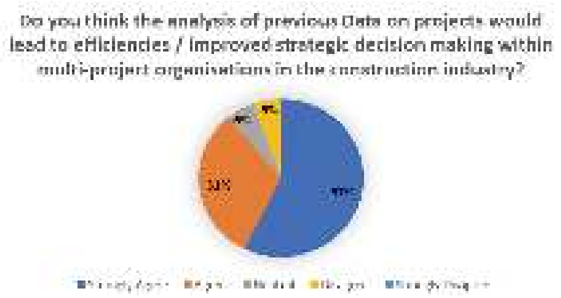

Fig. 6: Big Data

Participant 4 (P4) and 5 (P5) generated a theme around the importance of data collection on projects. However, they expressed that the accuracy of the data and knowing what data is relevant to the organisation were key points made by participants. Participant 4 (P4) highlighted the influence of bringing in professionals in Big Data, such as IT Architects that can cleanse the data being collected on projects and utilise the data for informed decision making. The following is key interviewees response:

Participant 4 (P4) - *“We've put good effort into capturing data and until we actually brought in professionals in big data we got nowhere, because we didn't know how to cleanse it properly we didn't know how to bring it back to first principles, you know garbage in garbage out and trying to understand what we wanted at our end game and work our way back to how we got that and not look for every bit of data and just get the real important items and be able to utilise that to make informed decision making. In our organisation it's vital because data drives everything we do, data drives productivity, data drives how we price jobs, how we can capacity plan.”*

d) Research Objective 4

Explore the extent to which decision making is influenced by knowledge management.

The results from the questionnaire showed (Fig. 7) 46% of the participants strongly agreed that the culture within the organisation can be one of the contributing factors to the adoption of digital tools for collecting and analysing data in the AEC sector.

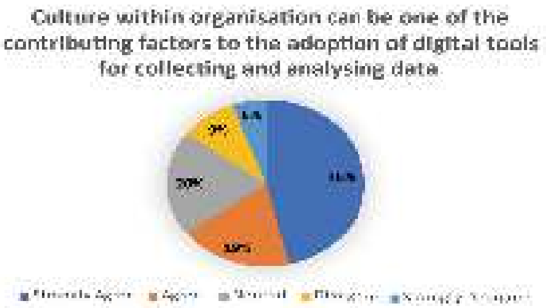

Fig. 7: Culture within Organisations

The results from the questionnaire showed (Fig. 8) 35% of the participants rated their organisations as **<u>Fair</u>** in managing/collecting existing project data for future decision making. We can see from the questionnaire that 15%, made up of both Architectural (62.5%) and Project management (37.5%) organisations, expressed that there was **<u>Very Poor</u>** efficiency within the organisation for collecting existing project data.

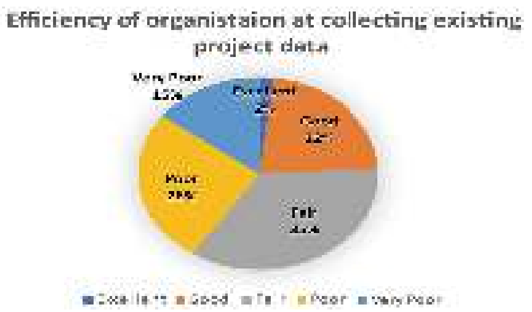

Fig. 8: Efficiency of organisation at collecting existing project data.

The consensus from the findings suggested the AEC sector (Fig. 9) is slow to adopt software tools and data platforms in AEC organisations. Both the interviewees and the participants of the questionnaire suggested this to be the case, whereby 17% strongly agree and 54% of respondents agreed with the statement in Fig. 9.

Fig. 9: Architectural, Engineering and Construction (AEC) sector is slow to adopt the use of data platforms.

V Key Findings

The key finding and subthemes from multi-project environments supported the ideas expressed in recent studies by H.G Gemunden et al, (2018) [10], which suggested an alternative model to the management of project-oriented organisations. The conceptualized model consists of three segments (1) structures, (2) people, and (3) values. The study suggests the proposed model will increase innovation and therefore have a correlation to the theory of the study that innovating project-oriented organizations exploit the information delivered by their projects faster which provides greater value to decision-makers [10]. The present findings are consistent with previous research around multi-project environments, with the evidence demonstrating the focus of the majority of organisations was around structures and processes, resourcing of people. However, a greater focus on the value of information, sharing collaboration, and the single source of truth was expressed from the construction organisations participating in this research. In practice, there is a lack of engaging and implementation of procedures to utilising the data collected on projects for future projects and decision making.

The current study found that the Project management Office (PMO) was not a familiar term within the majority of the participants interviewed. Only one of the participants interviewed was familiar with the term and this participant was from a large organisation. In line with previous research, the PMO would appear to be adopted more in larger organisations and as the majority of organisations in the AEC sector are SME's this could be the reason for the unfamiliarity of the PMO term and function within this research.

The findings indicated the AEC sector had unexpected differences in the level of adoption of digitalisation and maturity of adoption of software tools for managing and analysing projects. The majority of organisations embracing the adoption came from construction companies. However, this can be validated as the margin in the construction industry are so low, this is pushing the construction companies into investing in these software tools to gain competitiveness in the market. Compared to the Architectural and Engineering consultancy companies which seem to be a lot slower at adopting software tools or even collecting descriptive data.

An alternative argument to the construction companies' adoption of digital tools is the nature of the construction companies. For example, the traditional PW-CF1 Public Works Contract for Building Works Designed by the Employer, provides the contractors with a fully completed design. Therefore, the contractors can ultimately schedule out the elements of the building, organise supply chain and resources. Whereby the design stages of a project can be more fragmented in nature and the lack of client requirements, scope creep, and number of stakeholder involvement can leave this process very difficult to schedule and to meet milestones.

The findings of the questionnaire revealed that 40% of participants had heard the term Big Data, with the majority of 22.7% coming from the construction sector. Similarly, the results of the interviews reveal that the term was not familiar amongst the participants. However, one participant from the construction industry had a good understanding and was using data analysis within his organisation.

The results of the findings in this research support previous research into big data, that research and knowledge is limited on the topic within the AEC sector. The technical skills around data management and analytics, programming, and AI will be the key to the transformation within the multi-project management environment.

The key finding of this research conducted demonstrated a lack of understanding regarding the data required for making decisions within the organisation and using the correct software that's required. Bringing in the correct professional to help with first principles of understanding data and focusing on the value of the extracted data to the organisation. There is a sense that data needs to be analysed and provided to decision-makers in real-time, making decision making quicker and providing more informed decisions. Many management software tools are currently designed to collect, analyze and provided data in real-time to organisations, but knowing what each organisation needs is ultimately the key to the implementation of such services.

VI Relevance of Findings

This section presents the relevance of the findings relative to the two research questions.

Q1 – Transformation to digital software to manage multi projects is evident in the AEC sector?

The relevance of the findings shows the adoption of digital software tools was adopted to a degree with programs such as Office 365, Revit, BIM 360, etc. These were used individually and had no collaborative approach to an overall project-based software. The construction companies showed that the introduction of an all-in-one construction management software platform has been utilised for the overall organisation. This allowed the managing of multiple projects within a single platform, which allowed for the collection of data from all relevant projects to be set in an overall organisational database. Ease of use was a keyword that participants used to describe the selection of such all-in-one construction management platforms.

Research has shown to be aligned with the current literature regarding the trend towards digitisation. However, there is a gap in the existing literature on how the implementation of digital tools and software can be utilised in the AEC and what standard processes across the industry could be established.

The majority of companies in Ireland as referenced in Fig. 2 & Fig. 3 - Business in Ireland - SME (source: CSO Ireland) of the literature review section are made up of SME's. Established through the findings were obstacles such as organisational culture and time consumed with using such platforms were two factors that influenced the adaptation of digital tools.

Q2 – Innovation of data from projects supplies the raw information for making better decisions on future projects?

The research has concluded that data from projects can inform better decision-making for future projects. The research has shown that construction companies have utilised all-in-one construction management platforms for their organisations, which is central to a single source of truth database for the project, meaning all individuals associated with the project are getting the correct information from the one source, in real-time and not relying on several sources of information.

It can be concluded that awareness of data from projects can provide the raw information for better decision-making on future projects. However, there is a lack of the information or data collected and analyzed instantly to provide real-time decision making. The digitisation of this data can mean access to insights of previous projects and leverage the power of this information in real-time giving greater value on decision making. The evidence from this research supports the previous literature around Knowledge Management identified in the AEC industries to be problematic in the sharing of information and communication within multi-project environments, largely because of the industry's fragmented structures, complexities of projects and project-driven nature [1].

VII Limitations of Study Findings

SME's make up the majority of the AEC companies in Ireland. An implication of this is the resources, skills shortages, capital to invest in platforms and the practical limitations of balancing a strategic outcome and the implications of capital to invest in integrating specific all-in-one construction or managing platforms.

VIII Conclusions

The research has shown an overarching sense that digitalisation will drive innovation and transformation within the AEC sector through digital means of collecting data, with the extension of this data collected being analysed, and used for real-time decision making.

However, the industry is slow in the adoption and utilising digital tools, or possibly unaware of how valuable this data is for the organisation. The key to all this data is not the collection but the acknowledgment of knowing what analysed data the organisation needs and leveraging this data into knowledge and value.

The evidence from this research suggests that the adoption of digitisation is about two key drivers and that is people and process. This will ultimately lead to change within organisations. This change needs to come from a top-down approach, with key Leadership as an important attribute for the adoption of digitalisation within multi-project organisations as described in the roadmap published by National BIM Council - Digital transition for Ireland's construction industry [11].

Certainly, the current "Pandemic" has driven a lot of organisations into a more digital world quicker than they would have anticipated. Awareness from different disciplines in the AEC sectors is on the increase, with the construction companies leading the way with software for the management of a project.

IX Future Research

Further studies should be developed from this research involving a more detailed view on the efficiency in the AEC sector by creating a framework and adopting a proven maturity analysis of companies in each discipline to determine the level of digital practices within organisations.

This research has highlighted the lack of understanding regarding the implementation processes of digital platforms, comprehensive research around the risks and opportunities that digital technologies would bring to an SME with a particular focus on business models and skills within the industry.

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Lessons from the Liscate School Project applied to the TU Dublin Design + Construct Project

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Abstract

The objectives of this paper are to identify the lessons learned from the use of the FAC-1 contract on the Liscate School project in Milan, Italy, and to use these lessons in the development of the procurement strategy for the TU Dublin Design + Construct project in Ireland. The paper outlines the structure of the FAC-1 contract with specific emphasis on what it sets out to achieve. Using the Liscate project as a case study, the paper documents the means by which the procurement strategy was developed and implemented. The lessons learned from this project are outlined with a view to assisting the TU Dublin Design + Construct project team in their development of a procurement strategy. The paper outlines the initial outcome of a number of discussions and workshops that TU Dublin has conducted with leading construction and legal professionals in Ireland in order to clarify the opportunities of, the appetite for, and the barriers to using collaborative contracting in Ireland. These discussions show that there are several factors to consider if the introduction of the FAC-1 contract is to facilitate better digital workflows in Ireland and primarily identifies the need to alleviate the perceptions of risk surrounding the process if a strategy for collaborative contracting is to be followed.

Keywords – *Construction Procurement, Collaborative Contracts, Framework Alliance Contract FAC-1.*

I Introduction

Technological University Dublin is embarking on the delivery of a Design + Construct Centre at its Broombridge Campus in Dublin. This centre will provide a facility of national and international significance to serve the Architecture, Engineering and Construction industry and other aligned sectors. Through interdisciplinary and collaborative engagement, the centre will facilitate applied and practical innovation, education and research at all levels.

The Design + Construct Centre will play a pivotal role in:

- delivering Project Ireland 2040 [1]
- supporting sustainable development
- enhancing the well-being and health of communities
- advancing the key priority areas of apprenticeship, digitalisation, productivity and innovation.

It will also align with the objectives of the United Nations Sustainability Development Goals [2] and the Climate Action Plan 2019 [3] with targets in Built Environment for new builds and renovation, sustainable energy and infrastructure development. The project comprises the renovation of an existing university campus building of approximately 8,000 sq. m. to facilitate education, training, research and sports and recreation activities. The building is located in an established residential area in the north west of the city, between Cabra and Finglas and is currently used for sports and recreation by students, local schools and clubs.

As the philosophy of this project is to provide leadership for the future of design and construction, TU Dublin is keen to lead by example, through designing, procuring and delivering this building in a manner that will reflect the philosophy of the building itself. To that end, the technical solutions adopted will reflect leading sustainability practices in construction, design will be conducted using the best available and developing technological tools and the procurement will be conducted through collaborative means to maximise the benefits of the available technology.

With that in mind, TU Dublin was drawn to the issue of the need for a contract that would promote collaboration in design and delivery. Many models exist, such as the PPC Partnership contracts in the UK, the Integrated Project Delivery contracts in the United States and various other Alliance contracts in different parts of the world. In Ireland, public contracts are delivered under the direction of the Government Construction Contracts Committee (GCCC) and these contracts have been the subject of a long debate as to their suitability for use in a collaborative environment, such as that required where a project is delivered using Building Information Modelling.

In addressing this issue, TU Dublin has embarked on a consultative process to establish the views of several different stakeholders on the type of contractual arrangement that would be suitable for this project. In addition, TU Dublin sought the input of those involved with the Liscate School Project in Milan, Italy. This project was delivered using the Framework Alliance Contract (FAC-1).

This paper documents the developing journey of this consultation. A brief overview of Information Management and the FAC-1 contract is first provided, followed by an account of how FAC-1, which is a UK contract, was adapted and applied to the Liscate School project. A summary is provided of the key learning points that must be considered when using an unfamiliar collaborative contract for the first time in a country. Further detail is provided [on the Design + Construct project and how it has developed to date. Finally, an account is given of the steps currently being undertaken by TU Dublin in the procurement of the Design + Construct project, with specific emphasis on the lessons of Liscate and the barriers presented by the Irish construction procurement process.

II INFORMATION MANAGEMENT AND FRAMEWORK ALLIANCE CONTRACT (FAC-1)

One of the challenges of working in a BIM environment is that the information discrepancies and different skills among the parties can create information asymmetry. By rewiring the contractual obligations of the supply chain, it is possible to link and align the objectives of the client and consultants with those of the main contractor and the other supply chain members [4]. Such an environment enables the efficiency of direct links between the parties, fulfilling the need of the construction sector to create more structured communication among the team members involved in a project or programme of work. Combined with the use of BIM, collaborative information management is becoming a common feature and its legal value is progressively emerging. Thanks to compelling evidence of improved value and reduced risks [5], the motivations to collaborate among the parties are increasing. This phenomenon, initially experimental, is accelerating thanks to the pioneering experience of leading clients [6].

Collaboration requires not only the right contracts but also the right approach to procurement. Bennett and Peace [7] noted that single-stage tendering fails as a procurement system "*because it provided no overall direction, reducing everyone involved to defending their own interests*" - they acknowledged the attraction to clients of "*the simplicity of inviting competitive bids*", encouraged by "*professionals with a vested interest in old ways of working*" but suggested that these clients are "a*ll too often…sadly disappointed as they discover that claims, delays, defects and disputes make this an expensive and ineffective approach*". These assumptions are reflected in the trend expressed by NBS contract reports [8] which found that the legal framework through which the project is undertaken depends on the procurement method selected by the client. However, collaborative forms of contract are still limited by the behaviour of the people and familiarity in approaching contracts. In the UK construction industry, the main form of procurement remains traditional, and the adoption of collaborative approaches is shared by a limited number of projects [9].

In broad terms and in the context of construction and engineering projects, an *'alliance'* is an agreement providing that the parties to it will act through a structured approach to achieve a common goal [7]. An alliance tends to be a multi-party arrangement including the key stakeholders, client, contractor and professional team and potentially also key subcontractors [10]. Another definition suggests that an alliance contract records *"long term partnering on a project in which a financial incentive scheme links the rewards of each of the alliance members to specific and agreed on overall outcomes*" [11]. A multiparty alliance can ensure that all parties are aware of each other´s roles and their respective contract terms are consistent. This can motivate mutual trust among team members, which is necessary for successful joint working [12]. By the creation of an alliance, it is possible to restructure the relationships and to fill a behavioural vacuum across multiple appointments [13].

In a collaborative environment, the client can influence the designs and can help consultants and contractors to develop the project according to its needs and to obtain insights from different parties. In the complex scenario of a construction project, the need to provide for coordination and collaboration is growing. Subcontractors execute over 80 per cent of work on construction sites [14]. Non- compliance with a contractor's programme generates many inefficiencies in the construction process. The lack of integrated working systems among supply chain members can be solved through the collaborative agreement of programming and timelines. So as to coordinate the work of the different parties, it is important to distinguish when design information is actually needed as opposed to when a contractor perceives it is needed [15]. By detailed and methodical planning of the activities and the interactions, enterprise contracts can create a structured environment for collaboration [7]. Enterprise planning provides techniques for working along with other parties, aligning their interests and approaches. The benefits of collaboration are seen overcoming the concept of the single approach creating a joint entity that can correctly define the boundaries of a project (time, cost, quality, risks) [7] So as to provide successive levels of detail, this level of expertise can be achieved only by a mixture of experience from different areas of the market and by involving contractors and subcontractors gradually in a multiparty environment.

The FAC-1 model form provides agreed BIM deadlines, gateways, and interfaces in its multi-party Timetable (Schedule 2), with the flexibility to bring in BIM contributions from specialist sub-contractors, suppliers, manufacturers and operators through Supply Chain Collaboration. The inclusion of tier 2 and 3 allows to share and restructure information across parties [7].

Risks are also managed collaboratively in the FAC-1 through the use of an integrated Risk register (schedule 3). Such an approach allows definition of potential issues that are consequences of the interaction of FAC-1 and supports BIM with direct mutual licences of Intellectual Property Rights (FAC-1 clause 11). This potentiality allows different teams to create a dialogue on potential clashes and provides a contractual tool to integrate and coordinate parties for clash resolution by Early Warning (FAC-1 clause 1.8) and facilitated by the Core Group (FAC-1 clause 1.7).

III FAC-1 Applied To The Liscate School Project

FAC-1 was used as a BIM project integrator for the construction of a secondary school by the Liscate municipality close to Milan. The project was distinguished by a high degree of complexity worth just over £5m. The application of a collaborative contract enabled deeper cooperation and synergy between the client, architects, engineers, the main contractor, and the supply chain.

Due to the unfamiliarity of the Italian market to model forms, different workshops were organised before the selection process to help potentials contractors in getting familiar with the proposed approach. During those sessions, potential parties were trained in better understanding the meaning of the standard and its benefits.

The first step, in creating a collaborative culture, was to remove the so-called race to the bottom during the procurement stage. As also confirmed by Hackitt, poor quality and poor project controls are perceived as attributable to intrinsic motivation of doing "*…things as quickly and cheaply as possible rather than to deliver quality homes which are safe for people to live in*" [16]. ACE Northern Ireland also marked this point by initiating a partnership with the local government's Central Procurement Directorate (CPD) to agree on a new methodology where the lowest price is no longer the determining factor in awarding process.

As per the reasons mentioned above, the award criteria selected for the tender process were the most economically advantageous tender, mandatory as per the European Union public procurement regulations [17], where quality weighted 80 points, price 10 points and cost 10 points. The tender notice included selection criteria and award criteria based on transparent formulas to evaluate the propositions of the participants in terms of performance, environmental target, maintenance and safety solutions. By creating a collaborative environment, people are willing to share information rather than creating an adversarial situation. FAC-1 parties are encouraged to find collaborative solutions to problems thanks to the instruments offered by the contract.

The FAC-1 signed by the members of the team successfully provided the legal basis for optimising relations among parties and obtaining added value. The client drew up a series of annexes according to the functions and schemes that support FAC-1 and adapted the standard model form to the specifics of the project. The client included all important parties in the multi-party FAC-1 in order to ensure better information exchanges, not only with the general contractor but also with subcontracted supply chain members.

An objective of the collaboration set by the client was "*monitoring of the time and cost provided for in the Programme Contract and its annexes*" and all the features of the agreement were based on that assumption. The FAC-1 was the legal foundation used to assure and control the information workflows that are essential in a data-driven process, and guidelines were created to support the platform for sharing information. The Common Data Environment (CDE) and BIM guidelines were included as template documents in the model form.

The FAC-1 was designed to include among the alliance activities data sharing, BIM model management and maximum involvement of subcontractors and suppliers through supply chain collaboration. FAC-1 was used to link workflows to digital project controls (as alliance activities in schedule 2), setting out not only agreed success measures (schedule 1 part 2) but also the computational codes for achieving the required results (schedule 1 part 2). In terms of responsibility, the accountable team members for each of the agreed objectives were defined and the joint system for performance measurement. Alliance members used a joint risk management strategy to maintain alignment of their commercial interests and to encourage proposals designed to ensure they could reach their pre-defined targets.

The FAC-1 multi-party structure enabled the integration of BIM models and efficient information delivery using guidelines set out in the framework documents that were accepted by all the alliance members. The guidelines defined how to use the CDE platform for managing workflows and sharing information, and they specified the required information for built models.

Each alliance member provided details for inclusion in the timetable showing not only the operations to be carried out on-site but also the procurement of materials and the entry on site of subcontractors and suppliers. To enable better sharing of information, weekly meetings included all interested alliance member and enabled through joint risk management of problems that would otherwise have caused delays in the operational sequence of activities.

The Common Data Environment platform was designed according to the needs of the *Client* on the 'Alfresco Platform', which is an open-secure system that intelligently activates process and content in order to accelerate information flows. The information-sharing procedures were built on the necessity of bringing *Client* content under control with seamless information governance.

The CDE platform, plus the alliance timetable (FAC-1 Schedule 2) and guidelines adopted for information management, were inserted in FAC-1 as the formal basis for communication. They governed both the information requirements and the procedure for exchanging information that is essential to the success of a data-driven approach. This information data management is a key concept for the efficient implementation of the BIM platform, i.e. the loading, updating, sharing, verification and consultation of documents and information according to the needs of the client, the rules of filing, nomenclature and responsibility, as well as the additional information (metadata) related to each type of document. The CDE improved and streamlined control of the information flow, structuring processes and information which were subject to validation, amendment and archiving. The platform provided for the collection of interconnected data and was used to access, update and manage this data. This platform also digitally archived the documents and monitored approvals. It was assimilated to a database with a web-based interface and was therefore accessible anywhere.

The risk register helped to prepare the team members to deal with risks arising. Risks were identified with a 0-5 range according to their probability and impact, highlighting potential problems in advance and assisting in their responsible and systematic management. The risk register demonstrated not only foreseeable problems but also identified a person responsible for monitoring the relevant risks, the control intervals and, above all, countermeasures to the problems. The global analysis of risks was an example of the improved value, which derived from the use of FAC-1.

FAC-1 provided a collaborative framework including joint risk management processes. The standard allowed to forecast unforeseen events so as to minimise delays and additional cost. Example quality or performance improvement to the *Project* made by FAC-1 *Alliance Members* are:

- The use of cross-timber instead of natural timber for beams. This solution was proposed by the general contractor and by the wood supplier. The improvement guaranteed better quality and reduction of lifecycle costs in terms of maintenance. In return, the client agreed to shorten the payment period.
- Improvement in the quality of the wood floor. The general contractor offered at no additional cost a material that requires less maintenance as well as reduced delivery time and reduced on-site activities.

- Anticorrosion treatment of the external steel stairs. This new treatment was proposed by the general contractor instead of anticorrosion painting in order to improve maintenance and reduce on-site activities.

Through the CDE under FAC-1, each user could enter, share, modify, manipulate and display data (depending on the rights granted to them) following the pre-established information flow connected with digital objects. In this way, each user had predefined tasks, depending on its agreed role in the project, allowing them to access certain data, to accept or request changes to documents and to use the database linked to the BIM models. The client established the levels of information required at each stage both for technical elements and environmental units. The level of information required at each stage was determined according to the appropriate quality, quantity and granularity of the graphic and alphanumeric information, linked to the information requested by other service providers and according to ISO 19650 standards. Establishing these requirements in FAC-1 can allow for structured management of the data contained in the models and information databases of an entire real estate portfolio. It also enabled the management of an ISO-compliant BIM process.
Digital management of information through the CDE under FAC-1 updated the BIM model and provided stakeholders with the definition of robust workflows for the creation, archiving and updating of documents during and after construction. On the Liscate project, the data contained in the model was made available according to the needs and roles of each company, with different reading and writing privileges.
The CDE platform allowed all alliance members to have data control in real-time of supplies arriving at the site, of documents to be approved and of materials to be accepted. Documentation was automatically sent in digital format to people in charge following the regulatory flow, which ensured timely inspection and control procedures on site. This data management system also enabled cost management and the monitoring of quantities delivered and to be delivered, so as to have a computational knowledge of the progress of work. In this way, together with weekly coordination meetings, the interests of all alliance members were aligned and information asymmetries between the parties were removed.

IV KEY LEARNING POINTS FROM THE LISCATE PROJECT

The following actions, taken by the project promoters. summarise the key processes that promoted the use of the FAC-1 contract on the Liscate project:

1. Familiarise the market with the form of contract under consideration, with specific emphasis on the use of the contract as a tool to address the project objectives of all parties
2. Involve the market in the development of the contract awarding methodology and set out transparent processes that will regulate the contract awarding process.
3. Develop a clear series of annexes that will support the use of FAC-1, such as the means by which, emerging risks will be managed, timetable, mutual IP rights and disputes will be escalated and resolved .
4. In drawing up the FAC-1 agreement, involve all parties who can influence the outcome of the contract, i.e, the client, the consultants, the contractors and their supply chain.
5. Legally define the accountabilities and responsibilities of all parties
6. Follow a joint risk monitoring and management approach where all parties in the contract have equal input to the decisions reached.
7. Manage all information through a Common Data Environment to which all parties have live, real-time access.
8. All decisions agreed are updated immediately on the Building Information Model, so that all parties are accessing the same live information at all times.

V THE TU DUBLIN DESIGN+ CONSTRUCT PROJECT

a. Background and Project Description

Purchased in 2011, the 3.25-hectare site with a derelict warehouse at Broombridge in Cabra complements the developing TU Dublin Campus in Grangegorman. The site is close to the TU Dublin campus at Blanchardstown and is connected to the TU Dublin campus at Tallaght by Luas. The site is located immediately adjacent to the transport hub in Dublin 7 on the intersection of Luas, bus, mainline train and cycle greenway infrastructure. TU Dublin has invested in the purchase of the site and development of a full size all-weather, flood-lit sports pitch, changing rooms and a small administration office.
The objectives of the Design + Construct project are:

- to provide specialist spaces for collaborative, interdisciplinary education
- to increase flexible applied educational and training offerings
- to address innovation and enterprise needs in the AEC sector,

- to work with project team to ensure design actions which deliver high-performance, low carbon building envelope using materials products, digital technologies and systems which are intelligent, energy efficient, adaptive and cost effective.
- to explore innovative procurement approach to delivering an integrated, high performance building

The project schedule of accommodation includes three distinct areas,

1. Workshops and project spaces, collaborative learning space plus support accommodation
2. Indoor sports area
3. Social, student and community facilities.

The project is of strategic importance to the University and is a flagship project in the University philanthropic campaign.

The Design + Construct Centre at TU Dublin, Broombridge will be a live project for education and research; a Smart-building, a living laboratory for students, researchers and industry partners. Through the application of Internet of Things technologies, monitoring of utilities usage will be embedded into design specifications as a tool for post occupancy analysis and for on-going analysis of costs and performance. This approach will provide valuable data on the building's performance which will inform future strategies for improvement of performance and outcomes. The development of the detailed design and performance brief for the project will incorporate principles of sustainability, green technologies, performance and circularity, upcycling and reuse.

From a procurement perspective, the project is aligned with the Capital Works Management Framework (CWMF) and the Public Spending Code (PSC). The Project Board and Project Team have been established and the project has received approval to proceed to prepare the Preliminary Business Report and, subject to Project Reviews 1-4, to proceed to CWMF Stage 2 (statutory approvals) and Stage 3 (PSC) (Final Business Case).
A series of Working Groups have been established to focus on particular aspects of the Project Brief;
WG1 Building Design and Performance
WG2 Procurement Strategy
WG3 Pedagogical Development
WG4 Research, Innovation & Enterprise
WG5 Stakeholder Engagement, Community, Sports
WG6 Funding and Financial Sustainability

As this will be an exemplar project for the technology in the construction and use of the building, it is TU Dublin's wish that the project will also be an exemplar with regard to procurement strategy and methodology. With this in mind, all allowable and appropriate forms of procurement methodology are being considered.

b. Initial Approach

When the project was initiated in 2017, a cross-disciplinary project team was established to develop an outline brief and schedule of accommodation. At the time, the procurement office initiated the appointment of a single point architect led multi-disciplinary design team through a restricted procedure two stage appointment process. However, due to organisational changes, the approval to proceed to the second stage of the restricted procedure and appointment of the design team was paused.
This hiatus provided the opportunity for the project team to review the overall approach to the project and to re-evaluate and re-position the project within the organisational strategy, governance structures and procedures.

On completion of this review, it became evident that further development was required regarding the optimal approach to the procurement and project processes with an acknowledgement that while a traditional procurement approach may deliver the specific building design, technical and performance objectives

- there is a need for a more collaborative, cross-disciplinary, integrated approach to the appointment of the design team, specifiers, suppliers and specialist and main contractor/s.
- the brief was not sufficiently developed and did not provide a detailed description of the nature, scope and specification of the project.
- the assumptions made in the development of the brief were not fully articulated or tested
- the management structure was not clearly defined and the decision-making lines were only partially in place

c. Current Approach

As a consequence of these conclusions, the key project outputs were re-developed and the pre-project parameters were re-defined including the high-level requirements, assumptions, constraints, management structures and cost and timescales (ref Project Management Tools (GH) GN 1.1 (see https://constructionprocurement.gov.ie/guidance-notes/) . The project was positioned as part of the overall campus development planning and governance structures, aligning to both the CWMF and the PSC. (Completion of Strategic Assessment Report and Completion of Site investigation (Site and Condition Survey).
The following work packages are being developed:

1. Project Governance: development of governance and project management map including
   - Project Board, Team, Working Groups, Collaborative Innovation Teams, Task Forces, Advisory Board membership
   - Terms of Reference
   - Roles & Responsibilities
   - Reporting arrangements
   - Alignment with CWMF Project Review and PSC stages
2. Detailed Project Brief
3. Development of design and performance brief (Project Definition and Definitive Project Brief GN 1.2)
4. Project Execution Plan (Project Management GN1.1)
5. Procurement Strategy (Procurement and Contract Strategy for Public Works contracts GN1.4) and Procurement process for Consultancy Services (Technical) GN 1.6 and Risk Management Plan (GN 1.1)
   - Identify Standards, Performance and Performance in-use metrics, frameworks and outcomes
   - Analyse and compare procurement routes
   - Contract Strategy (determine level of integration)
   - Identify project constraints (financial, physical, functional, design)
   - Evaluate risk and risk allocation
   - Delivery and incentives
6. Cost Control and Budget (Planning and Control of Capital Costs GN 2.2)

This also provides a basis for the completion of tasks to fulfil the requirement in preparation of the Preliminary Business case (PSC). The project map Figure 1 below seeks to align the tasks.

VI Strategy for Learning from the Liscate Project

To develop the project map further it was necessary to commence a familiarisation process as outlined as the first lesson learned from the Liscate project. This has begun with a series of meetings and workshops with key thought leaders in the field of construction in order to establish the barriers that would need to be addressed in procuring the project through an inclusive, collaborative environment. Those participating in this stage include Government officials, representatives of professional organisations, state bodies, legal experts, procurement experts and members of interest groups and fora focussed on improving the means by which construction projects are procured. There are two aspects of procurement that must be considered in this phase, namely:

- the appointment of consultancy services (technical experts) and a definition of the timing and procurement strategy associated with these appointments.
- the subsequent appointment of the contractor(s) who will carry out the construction works.

The first of these discussions took place with the Office of Government Procurement (OGP), the purpose of which was to assess the appetite for innovation in procurement. As a government body, the OGP advised that there was little evidence that different procurement strategies other than the standard forms of contract would deliver a better outcome for the project. However, the project team was informed that, if a specific procurement need, which would not be best served by use of the GCCC contracts, then a case for using a different contract would be considered. Effectively the challenge to the project team is to establish the problem that the GCCC contracts could not address.

The second discussion that took place was with the Lean Construction Ireland (LCi) Client Forum, whose aims state:

‘*It is recognised that there are opportunities to improve the way projects are designed and delivered so as to optimise the benefits and value to all involved in their design and delivery, as well as the various stakeholders who will ultimately utilise the buildings, facilities, and infrastructure across their lifetime. There are clients and supply chain organisations who have successfully collaborated in more relational oriented contract models to deliver projects. The Forum has been established to optimise the learning, knowledge and expertise gained under these delivery models, and it provides an environment that is inclusive, collaborative and respectful in facilitating thought leadership, best practice delivery and high-quality build where all project members benefit*.’

The outcome of this discussion was an agreement to collaborate in a number of follow-up actions, including:

- Focussed round table workshop on the application of the lean philosophy to the procurement of the project.
- Feedback from the LCi on the project team’s documentation on the design brief and the procurement strategy as it develops.
- Sharing of procurement experiences, particularly on innovative approaches to procurement, as well as sharing experiences of other developments such Iintegrated Project Delivery (IPD), FAC-1, BSRIA Soft Landing, etc.

			Project Management	Design Activities (Building)	Cost Control Activities	Risk & Value Management
CWMF 16 project Parameters	Stage 1 Planning Initial	Strategic Brief (Feasibility/ preliminary report)	Project Definition • Objectives • Purpose • Scope • Deliverable/ Outcomes • Performance • Assumptions • Governance & reporting • Project Execution Plan	• Design re-strictions/ requirements • Location • Preferred options Feasibility study/ report Develop Definitive Project Brief Technical expert input	• Expected functional life • Budget • Constraints Cost Assessment of Preliminary report (capital and maintenance costs)	• Known Risks • Value manage-ment strategies Identify and assess project risk Develop high-level Risk Management Plan Confirm strategic functional performance
PSC Preliminary Business case		Strategic Assessment Report **Confirm strategic relevance**	**Specification of objectives** Consideration of **deliverability** Analysis of **options for implementation** and operation Plan for **monitoring and evaluation**	**Short list of potential options** Consideration of **deliverability**	**Demand analysis and underlying assumptions** Detailed **options appraisal**, including both **financial** (capital & operational) and **economic** (CBA) appraisal Analysis of **affordability** within existing resources	**Risk assessment** and allowance for optimism bias Outline **procurement strategy** **Appointment of technical experts/ consultants**
Outputs	**Project Review 1**	**O Site Investigation**	**1 Project Governance**	**2 Detailed Project Brief and specification**	**3 Project Execution Plan and Budget**	**4 Procurement Strategy and Risk Management Plan**

Fig. 1: Project Map aligning the tasks from both the CWMF and the PSC within the 5 work packages identified

LCi also emphasised the need to establish what, precisely, the collaborative procurement was being asked to resolve.

The third in the series of initial workshops was held with a wide group of procurement specialists across the Architectural, Quantity Surveying, Legal, Academic fields. Representation was present from Ireland and the UK. This workshop focussed on the appointment of the design team and the technical experts. The outcome of this workshop identified the key question of defining the problem to be solved, but focussed in on the need to address risk and the means by which a different approach to procurement could robustly handle risk.

Considerable emphasis was also placed on the need for a robust and transparent contract awarding methodology, with a number of different participants sharing their positive experiences experience of developing this methodology with the market – as was done on the Liscate project. Experience was also shared of involvement of the supply chain in the early project development stage – both from the points of alerting the market to the pipeline of upcoming work and of improving the client's approach to the project delivery strategy.

VII Conclusion

This paper is a snapshot in time of how a project team grapples with issues arising from its desires to deliver a project to a state of the art process and the reality of negotiating the myriad of regulations and cultural drivers/barriers that drive projects in what have been defined paths. The paper documents the lessons learned on the Liscate project, where a new approach to procurement was introduced on a project on the outskirts of Milan, Italy, using a contractual instrument developed in the UK. As TU Dublin continues its planning for the delivery of the new Design + Construct facility at Broombridge in Dublin, Ireland, it seeks to learn from the journey that was travelled by the Liscate project team. As the world of construction develops a need for greater collaboration, TU Dublin is undertaking a series of discussions in order to frame its starting point on the procurement route. The early workshops have identified several points of common ground between the early stages of the Liscate project and TU Dublin's Design + Construct project. Its next stage of development is to resolve the procurement questions and to move into full project delivery mode.

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Highly Skilled Workforces

ARISE (*cert*COIN)- inspiring demand for sustainable energy skills

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The European AEC Sector now faces impending challenges over the next decade concerning escalating climate targets. To reach these targets, it vital that the green economy deliver a better-skilled workforce and develops new competencies and methods of working. Training in the domain of digital construction technologies and processes, such as Building Information Modelling (BIM), are now seen as essential upskilling vehicles that must be embraced if the sector is to transition towards a greener agenda. To assist in meeting these training needs a selection of partners from the BIM EPA will partake in the Horizon 2020 ARISE project, aiming to contribute to this agenda by stimulating and inspiring the demand for sustainable energy skills. This will be achieved by monetising skills development and learning exchanges within a digital system based on skills recognition. The project will develop a suite of modules underpinned by micro-credentials that will enable the learner to acquire the skills and accreditation/recognition needed to meet the job requirements while also providing vocational mobility. This material will be hosted on an on-demand mobile-friendly training portal and will have procedures inbuilt in its architecture to measure progress and validate the achievement. This achievement will come in the form of a cryptocurrency titled CERTcoin. It is hoped that this innovative approach will support the transition of the construction sector by providing its workforce with digital and sustainable energy skills that will secure a greener future.

keywords– Building Information Modelling, Sustainability, Education, Horizon 2020, ARISE, CPD

I INTRODUCTION

There is a recognised need to build a more comprehensive understanding concerning the numerous factors that impact participation in training. Some of these perceived barriers that an individual must overcome include the value of training, insecurity and fear of failure, motivational or lack of desire to participate in training; and the extent to which previous learning experiences affect the likelihood of pursuing future training activities [1]. The understanding of training barriers is required more than ever within the construction sector. A sector that is one of the most significant contributors to the global warming crisis and responsible for: one-third of global carbon emissions, one-third of global resource consumption, 40% of the world's energy consumption, 40% of global waste generated, and 25% of the world's total water consumption [2]. Climate change and its associated impacts have been identified as the greatest challenge facing human society; its adverse effects include increased average temperatures, sea-level rise, increased heavy precipitation, and more frequent extreme weather events [3]. To help address this impact, the AEC sector has championed digitisation, as it acts as a catalyst for improvement of processes that, for example, enables us to model building assets and sequentially perform a multitude of analyses, including energy performance predictions that compare design alternatives, thus allowing for an improved data-driven built environmnet[4].

Digitalisation is now becoming pervasive in our daily lives. It is driving a level of connectivity never seen before in society, with digital methods and technologies, such as Building Information Modelling (BIM), now disrupting how we are traditionally doing business within the construction industry [5]. With BIM, buildings can be inspected from various angles, including sub-structures, intersections, and building performance characteristics, and allows for visual language tailored to different actors [6].

From an Irish context, the call for these digital skills is highlighted by the Expert Group on Future Skills Needs. The Group outline that changing technological and environmental factors, such as the increasing importance of BIM techniques and recent regulations around Nearly Zero-Energy Buildings (NZEB), create a need for additional upskilling and retraining to allow the sector to respond to thesetrends [7]. The Future Jobs Ireland 2019 Report also highlights BIM as a tool that will cultivate productivity improvements in the construction sector [8]. The difficulty in procuring trained individuals within the industry is discussed in a further report from the Expert Group on Future Skills Needs, highlighting that 16% of organisational responses report a specific difficulty in hiring BIM Operators / Experts [9]. To assist in overcoming these barriers, the Horizon 2020 ARISE project will help advance the upskilling and retraining process in the sector, as well as the recognition of these activities and the skills obtained. This will be achieved through the monetising of skills development and learning exchanges within a digital system based on skills recognition rather than solely the more traditional accreditation pathway.

II EUROPEAN NEED

Europe faces many impending challenges over the next decade, such as the climate crisis. To adequately address this crisis, we must develop a skilled and equipped workforce. The green economy is an instrumental part of sustainable development and COVID economic recovery plans across the globe. The organisation for Economic Co-operation and Development reports that countries and key partner economies have so far allocated USD 336 billion to environmentally positive measures within their COVID-19 recovery package [10]. The green economy must now deliver a better-skilled workforce and reduce labour market shortages by increasing participation in training. This can result in increased productivity and guarantee better compliance with deadlines and energy targets, thus reducing cost and waste. The key ideology is to facilitate BIMupskilling within the broader agenda of digital skills to enable the imminent transition, which is essential to the industry's decarbonisation and positive climateaction [11].

The European Construction Sector Observatory report that Automation and the increasingly widespread utilisation of BIM are still not widely used in the construction sector. The report states the industry needs to develop new competencies and methods of working. This report outlines that by setting ambitious goals for Europe, the Energy Efficiency and Energy Performance of Building Directives has driven the need for additional green energy and energy-efficient construction skills. To achieve this, a total of 3 to 4 million construction workers in Europe will need to develop their energy efficiency-related skills in the building sector [12].

ARISE will aim to contribute to this agenda by stimulating and inspiring the demand for sustainable energy skills from industry and individuals by redesigning the skills exchange, providing transparent upskilling transactions, and recognising upskilling performed. This will be achieved by delivering a 'portable' skills mechanism that providesthe learner with access and vocational mobile flexibility. The ARISE digital Individual Learning Passport (ILA) will assist with the transition from paper-based to digital credentials in the European skills area and deliver digital credentialing solutions using Blockchain technology for verifiabletransactions.

III ARISE BACKGROUND

In 2018, an initiative involving former Horizon 2020 and Erasmus+ projects including BIMCert, BIMEET, BIMplement, BIMzeED, and NET-UBIEP, as well as additional vital players in the upskilling of the AEC sector in digitalisation and sustainability, came together to form the *BIM Energy Performance Alliance* (BIM-EPA) [10,13,14,15,16,17&18]. In previous work, BIM-EPA partners had confirmed, with measurable results, the advantages of BIM as an improved enabler for higher levels of sustainable energy in buildings compared to traditional methods. They have also developed and showcased training programmes to upskill the construction sector workforce in digital construction with a focus on energy reduction.

A selection of partners from the BIM EPA have responded to another direct call from the Horizon 2020 initiative. This is the most extensive EU research and innovation programme ever, with nearly €80 billion of funding available over seven years (2014 to 2020). A part of this initial funding call was made available to focus on building a low-carbon, climate resilient future, which underpins the goals of the Paris Agreement and the Clean Energy for all European packages. A consortium of Northern Ireland (project lead- Belfast Metropolitan College), Republic of Ireland (Technological University Dublin), Portugal (CERIS/Instituto Superior Técnico), North Macedonia (Institute for Research in Environment, Civil Engineering, and Energy), Netherlands (Stitching ISSO and Building Changes Support BV), Italy (IBIMI), Denmark (Copenhagen

School of Design & Technology) and Belgium (Architects' Council of Europe) has proposed to respond to the call, by building on the outputs of several BIM-EPA members and other projects to provide a cohesive training response. This will deliver a set of interconnected, self-enhancing training modules to be realised in 4 key steps:

[1] The harmonisation of activities performed with partners of past EU-funded projects, in regards to foreseeing different actions, such as the definition of sustainable energy and digitalisation competencies to facilitate mutual recognition. This step will also involve associating the training content, previously developed by the BIM-EPA partners, and new ARISE material to a commonly agreed recognised set of Learning Outcomes (LO).

[2] The development of a digital delivery system for Continuous Professional Development (CPD) recognition pathways and training schemes and its deployment into the market. This recognition pathway will be a didactical structure used to assemble all existing and new learning materials into bite-size microlearning units. A suite of modules providing discreet micro-credentials will enable the learner to acquire the skills and accreditation/recognition needed to meet the job requirements while also providing vocational mobility.

[3] To assist in the market by increasing demand and delivery of upskilling, ARISE will develop an on-demand mobile-friendly training portalfor digitisation and sustainable energy in the construction sector. This e-platform and tools will assist individuals, industry, SMEs, large companies, and public authorities to engage and achieve digital energy skills maturity. The platform will have procedures inbuilt in its architecture to measure progress and validate the user's achievement, as well as issue a rewardand recognition (accreditation) system titled CERTcoin.

[4] The creation of a cryptocurrency (CERTcoin) of skills and learning in the digitally built environment enabled by blockchain technology to ensure the trust of the CPD type digital awarding. The purpose of this is to provide a model for providing professionals with a mutually recognised, comparable, and accepted leverage for their skills, to enhance their vocation employment while raising the standards and demand across the construction sector.

IV ARISE TARGETS

ARISE's approach and proposal is to improve and increase the collaborative skills of practitioners at all levels regarding the use of BIM and other technologies. These skills will enable and enhance the sector's ability to deliver energy-efficient buildings, leading to the scaling up of implementation of new construction processes, potentially with more significant impact when applied to retrofitting existing building stock. Facilitating BIM upskilling is recognised as an instrument to contribute to the European Green Deal by helping to ensure that the project life-cycle and costing analysis have a sustainable growth agenda for the future by using digital technologies [11&12]. This collaboration will be undertaken with Industry stakeholders (Public authorities, professional associations, building owners, tenants, and Facility managers) to support and directly stimulate the demand for such skills. An initial skills maturity level analysis will be used as a method to diagnose and reward skills development. This will enable the development of several levels of maturity of applied digitalisation.

A Learning Record Store will be implemented to enable digital delivery of both training, assessment, and recognition. For independent verification, these recognitions can be registered with blockchain technology resulting in an Interactive Learning Business Account (ILBA) This will enable acontrol track that can never be modified, with a consensus on the truth of the content, through multiple versions of the control track, createdbetween many nodes, thus providing quality assurance of the skills recognition.

Completing modules allows a CERTcoin to be claimed/given, which underpins maturity and builds up a portal for users to promote their successes. Data traceability with unique digital IDs for each user, integrated into Blockchain, will protect individual digital experiences. This will also permit independent validation of an individual's learning data history over time, through the ledger if necessary to demonstrate data integrity to third parties, such as auditors or regulatory compliance agencies, or during legal disputes.

The developed qualification will encompass the workforce and professionals included in construction processes and the essential stakeholders such as public administration and public/private owners. The qualifications that will be designed for public administration will enable these institutions to initiate, run, and implement processes to digitally support energy skills and to require such skills from the industry. Digitalisation tools, such as BIM, generative design, digital simulation, and blockchain processes, will be demonstrated to upskill the public administration workforce in digital ways ofevaluating and validating public procurements and other legislative actions to regulate the market towards energy efficiency.

V ARISE CHALLENGES

One of the challenges expected throughout the project's life-cycle includes a potential low number of participants in program trials. It is hoped this can be avoided through extensive communication and dissemination activities. Continuous monitoring of participants' progress and understanding of the trial's materials will assist with learner engagement and interaction as they test the innovative learning tools under development.

Additionally, as part of ARISE's technical groups, there will be direct input from Industry leads. They will help review and inform the training programme, make it suitable and impactful to the Industry, and facilitate the likelihood of its uptake by construction professionals.

There are also other concerns, such as the range of applicability and recognition achieved. Through continuous measurements and surveys of the level of inclusion of stakeholders, timely detection of weak spots, alignment with CPD schemes to make the program widely applicable and accepted across Europe, will help to circumvent such barriers. Another barrier that must be considered is the lack of government mandates across Europe for a common standard in certified skills. Partners from neighbouring countries will support the consortium efforts to overcome this barrier by engaging stakeholders from their countries in the project activities.

VI ARISE METHODOLOGY

The project will commence in September 2021 and will conclude within a 30-month timeframe. The ARISE methodology is designed to focus on the following six deliverables

1. Facilitate mutual recognition of energy skills and qualifications in the construction sector.
2. Develop maturity level-based digitalisation, including classifications for energy skills.
3. Underpin national, regional, and local initiatives to raise awareness of the benefits of sustainable energy skills.
4. Provide support and training to public authorities to potentially develop new legislative frameworks and digital processes.
5. Establish cross-sectoral partnerships and collaborations to raise awareness and demand for good energy practice in construction/renovation.
6. Start initiatives to reinforce the links between skills/education and energy performance

To achieve this, the project will measure the current level of energy and digitisation skills maturity, knowledge, and understanding within the built environment sector. This will be an updated review of state of the art, based on the most up-to-date literature, survey data, and previous reports and EU projects, as well as an internal research analysis. Thiswill result in three benchmarks: 1. EU Skills Benchmark; 2. Internal consortium Benchmark within the BIM-EPA; 3. Industry Benchmark.

These benchmarks will enable the development of a task-based qualification framework to enable a digitalisation transformation pathway. The framework will be an extensible foundation for the ARISE CPD system, and it will permit the generation of micro-learning, as well as the record store compatible learning statements, and the bite-sized units of learning outcomes that will form the upskilling modules. Ultimately, it will provide the skills framework enabling the transition from traditional to the digital method of application of skills.

This framework will be hosted on a gamification-type platform. Gamification has been found to be a productive tool to increase intrinsic motivation, introduce new technologies and products, and promote innovation and flexibility [19].

A work package will be dedicated to establishing and implementing the learning content and tools for the ARISE pilots. This learning content will be reflective of the skills established within the maturity qualification-based framework and aligned to support public administration, clients and users, as well as professionals (architects, engineers, technicians) and blue-collar workers. It will develop the micro bite-size modules encompassing a" just in time/beyond blended" approach. The beyond blended approach will include a combination of IT application and gamification rewards to facilitate its delivery. The micro size modules will be assessed using an AGILE methodology, which will enable adaptive planning, evolutionary development, prompt deployment, and continual improvement of the learning content and delivery.

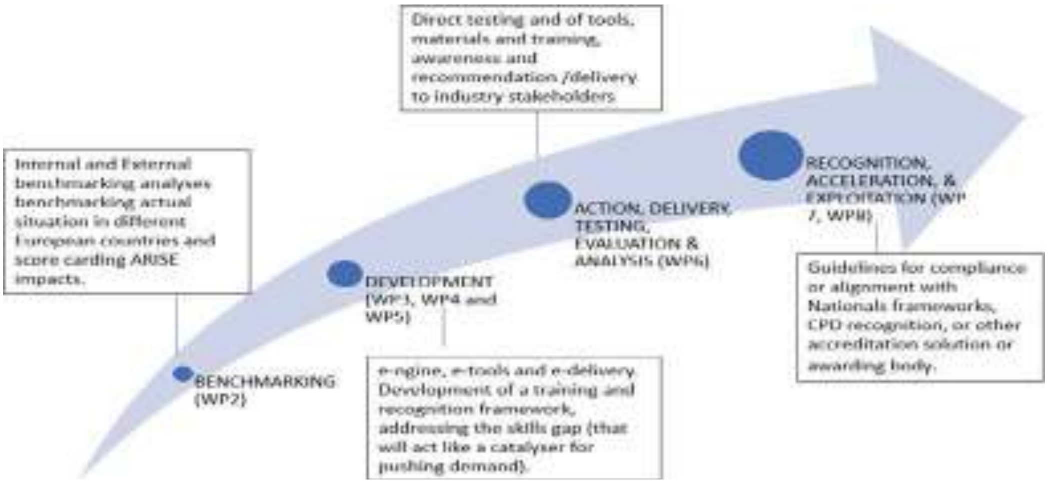

Figure 1 ARISE Methodology

A demonstration of the developed upskilling materials and pilot testing will be undertaken in both Consortium and associated partner countries. This will demonstrate the multi-criteria benefits of applying new digitalisation skills towards energy efficiency and ARISE's tailored upskilling scheme format for recognised competencies. These pilots will also be used to develop the matrix of competencies and skills to increase market competence. The matrix includes both the aspects of the digital tools of delivery and certification attribution (CERTcoin). The ARISE project will also develop a framework to align training modules with potential CPD certification systems and prepare guidelines for key market drivers. This will establish appreciation and acceptance of sustainable energy skills in construction, which will help to stimulate market demand for the skills. Figure1 provides an overview of the ARISE Methodology

VII Conclusions

The uptake of the developed scheme will increase company and workforce willingness for upskilling and professional development. It is expected that the project will make a significant contribution to increasing the number of upskilled construction professionals. The overarching aim is to support the transition of the construction sector by providing its workforce with digital and sustainable energy skills of the future, along with demand-side guidelines for marketable appreciation of skills and exploitation of benefits thereof.

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Recognised Micro-Learnings To Support The Digital Journey In The Construction Industry

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Abstract

The aim of this paper is to demonstrate how the human-capital basis of the construction sector can be enriched using Building Information Modelling (BIM) and digital tools to improve the sustainable building environment. The research within the BIMzeED project (www.bimzeed.eu), conducted across 4 EU countries, identified a number of gaps between the skills and needs of industry and the current availability of training. The gaps identified thus informed the development of 12 innovative and multidisciplinary Learning Units (LUs) addressing nearly zero energy buildings (NZEB), circular economy and compliance. The mutually recognised micro LUs delivered as blended, in-class/on-site or on-line training, are designed to be flexible as stand-alone units, combined as a group of LUs or integrated into existing curricula. Training the workers and staff in small to medium enterprises (SMEs) will improve their competitiveness by ensuring SMEs can keep pace with this fast developing industry, and integrating the LUs into existing curricula will ensure that the training available at higher and vocational levels meet the demands and needs of the industry. The LUs, as they are designed to be flexible and accessible, will enable SMEs in particular within the construction sector, to start the digitisation and transformation journey within their organisations.

Keywords – Micro-learning, Mutually Recognised, Active learning, Digital tools, Sustainable built environment, SME competitiveness

I. INTRODUCTION

There is a major opportunity for the construction sector to not only reduce energy demand, but also to improve process efficiency and reduce carbon emissions; however the industry is traditionally highly fragmented and is often portrayed as involving a culture of "adversarial relationships", "risk avoidance", exacerbated by a "linear workflow", which often leads to low efficiency, delays and construction waste [I]. Construction is a complex sector that includes a wide range of economic activities: extraction of raw materials, manufacturing and distribution of construction products, design and construction of buildings and infrastructures, maintenance, renovation and demolition, waste recycling, etc. It is also characterised by being a highly SME-based sector, where small and medium-sized enterprises (SMEs) and micro-enterprises make up the majority of the construction value chain and according to EUROSTAT, 94% of the construction companies engage less than 9 employees [II]. The image of the construction sector is widely perceived as a "low-tech trade" sector, but the construction industry is experiencing its digital revolution, with an intensification of digital support in all stages of building design and construction.

Recent policies in Europe require significant changes to how the industry moves forward. "A Europe fit for the digital age" is one of main priorities set by the 2019-2024 Commission, together with the European Green Deal [III], the new Circular Economy Action Plan [1V] and the Industrial Strategy [V], as well as a dedicated Commission Communication expressing the importance of supporting SMEs in construction and other sectors, in order to achieve a sustainable and digital Europe [VI].

To align with these orientations, the digitalisation of construction SMEs has to accelerate, not only within the existing workforce, but also to accommodate new jobs emerging from the gaps and needs in the industry. These changes have established the critical need to improve specialised training and skills with active uptake of new technologies and digital tools. At the same time, construction workers are asked to continuously demonstrate new abilities related to digitalisation, circular economy, energy efficiency and improved occupational health and safety regulations [VII]. While some of these skills are being addressed through public policies, further work is needed to encourage upskilling, and reskilling for the entire construction sector. Additionally, the construction sector suffers from a shortage of qualified labour and a lack of interest from young people, it is essential to make the sector more attractive to young workers and women and provide appropriate awareness and training to encourage entry.

This paper will discuss skills needs and how mutually recognised micro-learnings can support the Digital Journey of the construction sector to improve the sustainable built environment, modernise the industry and encourage young workers and women into the sector.

II CURRENT UPSKILLING CHALLENGES IN THE EU CONSTRUCTION MARKET

BIMzeED (Erasmus+) project intends to improve the human-capital basis of the construction sector, which is identified as a strategic initiative by the European Commission, acting on Higher Education Institutions (HEIs) and Vocational Education and Training (VET) systems in Europe. This project supports the construction industry, through education and training using technical innovation and digitalisation. Not only is digital training an important focus for the progression of the construction sector, but providing a low carbon efficient economy requires the integration of BIM with NZEB design and development approaches.

However, the European construction sector is one of the least digitalised sectors, whose productivity rate increased by only 1% [VIII] during the last 20 years, SME growth is also constrained by the lack of skilled workers and site or project managers, as well as those with digital and smart technology skills. An overview of the digitalisation process shows that the digital technologies are not understood in the construction sector. However, the industry is facing major challenges in achieving energy efficiency targets, in particular for nearly zero energy building, but they are also experiencing a digital revolution, with Building Information Modelling, digital cloud based management tools and other digital tools such as Augmented Reality, drones, 3D printing and smart controls.

Transferring knowledge in relation to BIM is currently highly fragmented and particularly weak at manager, craft and operative levels, so solutions to improve employability and cost effectiveness for SMEs is paramount. Over the last years, a number of relevant European projects have addressed various challenges in a comprehensive way, both in developing technological solutions and BIM adoption, addressing and solving market barriers and developing strategies for involving all construction workers and users to stimulating demand and uptake training. These main challenges related to the uptake of digital training include:

1. Lack of motivation and time

Flexibility in delivery and scheduling is required using blended or online approaches. The traditional “death by PowerPoint” delivery requires alternatives such as micro-learnings using digital (field apps, BIM, AR) and practical hands-on upskilling on-line, in-house or on-site.

2. Stimulate Awareness of digital tools

Increasing the demand for a quality workforce involves digital skills training with collaboration between educational and industry organisations and promoting champion case studies. Understanding the benefits and principles of digitalisation and the benefits of hiring skilled workers/professionals (quality compliance, competency) or upskilling staff is paramount

3. Lack of skills and expertise in SMEs

This is associated with the lack of participation of SMEs in upskilling their workers/managers in energy and digital skills. Adoption of a training plan to upskill the team with in-house and online training and hire specific expertise will empower a stronger united workforce.

4. Fragmented availability of training

Preparing the foundations for a one-stop-shop training platform or mobile app are proposed in two projects DASBE [IX] and BUSLeague [X]. It is essential to make it easier for the workforce to find suitable training nationally and locally with support and direction for a training progression pathway

5. New societal and technological career opportunities

The number of young adults and women taking up employment in the construction sector is decreasing, the workforce is severely affected by labour skill shortages and there is a misalignment between VET/apprenticeship training. The motivation of young people for climate protection, digital and IT jobs are an important step towards securing the availability of skilled personnel. Therefore, it is crucial to modernise the image of the industry and build the connection between young people and environmental innovative professional roles.

6. Mutual Recognition of Skills

The successful BuildUp Skills EU Exchange [11] and EU funded projects (NewCom, BUSLeague) place importance on the need for workers to be recognised for their new acquired skills. A skills register and/or passport will stimulate the demand for skills and enable the companies to promote their competence and skillset

As the construction industry incorporates greater digital innovation and embraces modern design processes, the need for specialist workers is set to rise, but a lack of investment in new technologies, a lack of knowledge on how to undertake the digital transition, and a lack of the skills required to implement that digital transition are the main barriers facing construction sector SMEs.

With the industry now fully reopened after COVID-19, there is a fresh enthusiasm in the air to explore, and a change in attitude towards digital tools forcing companies across the industry to invest in new technologies and to employ new practices in order to meet new challenges. Like many other industries, it is almost inconceivable that construction will return to its old way of operating. Everything from business processes, design, drawing up contracts, material supplies to activity on site has been impacted. Not only will technology and BIM learning, play a crucial role for the industry in the post-pandemic recovery era, its use in tackling the ongoing sector challenges and capitalising on the emerging opportunities must also be analysed and acted upon.

To stimulate market demand, appropriate measures are required to ensure quality of training, in order to build trust in the market. The question is to what extent these learnings will be adopted in the long-term? The industry has changed significantly to embrace energy efficiency, circular economy, sustainability and digitalisation, the traditional belief that the construction industry is for the "craft orientated" is no longer accepted. The construction sector has a wider audience which includes new emerging employment opportunities and positions for technical/BIM managers, on-site digital experts, technical operators to utilise AR, drones, robotics, communication experts to ensure knowledge transfer and retain communication strategies to improve cost and time management, energy experts and waste management/lean experts and the list goes on. One of the concerns raised in the sector is the availability, at scale, of the necessary skills to accommodate these skills gaps. To satisfy these gaps, would require significant upskilling of those already working in the industry and recruiting a substantial number of young people into the industry, to ensure they have the right skills and knowledge.

Table 2: Percentage of the Construction Sector by Age

Age Group	Percentage of Sector
15-24 year olds	7.7%
25-49 year olds	60.8%
50-64 year olds	31.5%

However, current figures for employment in the construction sector in EU in 2019 demonstrate that young people are not entering the aging construction industry. Not only does IT/digitalisation and new technologies motivate young people, but climate protection jobs are an important step towards securing the availability of skilled personnel [XII]. Technological and climate solutions will only have maximum impact if the skills exist within the workforce, the investment happens along the supply chain, and procurement acts as a driver for investment. We need to stimulate ways for the young and women to enter the construction sector and digitalisation is one approach, but the existing workforce also needs clear direction in digitalising the industry.

In this context, it is evident that building information modelling (BIM) integrated with energy performance compliance (NZEB) will facilitate the improvement of energy performance in a more effective and efficient manner. Computer generated BIM models using the cloud systems enables the planning, design, construction and operational phases of a NZEB Project to be simulated, in order to reduce so called energy performance gap and to improve the quality and understanding of NZEBs.

II. NEW APPROACHES TO EDUCATION AND UPSKILLING

It is important to consider and evaluate the overall approach and perspective on learning and teaching at higher educational, vocational level and interactive online training, specifically for the construction industry. At EU level, it is still a challenge to introduce relevant standardised environmental and energy efficient learning topics into mainstream training and degree courses at HEIs & VETs (European Commission, 2013) and encourage the construction industry (especially SMEs) to take up these programmes. An important outcome from the Build Up Skills EU Exchanges states "the need to provide flexible routes for career progression". SMEs consist of 95% of the construction sector, so it is important to consider their needs. A collaborative approach in developing the training materials with SMEs and industry is needed.

Educational theories in the past have been systematic with emphasis on classroom learning, however this model has been turned upside down especially with the advent of COVID-19 and opportunities to access vast numbers of open educational resources online. The classroom is rapidly transitioning from a teaching-centred to a learning-centred environment as a result of a recognition for the positive active-learning. While definitions of active learning vary, they share two common priorities. (1) Students are doing more than just simply listening, it is important to strengthen skills-development rather than just conveying information, and students have the tendency to engage in activities (e.g. debate, discussion, polls, forums) which promote higher-order thinking (such as critical thinking, analysis etc) [XIII]. Active Learning engages students in the process of learning through activities and/or discussion in class, as opposed to passively listening to an expert or trainer (Traditional Learning). It emphasises higher-order thinking and often involves group work. Active Learning can be enabled in face to face, blended and/or online environments.

One of the approaches to freeing up class time for active-learning is the "flipped classroom". In the flipped classroom approach, the "learning unit" is moved out of the classroom in the form of an audio-video or reading e-learning resources for students to study before coming to class. The classroom time can then be effectively dedicated to carefully design hands-on activities that strengthen the concepts and provide opportunities to enhance critical thinking skills. Students have demonstrated that the teaching method flipped classroom promotes stronger student engagement, flexibility and a more active approach to learning, as it provides the opportunity to study at their own pace with accessibility to video lectures and resources [XIV].

The New Skills Agenda for Europe, Skills Guarantee recognised that the non-formal education is key to life-long learning (LLL) and the European Association for the Education of Adults (EAEA) agrees with several key points in the New Skills Agenda, such as the necessity to increase participation in lifelong learning and to ensure that everyone has the opportunity to find pathways for upskilling via a "Skills Guarantee". The necessity to have skills recognised, especially for people who have acquired these through informal ways is also becoming more important within the construction industry. Ensuring continuous skills development of the workforce is necessary to allow people to develop their career pathways and to ensure that they have the right skills for future jobs [XV]. This has recently been acknowledged in the Sustainable Development Goals (SDG) 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all [XVI].

Such development together with the life-long learning requirements have seen the approach to a new learning style. Micro-learning aims to effectively streamline the learners' fragmented time by carrying out personalized learning activities through online open educational resources (OER). The main workflow of a micro learning system can be separated into three processing stages: micro learning material generation, learning materials annotation and personalised learning materials delivery.

The reports on future skills needs at the European Vocational Skills, based on initial experiences in using micro-learnings to upskill SMEs in the construction sector is positive. Additionally, the recommendations from a high number of BuildUp Skills and other EU funded projects (QualiBuild, TrainSustain, BIMCert, BIMplement, ICARO, BIMzeED, Construction Blueprint etc.) also reported that micro learnings should be considered in order to optimise the transfer of knowledge to the overall construction workforce. The use of micro-learning units or short modules has been widely received as the future in learning in the construction industry. To encourage uptake of micro-learnings, it is also necessary to provide mutually recognised micro-credentials. This system is already available in the form of continuous professional development (CPD), however a more robust system is required to ensure sustainability and acceptable by the industry.

The benefits to the industry for a European approach to micro-credentials will:

• widen learning opportunities and further shape the lifelong learning in all education, as it can offer more flexible, learner-centred forms of education and training

• a larger take-up of micro-credentials will serve social, economic and pedagogical innovation

• scale up flexible, modular learning in a mutually comparable manner throughout Europe, whilst ensuring agreed quality standards. As a result, it will be easier for learners to get these types of course recognised.

As one of the fast-growing niches in the construction industry is in the field of energy efficiency, NZEB and digitalisation. It is evident that the skills required to implement these, might best suit a life-long-learning approach, to be integrated into progressive career pathways. This is true for those workers who have already acquired basic competences in NZEB or BIM, however, the lack of LLL courses in many EU countries represents a significant gap which needs to be addressed. It is essential to promote informal education at HEIs and VETs, as well as lifelong learning (EQF level 6 & 7) in the field of NZEBs and renovation of existing buildings to provide the necessary technical knowledge to public authorities, designers, technical supervisors, and site managers, and other experts [XV11].

There is also still a large knowledge gap around BIM processes and digital data and its importance to the future of the construction industry. Research can address potential BIM related skills shortage; support companies to put BIM processes in place, thus alleviating some of the costs linked to BIM implementation; and help shift the construction mind-set towards innovation adoption. It was shown in some countries that industry's initiatives play an important role in the BIM implementation process, providing construction companies (from project's owners to architects, engineers and constructors) with relevant support and incentives. By helping the industry build BIM capacities through courses and trainings; knowledge and experience sharing; and workshops, industry initiatives must offset some of the costs relating to BIM implementation. Education, not exclusively through HEI and academia, is a key component and actors of the BIM ecosystem. BIM education is not only a technical issue: it is not only about training workers to use BIM software, but also significantly changing the working methods and process in a company for the future.

It is important to strike a balance between theory and practice when developing training and all players need to know not only the 'how', but also the 'why' and the 'what if'. The BIMzeED project establishes this balance and utilises a number of important models by incorporating a varied use of active micro-learning and innovative approaches to enhance learning, as well as providing flexible deliveries in blended or face to face and online versions to SMEs to complete in a self-directed format.

III. IMPACT OF MICRO-LEARNING USING BIM TO ACHEIVE NZEB.

Not only is digitalisation trainings an important focus for the progression of the construction sector, but providing a low carbon efficient economy requires the integration of BIM with NZEB design and development approaches. The BIMzeED project utilises Active Learning using the flipped classroom approach enabling a highly engaged classroom to ensure collaboration of all SMEs in the learning process. The learning environment is one of interaction, collaboration and stimulation. To ensure that SMEs are motivated, easily engaged in the training course and expand their knowledge further, it is important to include a number of active learning methodologies such as individual-based, paired and group-based activities (collaborative discussions and active tasks). Additionally, active learning strategies including Problem Based Learning (PBL), case-studies and enquiry-based learning are also included. The training methodology proposes to categorise the learning content into specific micro-learning units to be presented as a number of short training modules with 8-10-hour contact and 12-20-hour self-study. Each learning unit is delivered over 4 sessions, covering a main topic in each session enabling flexibility for the students and SME workers during their working days. This enables the industry to streamline their learning strategy using a training pathway to build up their skills, which is further recognised through a collection of credits/badges. Completing the Learning Units and building up badges/credits will encourage further study and upskilling enabling SMEs (professionals and workers) to progress in their vocation and progress towards accredited trainings and courses. Furthermore, the upskilling content will be described according to a methodology which is compatible with developed qualification (compare description of competences/units of learning outcomes) and mutual recognition.

The BIMzeED project objectives is to develop and pilot 12 Learning Units with the aim to increasing the understandings and skills of Building Information Modelling (BIM) and other Digital tools to achieve NZEB. To ensure viability and relevance, a number of gaps between the skills and needs of industry and the existing availability of training were identified which informed the development of the 12 innovative and multidisciplinary Learning Units (LUs) addressing BIM, NZEB, circular economy and compliance. Further support and expertise were provided by other academics and educators, professionals, SMEs, Industry, product and technology providers, R&D and policy makers across Europe. By working with SMEs to tackle skills mismatches and promote excellence in skills development, BIMzeED is in line with "renewed EU agenda for higher education" (Education and Training 2020 strategy – ET2020) and also ensures that SMEs are not left behind in this fast developing industry as BIM and digital tools can assist with achieving cost effective NZEB construction.

It is recognised that BIM has a number of socio-technological advantages not only at the technological level, but also the process level, and can complement the way that architectural design artefacts are created, but also profoundly change the collaborative process associated with how the building is used and maintained. It is also clear that the design, installation, operational and maintenance processes with regards to NZEB needs to be a collaborative effort between all stakeholders. There is a substantial need for all relevant parties within the construction chain (clients, architects, engineers, specialist, site supervisors, sub-contractors, workers and facilities managers) as well as other stakeholders, to be specifically educated in an integrated design and build approach and trained to work in cross-disciplinary teams using BIM and other collaborative digital tools. Moreover, it is essential that educational and training institutions nurture professionals and workers with such competences. New technologies require talent with substantially different skills, with experts in BIM and skills in artificial intelligence, data analysis and programming.

A number of gaps identified in the BIMzeED Roadmap [XVIII] were prioritised and integrated into the BIMzeED learning units. The Learning Outcome indicators from the BIMzeED literature review are as follows:

- Various studies and reports have revealed an actual lack of competences (knowledge, skills, responsibility) on the sustainability concept among practitioners in the construction industry
- Lack of knowledge, trust, and communication between various industry partners in the lifecycle stages of a building are identified as a main barrier
- Lack of specialised knowledge and collaboration (communication and trust) is one of the reasons for the under-performance of NZEB and sustainable building.
- Optimisation of building energy use requires an integrated design approach and cross-disciplinary teamwork, which leads to high quality indoor environments and satisfaction of the occupants' needs
- Better management of the information during the whole life cycle of the NZEB is necessary to avoid mistakes and establish trustworthy information at any time or when an intervention is necessary.
- Integrated design courses (especially those which include specific skills to manage NZEB challenges in cross-disciplinary teams) are scarce throughout EU educational institutions, and there are many experts having little or no knowledge on integrated design.
- BIM offers a foundation for comprehensive facilities management, especially in light of the trend toward "smart" buildings. Using detailed BIM models, owners can connect the building information with data from sensors and monitor its operations, thus optimising operations while meeting occupants' needs.
- In many EU countries, and among many stakeholders there is still a large knowledge gap around BIM processes and data and its importance to the future of the construction industry. This gap is not just isolated to certain areas of the industry; it pervades to the entire construction value chain.
  - Interoperability, is one of the most critical issues for advanced BIM users and needs to be addressed. Lack of automated processes (interoperability) for BIM (Building Information Modelling) to BEM (Building Energy Modelling) is one of the major gaps where technology needs to advance in the future.

The BIMzeED learning units were designed with the purpose to ensure a balance between theory and practice. In short, the construction industry needs to know not only the 'how', but also the 'why' and the 'what if'. Whilst the incorporation of practical training is important, it must not be introduced to the detriment of a poor theoretical basis. Trainers can implement a practical solution where possible, demonstrating the importance of doing, using full scale demo models and practical models, real equipment and practical walls, or visits to construction sites where NZEBs are under construction, are the most useful way of learning. This active learning method of doing can also be used in the online capacity, especially with the demonstration and practical sessions for BIM and other digital tools.

BIMzeED structured the training material and content using common learning units (LUs) with flexible standardised delivery (in class, on-line and on-site) suitable for HEI, VET and SME training. The initial training content includes NZEB related subjects with BIM maturity. The training content covers and delivered in a Blended Learning format supported by an e-Learning portal.

The following 12 mutually recognised BIMzeED Learning Units[19] are designed for relevant target groups with 2 LUs common units open for everyone.

LU1: Collaborative BIM to achieve NZEB (EQF 4-7) *COMMON UNIT*
Give all necessary tools and knowledge to all team members for BIM workflow generation and application and NZEB understanding.

LU2: BIM and nZEB for Workers EQF (4-5)
Inform workers on the BIM methodology used during NZEB project construction, and awareness to prevent and anticipate solutions.

LU3: NZEB Realization and Commissioning: Building Envelope and Air Tightness (EQF 6)
Understand the parameters affecting building envelope and air tightness, quality controls and create BIM objects suitable for nZEB design and the correct use within the BIM model.

LU4: NZEB Realization and Commissioning: Building Services & Smart Technologies (EQF 6)
Understand the parameters affecting building services and smart technologies, quality controls and create BIM objects suitable for nZEB design and the correct use within the BIM model.

LU5: NZEB Realization and Commissioning: Quality Assurance (EQF 4-7) *COMMON UNIT*
Focuses on quality assurance of the elements for nZEB qualification of the building, using BIM methodology and other digital tools as

communication tools.

LU6: BIM Model Uses during Construction (EQF 6)
Use of BIM models to provide optimization during construction and a digital twin design by anticipating and solving problems.

LU7: BIM Model Uses for specification and quantification (EQF 6)
Exploit model data through cost extraction, site planning and material listing, acquiring knowledge in the design of a construction model considering time (4D), cost (5D) and environmental aspects (6D).

LU8: BIM Model Standardization for nZEB Design (EQF 6)
Standardizing and validating the structure of the BIM model to achieve an nZEB design and optimize the workflow.

LU9: Building Energy Modelling (BEM) Design and Export (EQF 7)
Develop a BEM and understand how it affects the design of nZEB buildings and future needs.

LU10: Energy Simulation with BIM Tools (EQF 7)
Analysis and interpretation of a Building Energy Model (BEM) to guarantee economic viability and nZEB requirements.

LU11: Nearly Zero Energy Building Facilities Management (EQF 5-6)
Maintain efficiency during facility management by preventing and anticipating future problems and guarantee nZEB qualification during its use.

LU12: BIM in Facility Management Software (CMMS) (EQF 6-7)
Create a BIM model for facility management systems focussing using CMMS software and standards like COBie.

The BIMzeED project aims to train and upskill 120 educators at European HEIs and VETs by piloting the new learning resources and training materials, which will be made available as transferrable Learning Units. Additionally, 500 students from higher and vocational education levels, SME and individuals from the construction industry will also be trained in an online or blended delivery format. The mutually recognised LUs delivered as blended, in-class/on-site or on-line training, are designed to be flexible as stand-alone units, combined as a group of LUs or integrated into existing curricula.

The stand-alone learning units enable SMEs to choose a short online training programme, where a qualified BIMzeED trainer directs and facilitates discussion between groups of industry members from a mix of backgrounds. It is important to enable group discussions which supports the method of active learning, strengthening the understanding of SMEs through role play, case studies and industry experiences. The flipped classroom practice also enables the SME participant to review the content in advance and most importantly review in their own time to prepare for the online class, so discussions and demonstrations can be maximised and thus reducing PowerPoint feeds.

The approved stand-alone LUs will become available as self-directed training enabling the industry to pick and choose which LUs they wish to complete and build up badges demonstrating their skills to improving their employability and support a profitable and low carbon future.

Grouping learning units allows the vocational and higher educational bodies to establish a new course for the SMEs and students. In the case of learning units 1, 2 and 5, it was anticipated that these skills were particularly required at vocational level and permits a VET programme to be established at EQF level 4-5. Additionally, at higher education levels, all the LUs can be grouped together in a systematic approach to create a new accredited programme relevant to the skills needs of the industry. Alternatively the LUs can be integrated into existing accredited programmes to support and enable updating and improving the existing curricula. It has been recognised that many of the courses available at higher and vocational levels have not been modernised or updated in the last few years mainly due to burden of work of the educators and trainers, but also due to the restrictions and delays of the legal and administrative accreditation process.

Initial results from All the LUs are tested within the industry and at higher or vocational organisations to determine quality and relevance. The final results will consider the type of delivery, content of the LUs, accessibility, flexibility, quality and relevance.

IV. CONCLUSIONS

New employment profiles and sought-after skills could encourage more women and young people (new talents) to join the industry and to close the talent gap. In some countries (i.e. Ireland) new occupations are emerging within the NZEB areas. BIMzeED analysed the current situation in the Construction industry in several EU countries and reviewed a number of EU projects and provides in part a solution for the training and upskilling challenges in the field of NZEB and BIM. The analysis of current formal and informal educational programs in the construction industry revealed that topics related to the NZEB and BIM are not adequately covered, or not covered at all, resulting with a lack of qualified workers and professionals. A number of gaps have been quantified in BIMzeED and it is equally important to predict the future roles for the construction industry to determine the skills needs. The gaps and needs identified have been set out in 12 Learning Units as groups of competences required by the construction industry to understand and implement skills in the field of NZEBs and BIM. Competences have been prepared in a generic mode and also as specific actions within the Learning Unit. These Learning Units focus on the importance of drawing cogent conclusions on the type, level and mode of training relevant to SME employees working in an active construction industry.

Training the workers and staff in SMEs will improve their competitiveness by ensuring SMEs can keep pace with this fast developing industry and integrating the LUs into existing curricula will ensure that the training available at higher and vocational levels meet the demands of the industry. The LUs, as they are designed to be accessible, will enable SMEs in particular within the construction sector to begin the digitisation and transformation journey within their organisations.

It was always expected to provide flexible micro-learning with a variety of delivery methods and mode of training for SMEs to enable faster progression and also enable a flexible training pathway for the construction workers by building up credits in the form of mutually recognised badges

The expected benefits of digitalisation Skills for construction SMEs are diverse – including e.g.: increased efficiency and competitiveness; improved collaborative work across the construction value chain and during different stages of the construction lifecycle; better control and management of material resources, waste reduction and improved energy and environmental performance; resilient and greener buildings and infrastructures, etc.).

V. ACKNOWLEDGMENTS

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CitA BIM Gathering **Proceedings**

Smarter Cities, Smart Building and Data

BIM-based parametric adaptive design of kinetic shell facades in buildings

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Abstract - Design processes need to consider building adaptation to the changing conditions of usage, environmental changes, and the changes in users behaviour. Technological advancements have allowed to develop and access distinct approaches in design, where interactive physical mechanisms can be built that respond to their environmental and surrounding conditions. This paper investigates the relationship between the technological advancement in kinetic shell structures over time, examines different kinds of adaptive kinetic shells, highlights the importance and advantages of these structures, and proposes a BIM-based parametric adaptive design for multi-functional kinetic shell facades. The paper proposes a parametric workflow to test adaptive kinetic façades for curvilinear buildings to enhance the sustainable performance of buildings by reducing solar radiation intake based on the location of the building and the time of the day. This workflow utilises energy simulation of an architectural structure using kinetic façade system to optimise the best solution of daylighting adequacy and thermal performance. The workflow was validated by conducting a case study. The study concluded that the developed parametric workflow can enhance the efficiency of architectural buildings on multiple sustainable and financial aspects. The study also approved the advantages of adaptive kinetic shell structure in multiple locations and under different environmental conditions.

Keywords - *BIM, adaptive design, kinetic shell facades*

I INTRODUCTION

Adaptive architecture involves a range of design fields from designs for media facades to eco buildings, dorm responsive art installations to stage design and from artificial intelligence to ubiquitous computing [1]. When applying adaptive architecture, the design structure, behaviour or resources can be changed according to a programmatic demand by the designer. Few existing buildings around the world (e.g. bionic tower, Dubai city tower, Illinois tower, etc.) have the ability to dynamically move as a whole structure or partially rotate. In this regard, Kinetic architecture is a design approach in contemporary architecture which explores the physical transformation of a building with the objective to redefine traditional applications of motion through technological innovation. The use of robotics, mechanics and electronics is essential to this new approach. The concept of "*Kinetic Architecture*" has changed architectural design to be more transformable, dynamic, and interactive to achieve many design objectives including environmental goals, social interaction, and sense of place [2]. This paper will focus on the adaptive design in the kinetic (dynamic) shell façade systems.

Building façades are considered to be the most important protection structure from the external environment; such as sun glare and direct heat gain. The advancement of Building façade systems helps in changing the traditional static design of façades as a cover only to play a more active role; such as integrating photovoltaic cells to help generate energy than just save energy [3]. An efficient building envelope enhances daylight uniformity and improves energy performance of the building. However, designing facades is a challenging task for architects when considering multiple objectives; e.g. to reduce energy consumption and improve the occupant's health [4].

This paper introduces a BIM-based parametric workflow to design an adaptive kinetic façade suitable for curvilinear buildings. The methodology considers various building and environmental factors to design kinetic shells that enhance the sustainable performance of buildings by reducing solar radiation intake based on the location of the building and the time of the day. The objectives of the study covers: 1) evaluating different adaptive kinetic shell structures over time; 2) testing the adaptive kinetic shell structures on multiple environmental and financial aspects; 3) Parametric modelling of the kinetic façade system by optimizing the best solution for daylighting adequacy and thermal performance. The methodology uses the visual programming language (Rhino-Grasshopper).

II Background

Living systems usually exhibit adaptive behaviour to react to their environments that change or are changed by the system's behaviour in order to maintain the continued system operation. A self-recognizing system maintains its existence through restoring a favourable balance, or homeostasis, between internal and external conditions. This point of equilibrium is cyclic and will change as the organization of the system evolves ever further from an original condition [5].

The invention of the wheel is considered the starting point in the world of kinetic architecture; movable stones, hinges, and hut openings are some basic traces of the adaptation of mobility in architecture. There is evidence that movable bridges were used in Egypt in the fourteenth century as well as in Babylon [6]. Later in the Middle Ages, kinetic architecture was used for both security and weather protection in addition to enhancing the physical appearance of structures; for example: the removable rope and canvas rood over the Roman Colosseum, and the drawbridges.

A great change to the means of the rotating kinetic architecture was in 1935, when Villa Girasole in Italy was constructed to trace the movement of the sun by rotating on hinges. Then in the 1950s, when the energy conservation movement started, Francois Massau built a rotating house to face sunlight anytime of the day. In the 1960s many places around the world started designing revolving restaurants at the top of towers to rest atop a broad circular revolving platform that operates as a large turntable. The Space Needle in Seattle was one of the first in the world in 1962, along with The Cairo Tower in Cairo.

With the CAD technological advancement in the seventies, kinetic architecture has been classified into two categories: pragmatic and humanistic. Pragmatic applications concern with solving problems, optimizing solutions, and implying space efficiency, shelter, security, transportation, safety, and economics. On the other hand, humanistic are concerned with the physical and psychological effect of the architectural environments' changes upon their users [7]. An application of Kinetic architecture can address both pragmatic and/or humanistic conditions.

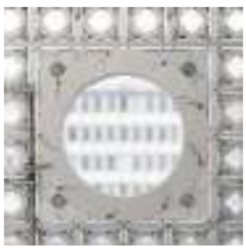
Few existing modern buildings have been investigated to analyse the impact of using these systems on building performance. This analysis will be taken in this study as guidelines for the proposed design workflow. Table 1 provides a summary on five buildings in different locations which installed different kinetic façade systems. Kinetic façade systems prove to be effective in designing a building envelop, by reducing energy consumption, making the kinetic façade an optimal method to address harsh climates, particularly in the case of sun protection, and to provide convenient natural lighting and fresh air. In addition, the kinetic façade system could be used for energy saving as it can hold photovoltaic cells embedded in the structure to generate electrical power needed for the building.

As an example of these systems, Fig. 1 shows the kinetic façade system used in the building of Arab World Institute constructed in 1987 in Paris, France [8].

Table 1: Buildings with Kinetic façade systems

Building Name	**Location**	**Year built**	**Purpose of façade**
Arab Institute	Paris, France	1987	NLC**
Nordic Embassies	Berlin, Germany	1999	NLC
Al Bahar Towers	Abu-Dhabi, U.A.E.	2012	SRP**
Dubai Apple Store	Dubai, U.A.E.	2017	SRP, NLC
Council House 2	Melbourne, Australia	2006	SRP, NLC

**Natural Light Control (NLC), Solar Radiation Protection (SRP)



A: Circular Shaped

B: Square Shaped

C: 8-Points Star Shaped Diaphragm

Fig. 1: Kinetic façade system on Mashrabiya diaphragms [8] Courtesy of: https://www.imarabe.org/en/architecture

This kinetic system has used Mashrabiya diaphragms that are controlled though pre-programmed settings to control daylight transmission. These diaphragms allow light to penetrate partially into the building and have a series of photoelectric cells, just like the diaphragm of a camera that could open and close. The South façade presents patterns of arab geometrical shapes in 240 mashrabiya diaphragms. The mechanism is set to perform a maximum of 18 movements a day.

The construction of the Nordic Embassies was completed in Berlin. The complex façade system in these buildings has a 226 m long stainless-steel and copper band consisting of 3,926 dynamic louvres that open and close to bring natural light to the interior rooms and courtyards [9].

The Council House 2 (CH2) in Australia kinetic façade system is covered with a system of timber louvers made from untreated recycled timber and are moved by a computer controlled hydraulic system that pivot to optimize the penetration of natural light and views. The louvres open and close depending on the amount of sunlight hitting the western façade [10].

With a total height of 145.1m, Al Bahar Towers has one of the largest computerized kinetic façade structures in the world and is considered a benchmark in the built environment in one of the hottest dry climate locations, AbuDhabi - UAE. The façade has 2,098 dynamic sun shading units and each unit has a linear actuator to dramatically protect the building from excessive exposure to solar rays. BIM parametric algorithmic modelling has played a crucial role in designing the building façade to optimise the deflection limits of glass panels [11].

The design of the Apple store in Dubai Mall adopts the traditional Arabic Mashrabiya with 'Solar Wings' gently shade the outside terrace during the day and open majestically during the evening. The façade is made entirely of lightweight carbon fibre. Each wing has multiple layers of tubes forming a dense net. Following an in-depth study of sun angles, the rods have been distributed in higher concentration where the solar radiation is most intense over the year [12].

III Methodology

From the studied façade systems, a design workflow to enhance energy simulation of buildings with kinetic façade systems is proposed. The workflow utilises BIM parametric design principles that provide the possibility of modifying parameters without the need to create full models. It aims to optimise the best solution to balance between daylighting adequacy and thermal performance. The adopted parametric algorithms will allow customization of components in the kinetic façade system in order to produce the best anticipated energy simulation while providing the needed amount of daylight to the building.

The typical techniques for buildings design used to be algebraic, symbolic, and often vector-based. An important turning point was the foundation of Computer-Aided Design (CAD) systems by IBM in 1974 (IBM TRIRIGA CAD Integrator/Publisher) which provided bidirectional tools that integrate computer-aided design application with the IBM environment and enhanced the standard CAD functions. CAD implementation has replaced traditional drafting and design methods and allowed industries to plan, simulate and produce their new ideas in a single platform which became able to produce full solid 3D models in the 1980s [13].

Algorithmic Design (AD) was then defined as a programming-based approach to design, which uses algorithmic processes to generate highly complex geometrical shapes which allows architects to efficiently comprehend and analyse complex geometries using algorithmic processes as flexible series of commands and logical procedures [14, 15].

In addition, because AD is typically parameterized, a wide range of different solutions can be quickly generated and tested by providing different values to the parameters, thus supporting exploration and optimization in the design process [16]. This establishes the generative evolutionary paradigm that can replace the potentials of trial and error associated with the traditional design approaches.

The adopted design workflow, as shown in Fig. 2, has three connected phases; Architectural, Solar, and Structural. Its multiple input data include: Plans outline, Number of floors, EnergyPlus Weather data (EPW) file, Dimensions of the structural elements, and Materials used. The design settings automatically detect the location of the building based on the data from the EPW file. It will also have an automatic optimization for the dimensions and materials used in the structural analysis phase; while it can all be changed by the designer before making the final decisions.

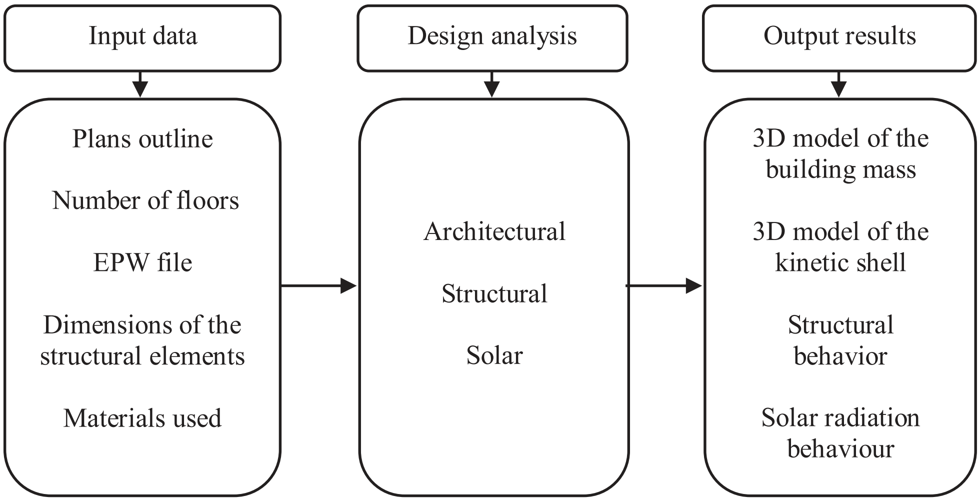


Fig. 2: BIM-based parametric adaptive design workflow

At this stage of the study, the AD for this study is only developed to design the façade for rectilinear-curvilinear buildings with 3-4 sides and clear boundaries, while it would not give the expected result for more complex shaped buildings.

Fig. 3 represents the algorithmic kinetic façade design process based on the adopted multidisciplinary workflow that considers the Architectural, Structural, and Solar analysis. The process provides an opportunity for changing the design approach from static to dynamic. The kinetic façade is topologically transformed to determine the indoor comfort which is evaluated thermally and visually considering the performance of the transformable façade parameters. If the target comfort criteria are met by certain settings of the kinetic façade, an optimal design form is reached. Otherwise, other generative design parameters will be applied for developing a new façade typology. The iterative design process will run until the customised parameters achieve the design objective functions.

In this study, Grasshopper, a visual programming editor, is integrated with the robust and versatile Rhino 3D modelling environment. This integrated environment enables the use of sets of generative algorithms by the designer to create 3D geometry and multiple functional analysis, while the advanced uses could include structural engineering analysis, lighting performance analysis, energy consumption analysis, wind simulations, and other architectural related analysis. The final outcome of the design will have a set of information that could be exported into many other formats after being transferred into the Rhino software.

a) Architectural analysis

The architectural plans are imported and the offset distance of the façade can be determined. The kinetic shell façade will be designed in two models: square cells and vertical panels. The solar analysis will be conducted for both models in the case studies.

Each surface of the building will be divided into square cells. Each square was dealt with as a unit, as shown in Fig. 4. Each square will have four corners (1, 2, 3, and 4) with midpoints on the edges: a, b, c and d accordingly. The centre of the square cell 'm' is pushed outward based on the normal vector of the single cell by an amount 'x' that is calculated using the angle calculation process based on the sun angle at the certain time. By fixing the square corners, the midpoints will move automatically to create a new shape.

This movement of point 'm' is created by a DC controller fixed to it and connected to a central control system in the building that controls all movements. The technical details of these DC controllers are beyond the scope of this paper. Fig. 5 (a and b) shows the simulation of creating the parametric building façade by merging all cells with the structural pipes around them that enables the export of a 3D model and conduct the solar and the structural analysis.

Creating the vertical panels is similar to creating the cells but differs in the movement mechanism where the panels are divided based on the height of each floor and they rotate based on the angle of the sun to open and close accordingly.

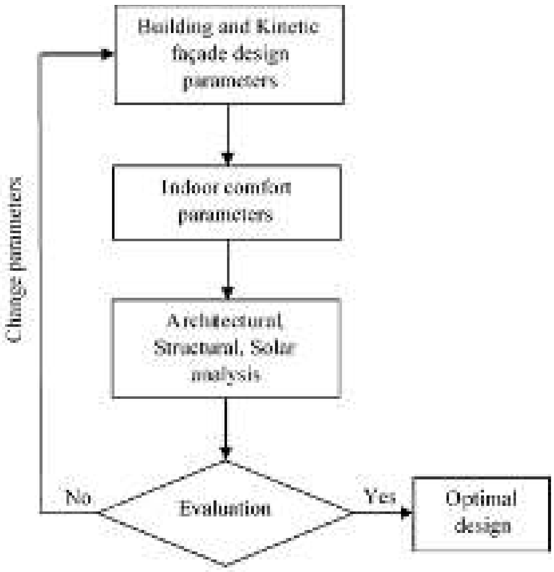


Fig. 3: Algorithmic kinetic façade design process

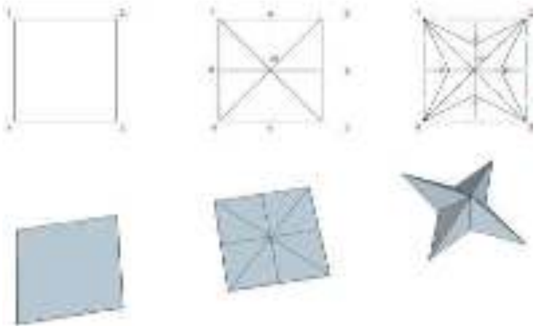


Fig. 4: Cells Mechanism

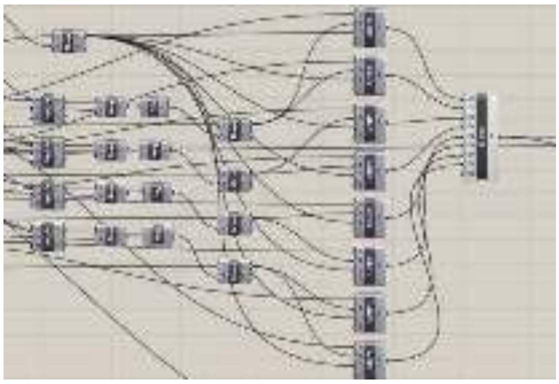


Fig. 5-a: Simulation of cells of the kinetic shell façade (Grasshopper file)

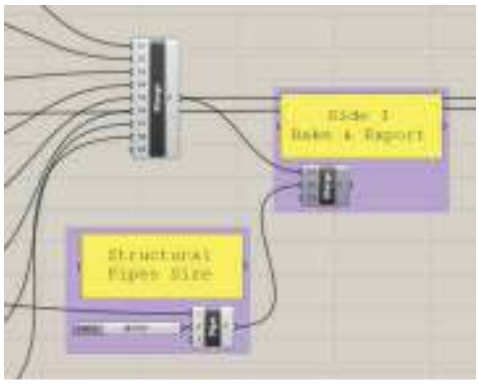


Figure 5-b: Simulation of full architecture of the kinetic shell façade (Grasshopper file)

b) Solar analysis

The solar analysis uses the architectural data to produce 3D models with building performance analysis. The imported EPW file (for this study, the solar analysis plugin (ladybug) has been used [17]) contains weather and solar information about the building site. The analysis period of time should be defined to generate the selected sky matrix which calculates the solar radiation based on the angle of the sun at that time. The sun vector taken from the EPW file at the studied time is analysed and transformed using a basic formula to represent the movement of the kinetic shell cells around the building, so they would open and allow sunlight at a certain angle and they would close to minimize the solar radiation. This analysis helps calculate the difference in angle between each cell and the sun vector at the studied time, yet the user is able to change this ratio. Fig. 6 shows the simulation of the solar analysis in the workflow.

c) Structural analysis

In this analysis, structural edge, supporting structural braces and structural poles will be fixed to the slabs of the building in order to support the façade. The placement of these poles will be optimised according to the structural stability of the façade.

The structural analysis of the kinetic shell façade could be conducted for each side alone or could be conducted for the whole structure with the enforcement poles.

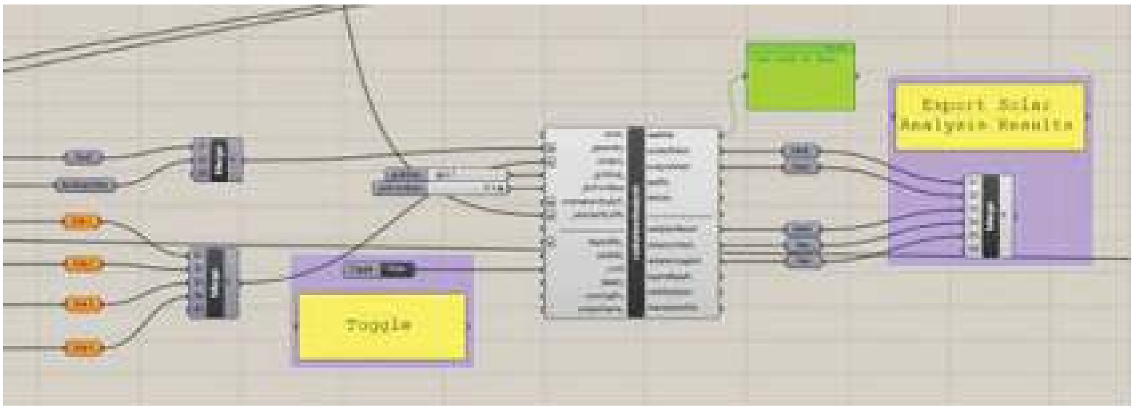


Fig. 6: Simulation of Solar Analysis (Grasshopper file)

IV CASE STUDIES

Two buildings are considered as case studies in different locations around the world to ensure the effectiveness of the developed workflow model at different climate conditions. Both buildings will be redesigned as a mass only, and the radiation analysis will be conducted for three settings for each building: the building as is, the building with the kinetic square cells (option1), and the building with vertical panels (option2). The analysis is set at different times between 10:00am to 13:00pm on the 31st of December and the 21st of June.

a) Case Study 1: CUBE building

Cube is an educational building in Tilburg, Netherlands. The floor plan in Fig. 7 has an area of 11000.0 m^2 and was constructed in 2018 as a part of the Tilburg University Campus. The building is symmetrical with no closed-off facades consisting of 2 floors, while the panels on the east and west side are also used as a shading device.

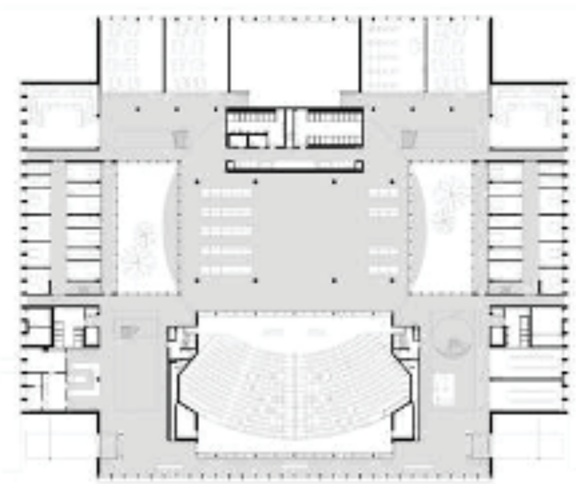


Fig. 7: Cube, Tilburg, Netherlands, Floor Plan.
Courtesy of http://kaanarchitecten.com

b) Case Study 2: The Vaughan Civic Centre Resource Library

The Vaughan Civic Centre Resource Library is public library in suburban Toronto, Canada. It has an area of 3306.0 m^2 and was constructed in 2016. The glass and aluminum clad structure sits along a pedestrian promenade that leads to the city hall, forming a staggered and slanted pattern on the exterior. The building's appearance changes during the day due to its sculptural shape and façade treatment. The building has a challenging design with a functional structure considering curves on all axis, as shown in Fig. 8. The northern side of the building is taken as one curve, since the program is set to design structures for 3-4 sided curvilinear buildings.

Fig. 8: Vaughan Civic Centre and Public Resource Library, Vaughan, ON, Canada.
Courtesy of http://zasa.com

V Results

Option 1 analysis uses a kinetic façade designed as square cells as shown in Fig. 9-a that would open and close based on the angle of the sun vector at specific times. Each cell is estimated around 1mx1m in dimensions.

The eight surfaces inside the cell would move a maximum of 0.4m on the inner direction, while the centre point would move the exact same in the outer direction based on the normal vector on the cell itself. The movements of the kinetic shell are responsive to the sun vector at every analysis time.

Option 2 analysis uses a kinetic façade designed as vertical panels as shown in Fig. 9-b that would rotate to open and close based on the angle of the sun vector at specific times. Each panel is estimated around 1m width, and the height is based on the building's floor height. The number of panels vertically is the number of floors and each floor has its set of panels with structural elements. The solar radiation analysis is conducted to the mass building and the movement of the panels are responsive to the sun vector at every analysis study time.

Table 2 shows the analysis results of the amount of radiation in kWh/m2 falling on the mass model. This is computed through a mass addition of results at each of the test points multiplied by the area of the face that the test point is representing.

When comparing the results for both case study buildings, it shows that option 2 provides the minimum solar radiation while keeping a good natural light ratio.

The solar analysis result shows how the proposed workflow for the kinetic shell could provide sustainable design for buildings. In addition, the choice of façade systems used for the design is relatively flexible and could use solar panels for the vertical panels that can follow the sun direction based on the sun vector.

Fig. 9-a: Option 1, Cells Render

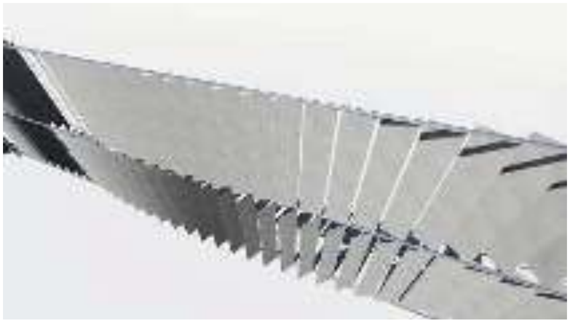


Fig. 9-b: Option 2, Vertical Panels Render

Table 2: Simulation results (Amount of radiation)

Building Model	Date	Time	Amount of radiation (kWh/m^2)	Time	Amount of radiation (kWh/m^2)
		CUBE building		Vaughan Civic Centre	
Original Mass Option	31st Dec.	10:00-11:00	46.266344	08:00-09:00	123.280769
		11:00-12:00	46.4565	11:00-12:00	98.978298
		12:00-13:00	191.440829	14:00-15:00	80.27975
	21st June	10:00-11:00	277.007711	08:00-09:00	389.43389
		11:00-12:00	299.808008	11:00-12:00	287.712422
		12:00-13:00	307.093605	14:00-15:00	271.900825
Option 1	31st Dec.	10:00-11:00	35.878934	08:00-09:00	36.701323
		11:00-12:00	57.429033	11:00-12:00	47.130328
		12:00-13:00	112.646116	14:00-15:00	39.128479
	21st June	10:00-11:00	219.433151	08:00-09:00	222.656853
		11:00-12:00	236.437601	11:00-12:00	157.438307
		12:00-13:00	241.654189	14:00-15:00	158.284735
Option 2	31st Dec.	10:00-11:00	31.509894	08:00-09:00	25.243718
		11:00-12:00	50.503567	11:00-12:00	41.921875
		12:00-13:00	99.228155	14:00-15:00	29.989777
	21st June	10:00-11:00	197.213665	08:00-09:00	149.671351
		11:00-12:00	210.014963	11:00-12:00	144.079064
		12:00-13:00	212.283023	14:00-15:00	137.323117

VI Conclusions

This study investigated literature and existing buildings designed with kinetic shell facades. From this investigation, certain sustainability factors were defined to analyse buildings' façade and were considered for developing a BIM parametric design workflow of kinetic shell facades. Visual programming language was used for developing this workflow. The workflow model is designed through developing a series of complex functional commands based on how the kinetic facades could work on any 4-sided curvilinear structures by importing the outline of building plans.

The workflow model has been applied on two case study buildings with curvilinear façades on four sides. The model helped in the analysis of the façade performance to reduce the solar radiation on different times during the day. Further development can improve the model functions by providing more flexible design for any building shape or choice of materials and structure.

The main outcome of the study proved the advantages of using adaptive kinetic shell structure in multiple locations and under different environmental circumstances. In addition, the developed parametric workflow can be used to design efficient architectural buildings on multiple sustainable and financial aspects.

Traditional early design stages could be changed due to the emergence of adaptive design workflows which are required to interpret and analyse conceptual designs from a building performance perspective. Incorporating visual scripting tools and algorithms enables data communication among various design tools quickly and effectively.

By leveraging this design approach, it becomes possible for designers to generate more effective solutions. This could be achieved by defining parametric values and utilising adaptive design tools to analyse and iterate optimal design solutions.

Designers are still required to evaluate design outcomes and modify the design parameters to refine the adaptive design process. Further development of this approach can utilise Artificial Intelligent techniques to analyse/refine more optimum design solutions by generating more parametric values for the design options.

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CitA BIM Gathering **Proceedings**

New and Emerging Technologies

Drones in Construction

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Abstract - Drones are rapidly becoming widely adopted within the construction industry with a 58% annual growth rate in use. Benefits arise due to the unique perspective achieved through the data captured. These include improved documentation, operations, and productivity gains. Drone technology can be implemented to monitor progress, aid in health and safety inspections and assist quality assurance through specialist thermal imaging cameras. Construction companies can benefit from Photogrammetry outputs such as orthomosaic drawings, topography surveys, and 3D model generation. A case study in the development of a drone programme by a building contractor found that developing an in-house team allowed more scalability and flexibility to carry out drone flights to meet the needs of specific projects. A qualitative review found that there are time savings achieved on a project through drone data captured, however this is difficult to accurately quantify. Photogrammetry can increase the benefit of drone outputs in construction, for instance through volume calculations, validation of work to date, and communication to the project team through image annotation. Drone data is a tool that can be used to aid in the management of a construction project but does not replace the need for human interpretation. Looking to the future, drones can become more integral to the construction project through hardware development by adding attachments to the drone for specific tasks such an exoskeleton for internal building inspections or stakes for setting out coordinates. Software development will play a major role in construction drone use with the implementation of 5G to autonomise and speed up the drone data transfer and enable integration with other platforms.

Keywords – BIM, Case study. Construction, Drones, Integration.

INTRODUCTION

Drones are moving from niche to mainstream practice within the construction industry, as reliability of use increases along with quality and decrease in cost of adoption. A drone is an Unmanned Aerial Vehicle (UAV) which can be controlled remotely or autonomously through a variety of sensors and an onboard Global navigation satellite system (GNSS). In 2018, 32% of construction companies used drones on site. This represents a growing trend - a 58% annual increase in drone use was recorded by the NBS from 2017 to 2018 [1]. The growth of the drone industry is set to continue; it is projected that by 2030 there could be over 76,000 drones in general use with over 4,800 used in construction [2]. This rise in popularity can be attributed to several factors – according to a 2021 survey, 86% of construction firms found using drones helped them improve documentation, 56% cited improved operations and 47% cited increased productivity [3]. There is a wide array of options in terms of manufacturers and specifications for commercially available drones, which fit most needs and budgets. The reliability of drones has also increased, and most commercial drones now come with obstacle avoidance as standard, which reduces the chance of damaging the drone, property, and people around it, making it safer to operate on a busy construction site. Image quality has increased through higher resolution cameras and gimbals (to which the cameras are attached to reduce camera vibration) resulting in better image quality. Finally, as competitors are offering drone capability to construction clients, organisations are under pressure to compete and include the use of drones in the services that they can provide.

Any company undertaking a drone programme must consider several key factors. Of most importance are the regulations for commercial UAV flights within the country the business operates. Other factors to consider include the type, size and scale of the projects to be undertaken, and the range of data that is required against the specifications and cost of the drone. The camera is the main output component of a drone; therefore, companies must consider the required attributes in terms of quality, range of motion and capabilities, such as video or thermal imaging that are required from the drone's camera. Some premium drones offer interchangeable cameras for different uses. A prospective drone programme should also ensure that the drone manufacturer's guidelines, such as operational temperatures, maximum wind conditions as well as take-off and landing zones, can be met, as different drones may require certain weather conditions for optimal flight affecting the number of days it can operate.

Finally, in this market many specialist third party companies can provide all the drone services necessary to operate and deliver the data required, mitigating the need to undergo the research, training and costs associated with developing an in-house program. This is a viable option for many construction companies as they get the benefits that drone data provides without the upfront costs and investment of setting up in-house capability.

TYPES OF DRONES

Fixed wing and multi-rotor wing drones are the two main types of drones used in construction. Fixed wing drones have a rigid body and rely on thrust from a propeller to move forward while the wings provide the lift to remain at a constant altitude, therefore they cannot remain stationary once in the air. Benefits of the fixed wing system include greater stability in higher wind conditions through better aerodynamics. Also, due to the energy efficiency provided by the fixed wing design they can travel longer distances, with some commercially available fixed wing drones covering 5km2 over a 90-minute flight time on one battery [4]. Fixed wing drones require pre-programmed flights which are then completed autonomously with no manual interaction required, the onboard camera remains at a fixed position and cannot be adjusted, therefore extra consideration needs to be given to pre-flight planning. These drones are primarily used for large scale projects, such as corridor mapping for road construction.

Multi-rotor drones are made up of a body and several rotors that use the rotation of each propeller to provide lift to the drone. The most commonly manufactured type of a multi-rotor drone is a quadcopter (4 propellers) while some multi-rotor drones have up to 6 or 8 propellers that can accommodate higher payloads such as high-quality camera rigs or compact LiDAR scanners. Due to the energy output required to provide lift on a multi-rotor drone, a higher capacity battery is required to power each rotor which increases the weight and decreases the duration of a flight - most quadcopters manage a 25-35-minute flight time [5]. Many drones are now fitted with obstacle avoidance systems in multiple directions to prevent crashing in both autonomous and manual flight modes. Software applications are available for multi rotor drones to achieve fully programmable and repeatable flight paths for site surveys and inspection, similar to those for the fixed wing operations.

APPLICATIONS OF DRONES IN CONSTRUCTION

Fundamentally drones provide a unique perspective in data capture for the progress of a construction project. They provide a point of view which is not possible or practical with other image and data capture techniques.

a) Progress Monitoring

Drone imagery provides the wider project team with information on the activities completed to date on site. Publishing this information can save the wider team time travelling to site, enabling them to add annotations and come to an understanding of any issues or add commentary on site progress. These annotations can enable better communication between parties seeking approval for permits, method statements or other processes decreasing the time taken for approvals and down-time for activities on site. The image and video produced by a drone serves as a record of any activities undertaken to date of a construction project. Furthermore, aerial imagery can aid in programme management, identifying areas in which activities can start ahead of schedule and increase project programming efficiencies. Drone imagery can also contribute towards better logistics planning for set-down areas, storage compounds, vehicle routes or crane positioning. Through the use of CAD software, the images can then be overlaid onto construction drawings to provide scale to the images and understanding of the site context. This in turn allows for accurate measurements of areas of vehicle access, crane jib extents, and further detail to the coordination of trades.

b) Health, Safety & Security

Drones can also be implemented for health and safety monitoring on sites. Their use removes people from any hazardous areas where land-based inspections might result in injury, such as slips or trips which represent 47% of fatal accidents in 2019-20 in construction in the UK [6]. Other hazardous situations where drones provide benefit include surveying of structurally defective structures, in proximity to chemicals or similar materials, difficult to access areas, areas where heavy machinery is operational, or uneven surfaces. Drones can aid health and safety inspections and provide records for areas of work which may not be easily investigated through land-based site inspections. In addition, regular drone inspections on site can act as a deterrent for cutting corners, as site activity is documented in the drone imagery - which can cover the entire site in a short period of time. However, drones may cause their own risks through malfunctioning equipment, collisions or low altitude flying which in congested construction sites with plant and equipment may present its own challenges; however, these risks can be reduced through pre-flight check lists and risk assessments.

Drones provide a quick and efficient way to survey and inspect large areas in a short time to check there are no unauthorised personnel within the site boundary. It also provides a quick examination of the condition of site hoarding to identify any weak points which may allow trespassers, avoiding injury and protecting the high-value equipment and plant from theft. Frequent flights may act as a deterrent to individuals considering trespassing onto a construction site.

c) Quality Control

There are a variety of multi-rotor drones with interchangeable cameras, which permit the integration of thermal imaging for inspection. Some other models come with thermal imaging specifically in mind, such as the Autel Evo 2 Dual, Parrot Anafi USA and the DJI Mavic 2 Enterprise Dual. Their standard and thermal imaging integrated cameras are designed to identify differences in temperature. This can be utilised within the construction sector to identify leaks in the building envelope, heat loss, defective material, and along with the compact size are easy to transport to a multitude of sites quickly and easily. The use of thermal imagery provides instant validation and data on the built structure, therefore any defects can be corrected in a timely manner, potentially keeping the project on programme, and avoiding extensive rework or damage to other aspects of the works on site. Such examples include water ingress to building roofs which may damage partition walls, causing rework and delays to project completion.

d) Photogrammetry

Photogrammetry can be integrated with the use of drone imagery to provide valuable data to contractors on site. Photogrammetry is a process in which 2 or more overlapping images taken of an area or object are processed, and the difference in perspective from each provides enough information for software to calculate the distance from the camera source through triangulation to regenerate that specific area as a digital tie point. This digital reconstruction gives 3 dimensional coordinates to the captured images and is based on the contrast within the pixels of the image. When this process is completed using drones over the context of a construction site, a 3D digital model can be created.

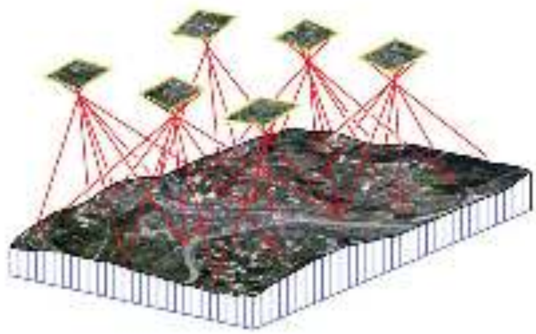

Fig.1: Photogrammetry Triangulation Diagram [7]

There are several software solutions which generate construction specific photogrammetric outputs including Pix4D, Drone Deploy, Context Capture, and free open-source platforms such as MeshLab. The use of drones provides the ability to capture the whole site in a short period of time. Automated flight paths can be created through photogrammetry applications, ensuring consistent overlapping between images which allows for an increased quality and repeatable output over time throughout a project. Several factors influence the quality and detail of the results, these include the distance of the drone to the subject, the resolution of image produced by the camera and the amount of overlap between images. Outputs provided by such software include orthomosaic imaging, 3D topographical surveys and 3D models.

Orthomosaic images produce an ortho-rectified image of the area captured. This can be used to provide improved perspective of the site compared to standard images, over a larger site. The 3D topographical survey can provide bulk dig/fill calculations for measuring volumes of material to be transported to and from site. This is generated through coordinated CAD exports which provide the 3D coordinates from the captured data. This can be a more accurate and time efficient manner than land-based survey methods, dependent on the area and volume of material to be calculated.

Finally, 3D models can be generated through the photogrammetry software, through textured mesh models or point clouds. Point clouds can be imported into CAD software to recreate existing site context, structures, or specific site elements required to complete or interpret the design of the building. The point cloud can also be imported into a project Common Data Environment (CDE) to validate or quantify work completed to date, ensuring the correct coordinates of components such as civils infrastructure, structural elements, site boundaries and building facades.

Increasing availability and support of web-browser viewing for outputs of photogrammetry from DroneDeploy and Pix4D Cloud allow the information captured from drones to become more accessible to the project team and shared with external stakeholders. Previously, restrictions of software licenses and the need for high-performance computers limited sharing and viewing of data. Using web-based applications, the entire project team can inspect the generated 3D model at greater detail further advancing their understanding of the project.

CASE STUDY

Felix O'Hare & Co Ltd (FOH) are a building contractor based in Northern Ireland whose work concentrates on commercial building projects with a typical value of £2 - £50 million. Their investment in drone technology began in 2014, with a purchase of a multi rotor, DJI Phantom 2. This drone was used on key projects for progress images throughout construction and to aid in programme management and scheduling activities. At the same time, several projects within the company outsourced their video production to third party companies who provided edited drone videos for client teams and marketing.

The use of drones in the company progressively increased to cover most new build projects, as a growing number of clients requested monthly drone footage within their specified project deliverables. In 2017, as the demand for drone images and videos from clients increased, FOH invested in a DJI Mavic Pro – one of the first compact, foldable multi-rotor drones with 4K video capability. This drone was chosen primarily because of its compact size which made it easier to transport to multiple sites. In 2019, 3 employees undertook training to achieve commercial licensing for drone flights within the UK. This was to ensure there would always be a qualified drone pilot available for any flight. All image and video production are now completed in-house, reducing cost and the reliance on third party specialists. This data now provides an overview of a project in a very succinct manner, making the data available to the project team, and providing material for marketing and social media engagement. Video editing is necessary on some projects to obscure confidential or sensitive information on neighboring properties, such as schools and government buildings.

At present the company collects drone imagery at least once a month on all new-build projects. This data is then shared on the projects' CDE for the whole project team to access. On several key projects it is collected on a more frequent basis to ensure imagery is up-to-date and this digital information has become a key focal point for any progress or internal meetings. A Contracts Manager for FOH found that "the aerial imagery provided on a frequent basis allows for increased awareness of the site and opportunity for parallel working to find programming efficiencies." However, due to the constantly changing environment of a construction site it is difficult to identify direct time savings from drone data as it is a multifaceted endeavour. It is also used for logistics planning and markup of areas to provide subcontractors with a better understanding of the site and its work sequencing. This data also provides a means to sketch out and plan set down areas for storage compounds, optimizing the use of the space on a site. Finally, the information is used by quantity surveyors to validate payments for subcontractors and serves as a record of the work completed to date.

Fig.2: Orthomosaic Image CAD Overlay with Annotations

Aerial mapping to provide 3D topographical surveys has been used on several projects which require large volumes of material to be transported off-site. This technique was validated on one project against a site engineer's land-based measurement method and tracked against actual volume unloaded. Since then, aerial mapping has been used for larger bulk digs, which takes less labour hours to calculate results.

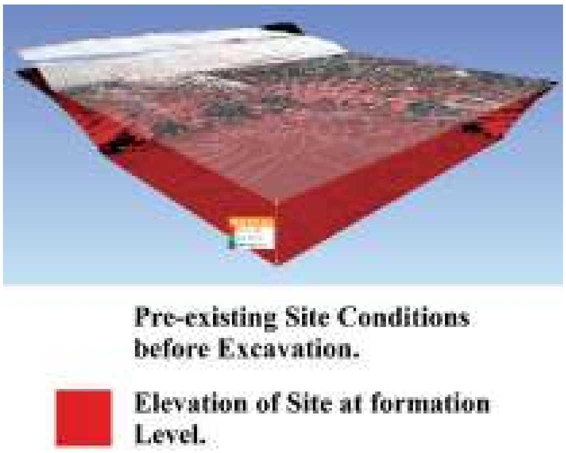

Fig.3: Topographical Survey Volume Calculations

However, for excavations that require a gradient or several changes in elevation, it is still necessary to export the drone topographical survey in CAD .dxf format and import this into surveying software to calculate the difference against the required grade to give a final cut/fill quantity. This provides the site team with an accurate estimate of how many lorry loads are required to transport the material and how many days are required for this transport.

This drone-based 3D topographical survey can also be imported into 4D Scheduling software, in which it is linked to the 3D design model and the project programme to produce a video animation of the progress of work and activities through the project. The animation includes the excavation or fill of material in order to show the groundworks subcontractor the stages and progression of work. This data is also sent to the Health & Safety management team to help identify any permanent or temporary works within the construction operations that may present a hazard.

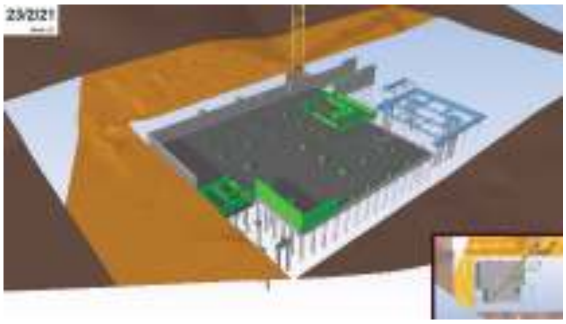

Fig.4: Topographical survey imported to 4D Programming

The company has developed other possible workflows for the use of drone data to further exploit its potential. Drone photogrammetry was trialed on the steel works construction of the new students' union at Queen's University, Belfast - a Building Information Modelling (BIM) Level 2 project with a fully developed BIM model. This trial looked at the accuracy of a drone generated point cloud of the steel works, with total station surveyed Ground Control Points (GCPs), compared to the design model. This was also tested against a ground based 3d laser scan data of the erected steel, collected on the same day using a FARO Focus S150, to compare the accuracy and time taken. The drone flight was completed within 30 minutes with no interruption to site activities. The laser scanning required 4 hours of on-site including halting construction works for several minutes in various locations in order to safely complete the survey.

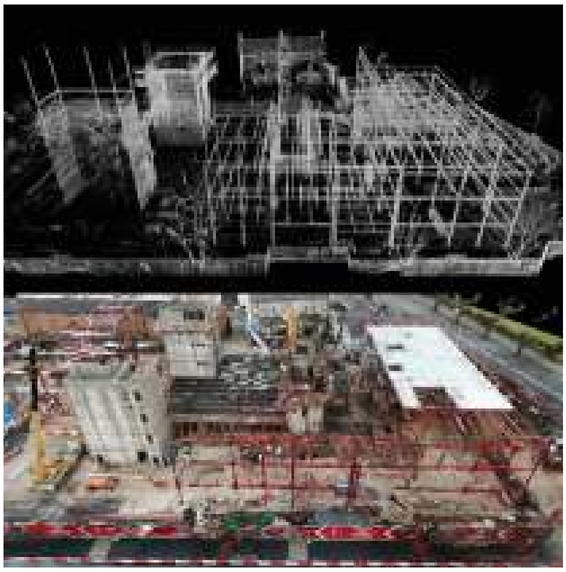

Fig.5: Comparison Between LiDAR Scan & Photogrammetry

This trial highlighted that, although the drone was able to capture the overall site to a good level of detail, it struggled with the depth of field around the relatively thin structural steel. The data was captured using a DJI Mavic Pro with a 12MP image, - a drone with a higher resolution of camera should increase the detail; however, the processing of the data cannot capture the detail that is possible when compared to a terrestrial laser scanner. Due to the strict tolerances and detailing of structural steel, drone photogrammetry is not the optimal validation tool. However, when used for validation of for example, manholes and drainage lines, it has proven to be extremely useful.

Fig.6: Validation of piling Location between CAD drawing and Drone Photogrammetry

This trial has shown that the integration of both ground based LiDAR and drone photogrammetry provide an optimal approach for validation and verification of built components on this site.

In the future it is proposed that the drone integration for Project Management within the company will grow, and mapping tools will be used on a weekly basis across all suitable projects. The adoption of a higher quality camera system should increase the image and video recording quality and a heavier drone will improve stability in high wind conditions, increasing the possible number of flying hours per project.

THE FUTURE

The increase in drone uptake within the construction industry will encourage the development of drone hardware, software and use cases for the specific intent of the industry's requirements. With regards to the hardware within drones, developments will include 4K imaging and video recording, along with increasing battery life for most applications and use-cases within construction. The authors contend that the main area of development will be towards software and for extraction and interrogation of the data.

a) The Connected Job Site

With the current standard of autonomous flights, the next progression will lead to completely autonomous drones which are able to fly the same flight path throughout set intervals. Autonomy will extend to charging, and the data will be directly uploaded to the cloud for processing, which will be aided by the introduction of 5G networks. This will be difficult to achieve in practice, as the take-off and landing of the drone are the most complex and unpredictable part of the flight due to the movement of people and traffic, changing ground conditions and wind speeds. Barriers to adoption also include government regulation of airspace to allow unsupervised flights by responsible pilots. In case of an emergency, the autonomous drone may not be able to react in an appropriate manner to avoid other air traffic or obstacles such as cranes, which are commonplace on a building site. Currently, methods such as high accuracy sensors are being developed in order to try and mitigate the risks which occur in emergency and unforeseen circumstances. Another advancement under development is the use of communication between all aerial vehicles in order to identify where they are in space relative to each other. The use of artificial intelligence will be used to train drones to learn to deal with changing circumstances; however, these are in very early development and need to be tested rigorously before any government body will authorize the unsupervised flight of drones in an airspace [8]. A Vodafone Report continues to highlight the benefits of 5G connectivity with drones. They define this as a cellular-connected drone which is linked to a mobile network through a sim card, this cellular connection is more reliable that current Radio and Wi-fi transmission signal. It also allows drones to provide a live feed of drone imagery to the cloud while in flight, which will allow the project team to view the site in real time at specific times or activities without the need to travel to site; it will also equip drones with the ability to automatically upload data. The report also emphasises the importance that 5G would play in communication between aircraft, to avoid collisions with manned aircraft, and other unmanned aircraft in the area [9].

Furthermore, autonomous flights can only be completed in ideal weather conditions, as in high winds or during rainfall drones cannot operate. Therefore, weather reporting integration with the (virtual) cloud and drone needs to be established to programme acceptable flight conditions and continuously obtain feedback in case of changes to weather conditions throughout the flight.

b) CDE Integration

As discussed above, the ability to automatically upload and process data to the cloud is the next step in order to streamline and advance drone workflows in construction. This will require collaboration between manufacturers and software providers to fully develop this capability. Platforms such as Drone Deploy currently have features which use an internet connection through a mobile device in order to upload flight imagery and video to their cloud database for processing. This processed data can then be imported into a Common Data Environment solution such as Procore, Dalux or Autodesk BIM 360. However, it remains the case that inspection and reporting of issues raised through the photogrammetry processing solution such as DroneDeploy or Pix4D, provides the most useful results, which would in this scenario create two different platforms in which issues would be raised and must be checked by the site team. The interoperability and communications through plug-ins between these two types of platforms (the Common Data Environment and drone processing platforms) is currently being developed, as the importance of drone data for construction is increasingly recognised and introduced to more projects as a key tool for project management and communication.

c) Drone Attachments

Another development which could see wide adoption within the construction industry is the use of drones for setting out the positioning of roads, buildings, services, or other external infrastructure. This technology at the time of writing, is being tested by developers including an Israeli based robotics company, Civrobotics. Their 'Civdrone' can stakeout up to 500 coordinates on a project per day using advanced kinematic and GPS positioning technology within the drone system to accurately mark points by using a robotic arm that pushes physical markers into the ground. Compared to manual setting out using traditional methods such as a GPS or total station, this provides a reduction in time with little or no reduction in accuracy. This feature could be particularly useful for large civils and infrastructure projects that cover several kilometres, decreasing the time and resources dedicated to setting out the required coordinates, and eliminating the possibility of human error [10] [11].

Fig.7: CivDrone Setting Out Product [11]

Caged drones are typically a multi-rotor drone which has an 'exoskeleton' which provides a protective layer to the propellers and body of the drone. This cage allows it to stabilise and avoid damage upon collision with any surface. This allows the drone to inspect enclosed spaces that are unsafe or too small for human involvement. This technology was created following the Japan Tsunami in 2011 to allow inspection of damaged buildings or to look for missing persons [12]. It has been adopted for further applications such as surveying excavations, caves, and nuclear power plants. However, due to the nature of the environments in which this drone operates, it does not totally prevent damage to the drone as it can be damaged by sharp objects or fall from collisions. Also, several additional attachments are required, such as lights and sensors to capture the data needed, which in turn, reduces the battery life of the drone.

Fig.8: Elios 1 Caged Drone [12]

Construction organisations should also keep abreast of the capabilities that are expected to be developed in the future, as this is an ever-expanding area which has the potential to provide greater benefits to construction projects. There is continuing opportunity to include increasingly job specific attachments and equipment to drones to automate tasks or capture more useful data.

CONCLUSION

Drones have proven to be a powerful tool when used in construction, and through their continual development they present more possibilities for the provision of useful information to the entire project team, relaying accurate information efficiently to complete and validate the project as required. In order to introduce drones, it is advisable for an organisation to develop a plan and to set goals for the benefits drones are expected to bring. When planning for the implementation of drones, a company should consider the set-up costs, data protection, legal requirements, insurance, training time as well as administration and documentation requirements of drone flights and identifying the person(s) within the organization best suited to carrying out drone operations. The company should also carefully consider what software they plan to use in order to process and export the data into a suitable format – this may require additional skills and software licenses, such as photo editing, video editing and photogrammetry software.

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A Proposal to Harmonize BIM and IoT Data Silos using Blockchain Applications

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Abstract–The integration of Building Information Modelling (BIM) and Internet of Things (IoT) provides significant end-to-end benefits for the architecture, engineering, construction, and operations (AECO) industry. Example of applications include on-site assembly services, data localization for built environment, occupancy performance measures and many other analyses that can be used to improve the built environment. However, silos in the BIM and IoT data exchange have impacted the digital process adoption in AECO industry, which aims to change the dynamics and behaviours of the current working process. This study sets out to critically analyse the Blockchain technology's potential to connect, integrate and advance AECO industry information exchanges and digital processes by using BIM and IoT integration use case as a methodology to identify, clarify and organize the proposed system requirements. This paper presents a comprehensive literature review to uncover the current state of BIM and IoT data silos. Moreover, an online survey assessment and a simulated test were conducted to critically evaluate, investigate, and examine the opportunities and solutions in harmonizing BIM and IoT data silos by using the Blockchain application.

Keywords– BIM, IoT, Blockchain, Digital Twin, Data Silos, Integrated

1.0 Introduction

The recent Global Lockdown following the COVID-19 pandemic has affected many businesses, workforces and multiple parts of supply chains that are not designed to be managed remotely. These businesses have suffered from a disconnected system and fragmented data, which then triggered economic loss and global recession [1]. The "new normal" therefore, will require a smarter way of working and a higher degree of security, transparency, and trust in a data management system [2].

In the architecture, engineering, construction, and operations (AECO) industry, technological advancements such as BIM, and IoT have improved the accuracy of low-level assets information and collaboration between machine and human interfaces [3]. However, the fragmented data and data silos which are commonly created by a centralized, unintegrated database system across two or multiple repositories still exist. To eliminate these obstacles, there is a need for an integrated system that can provide a transparent, unified, and trusted environment [4].

Blockchain technology emerged as a disruptive innovation to democratic data sharing in a decentralised and trusted environment. With a wide range of decentralized applications, Blockchain can be a potential solution to the disintegration of data silos [5].

This research sought to critically analyse, evaluate, and discuss the ability and roles of Blockchain technology and its application in harmonizing BIM and IoT data silos through a literature review, an online survey and a simulated test which aims to critically examine and rationalize the use of the Blockchain technology as a solution for BIM and IoT integration processes.

2.0 Literature Review

2.1 Overview of The Key Technology

2.1.1 Building Information Modelling (BIM)

According to [6] "BIM or building information modelling is a process for creating and managing information across a construction project's lifecycle. This advancement represents physical and functional characteristics, such as geometry, spatial relationship, and geographic information in a digital format to support decisions during an asset' lifecycle," and with the release of ISO 19650, a more connected and integrated BIM processes are expected [7].

2.1.2 Internet of Things (IoT)

IoT is a system that employs interconnected smart devices to transfer data using internet without necessitating human interactions or human-to-computer communication [8]. "The Internet of Things is a paradigm where everyday objects can be equipped with identifying, sensing, networking and processing capabilities that will allow them to communicate with one another and with other devices and services over the Internet to accomplish some objective" [9].

IoT deployment can be categorised based on the process capability of sensors object's recognition. The categorisation are as follows; (1) activity-aware objects, (2) policy-aware objects, (3) and process-aware objects [10].

Such categorisation is vital in designing the data management framework for a BIM and IoT-based application involving various objects, devices, sensors, and daily items. These objects have been increasingly applied in various smart homes products to enhance work productivity, living comfort, and entertainment.

2.2 Challenges of BIM and IoT Data Integration

The interweave between digital and physical assets either directly or indirectly creates a significant amount of information that can be utilized to improves security, minimizing human effort, saves time, and efficient resource utilization however fragmented data management causes anomalies and inefficiencies between human and machines. The true relationship between BIM and IoT can only be achieved if a Single Source of Truth is established s.

According to [11] data fragmentation happened because data abstracted from the sources are still locked-in silos and stored in isolated databases. Figure 1 shows the current fragmented relationship within BIM-IoT environment that are segregated and locked-in silo.

Figure 1 - Silo and fragmented data management in the current BIM and IoT process.

From the literature review, it shows there are several key issues contributing to the poor relationship across silos within BIM and IoT environment. At the outset there is four core themes being addressed in this research, this includes, security, fragmented data, data ownership and trust.

2.2.1 Security

This lingering issue concerning IoT applications security has continued to impede the implementation of the technology in the AECO industry. According to the National Institute of Standards and Technology of the United States (NIST), security can be classified as "the protection of the confidentiality, integrity, and availability of a technology solution". The essence of security is ensuring every component function as established and assuring that authorized and unauthorized users are kept safe from possible threat [12].

However, the connected IoT domains, devices, and sensors to the Internet raise concern about data privacy. IoT devices, by their nature, are vulnerable to attacks from data theft and malicious activities due to their behaviours.

Furthermore, "the orchestration of IoT in a highly modular environment with many moving parts and inter-dependencies between the stakeholders of this environment has led to many security issues" [10].

System separation and staying offline are not viable security approaches and are ineffective for business operation. The lack of seamless interoperability and integration reduce business outcomes; hence the futile attempt of adopting the IoT in AECO industry [13].

2.2.2 Fragmented Data

[11] indicated that the file-based data management is the prevalent data management strategy in the industry. They further argued that the growth of siloed in file-based system is attributed from the traditional systems and processes practised by most businesses. This creates data reliability and interoperability issues between parties. Lack of BIM and IoT data integration in the AEC industry limit the benefits of integration from being fully realised.

[14] gave an example of how categorisation of trade segments in the current BIM process, project teams (e.g., design team, supply team, construction team, and operations team), has made the exchange of activities between the team members and technological interoperability less feasible. Information was reorganised according to the top-down model and notable resources were used to process submittals, change orders, and RFIs.

However, these approaches are only appropriate for small projects. In a more complex project, level of granularity and document continuity can become an issue [15].

This issue has contributed to significant fragmentation in data management mechanisms and limiting IoT domains access and prevent them from making connection into BIM environment. [15].

Instruments, applications, or software employed to manage business information is also a disintegration source, as these devices function under the information silos model. Common interoperability issues in these sets of tools often limit data sharing between parties [16].

[6] claims that BIM processes lack continuation at the construction, post-construction and operation stage due to fragmented processes between trades and FM operators. They explained, in the post-construction stage, a model does not represent the structure as a living element; it represents only the as-built form of the building. Even during the construction stage, a BIM model is only as good as the information provided to it. If the data is inaccurate, the model will be too. The lack of information continuation in the siloed collaboration model that is maintained within BIM is slowing the construction project from progressing [6].

2.2.3 Data Ownership

Data can be considered as a commodity in Industry 4.0. Its function will allow companies to acquire or maintain a competitive edge. Platforms that capture a critical mass of BIM and IoT data in the near-term will be well-positioned to dominate the built environment market. They will also be challenging to defeat which is attributed to the vendor lock-in approaches which are attained when the building data are completely "transactable" for project contributors and not secured in proprietary systems.

Due to competitiveness, BIM and IoT platforms have no incentive to share data/market with their competitors. No secure mechanism exists to share data in real-time across platforms seamlessly. The lack of policy and solutions to address these interoperability issues are a massive obstacle on innovation within the AECO industry and will continue to fragment the industry into monolithic data silos. Without a new approach that enables data/device sharing and interoperability, the full potential of integrated IoT-based BIM applications cannot be harnessed [17].

Furthermore, data heterogeneity is prevalent in IOT data infrastructure, which contributes to wasted prospects for businesses to generate value and to maximized functions offered by IoT rich datasets [18].

2.2.4 Trust

A primary difficulty in the implementation of BIM and IoT is poor relationship among stakeholders [19]. Trusted relationship is essential for organizational communication which in force its importance as an asset for many organizations [20].

[20] further cited, "as a general approach this trust was enabled by third parties and intermediaries who ensured the contracted parties that they have authority, transparency and legal right to do business with each other. However, this approach on a fast-paced global economy with growing complexity and volume of interaction is increasingly difficult". Transparency and trust established by a third party has become too complex as information is always concealed, and the procedure is frequently laborious and expensive. Additionally, since the 2008 financial crisis, it become clear that the system was highly vulnerable.

[20] observed that true collaboration encourages professionals to work together in the four modern pillars of procurement, simulated design, lean process, and energy efficiency design. However, [22] observed that this requires trust in partnership, security, assurance in data reliability and information quality before true collaboration can be achieved.

2.3 Re-thinking BIM and IoT Integration

[19] recommend project teams must consider approaches that can establish the end-to-end collaboration via a single source of truth covering their organization. Data could be stored and accessed in the cloud database through web services and not be prone to manipulation and fraud. The governance of those data should not be put on any centralised means that can be exposed to actors who often breach their moral duty. However, this required a robust system to ensure reliable data flow. Each business that installs IoT solutions must possess a strategy to safeguard trust, identity, confidentiality, protection, safety and security of devices and people. It is imperative to acknowledge that an IoT device or solution can be threatened at any time. Business owners must observe security as a controllable risk, along with other risks.

The literature review suggests a number of conceptual solutions for BIM and IoT integration. However, many challenges such as trust, security, data ownership, and management need to be addressed for both technologies to work together.

To achieve and deliver true integration in the BIM and IoT environment, a common system is required for keeping track of the built assets. Also needed is a system that gives definition and order to the society, which comprises security, speed, and transparency. The next section describes and justifies selecting the Blockchain technology as the answer to the issues.

2.4 Blockchain: Definitions and Characteristics

"Blockchain technology is a growing list of records or "Block" that is occupied with collective databases. Every block comprises a cryptographic hash of the previous block, performed data, and timestamp". The validated data in the blocks are confirmed and secured by a peer-to-peer (P2P) network, which collectively adheres to the consensus mechanism [23].

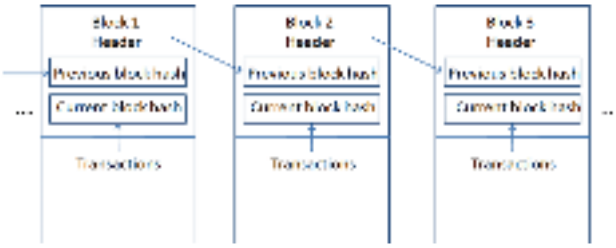

Figure 2 – Basic Blockchain transaction mechanism

The Blockchain technology can be considered as the distribution of trust; it allows people to share their data with others in a verified, immutable environment. Data is administered by a trust-free system, but the realisation of the trust hinges on the framework of generating the trusted interfaces [24].

The Blockchain technology also allows individuals, organisations, and domains to have full rights and control over the sharing, collaboration, and privacy of their information without having to rely on third-party intermediaries [25]. This process (Figure 3) and the key characteristics of the technology are discussed in the following section.

Figure 3 – Blockchain processes [26]

2.4.1 Immutability

Immutability refers to the capability of Blockchain of restore records of data across a peer network of a computer system without losing its accuracy. Each transaction contains a hash of the previous transaction thus making it very difficult to tamper with [25].

Immutability is highly desirable for a supply chain ecosystem. In a Blockchain-based supply chain process, a consensus mechanism is used to improve transparency and provide greater traceability of products or services. Every transaction (including origin, transit, and price) is recorded in an immutable ledger, allowing trust to form and transforming a set of information into the creation of value [5].

2.4.2 Transparency

The usage of Blockchain enables the attainment of transparency by permitting users read-only admission to prior dealings and the capability to review the content of smart contracts. This aspect is valuable for goods that have to be traced in the supply chain. Although transparency is necessary in numerous businesses, such aspects might not be applicable and universal. Private users might be worried about privacy issues over their sensitive personal data, and businesses might experience the fear of sensitive information leakage [27].

2.4.3 Decentralized nature

"Decentralization refers to the process of distributing and dispersing power away from a central authority." Blockchain is planned as a decentralized, circulated system; consequently, the technology does not have any single point of failure, establishing its resilience, efficiency, and democracy. Decentralisation provides each member a chance to become a network processor [28].

2.4.4 Consensus

The advanced consensus procedures across network nodes have established the realisation of decentralisation. Such protocols guarantee that the responsibilities of accumulating transactions and producing new blocks adhere to stringent instructions, which do not contain bias. The most popular consensus algorithm was applied in Bitcoin, the "proof-of-work" (PoW) mining, is founded on unravelling a mathematically challenging puzzle with dynamically modifiable difficulties [29]. In other words, the Blockchain consensus can lead to new powerful processes for many areas, applications, and organisations.

2.5 Applicable Uses of Blockchain Technology

In this section, several applicable uses of Blockchain technology to the AECO industry are discussed. Some of these applications can be served for a more specific integrated data management solution or collaboration processes for any new construction projects.

2.5.1 Distributed ledger

Distributed ledger technology (DLT) is a consensus replicate of an asset database which is communal and synchronised across a peer-to-peer network of numerous sites, locations, or establishments [30]. DLT can possibly address privacy and security issues through its undisputable qualities which are unaffected by hacks and modifications [31].

DLT can aid in solving numerous BIM and IoT problems. It can confirm the incorruptibility of information through the immutability and identification of the person making changes along with facts of the variations. This facet enables improved logging and tracing of intellectual property and copyright, contributing to improved assurance of relevant stakeholders to cooperate [32]

2.5.2 Smart contracts

Smart contract features an important role in the Blockchain development. It offers an exclusive interface for "machine-to-machine interaction which provides a safe, trusted, self-managed record and transfer of assets. A smart contract combines user interfaces, protocols, and promises articulated through those interfaces, thus permitting associations to be made formal and protected over public networks. A smart contract will allow users to deploy a metadata on a Blockchain network in a verified environment, directly through deterministic procedures, therefore allowing numerous issues to be addressed without requires validation from a third party" [33]. Indirectly, such feature, promises lowers the legal costs of any project [5].

A smart contract has its properties in the Blockchain, and therefore, the former cannot be changed unless all the actors involved agree to the alteration. Therefore, a smart contract manages and preserves its records of assets on the Blockchain, consequently permitting it to function as an escrow for two or more parties involved in a specified transaction. Since a smart contract exists in the Blockchain, it is practically clear and susceptible to manipulation [34].

The smart contract functions as an independent payment entity on the Blockchain, which could deterministically perform payment after the completion of a job. Automation in many types of repetitive tasks traditionally performed by people can reduce the time, costs, and risks associated with them [35].

The smart contract offers a stimulating prospect for BIM and IoT data exchange methods to directly confront trust issues between the exchanges in both technologies.

2.5.3 Peer-to-Peer Network

"Peer-to-peer network is a distributed and connected computer system or "peers" on the Internet. It enables a highly resilient consensus mechanism for the Blockchain without the need for any intermediary" [36]. [37] in his whitepaper states that the peer-to-peer (P2P) network in P2P electronic cash, Bitcoin, helps to prevent double-spending in a transaction by establishing a consensus to record a public transaction. This application can also be incorporated to different practices that requires transactions such as project management, payment, procurement, asset management, and supply chain management. The P2P network at its core can serve as an application for communication management and data validation for an IoT-based BIM application [38].

3.0 Research Design

This research proposes Blockchain as the key technology to support AECO digital transformation thus enabling data transfers and value between the heterogeneous IoT-based BIM applications via cross-chain communication. The technology could complement BIM and IoT technology by providing trust in data to inform decision-making and optimise business processes throughout a project's life cycle.

This research was evaluated, examined, and tested using two methods of gathering data. First method used is a web survey where the self-selected were voluntary and anonymous. The opening questions were formatted to locate demography and roles of the respondents, it then flows into a series of indicator about Blockchain technology characteristics, obstacles and potential use case in AECO industry. The survey closing with an open-ended question, given respondents an opportunity to raised opinions about this research in general. The survey aims to critically evaluate the knowledge level of AECO industry practitioners on their understanding of the Blockchain technology. The results from the survey reflect their perception on the Blockchain spaces for AECO industry.

An action research was then conducted to critically examine the potential of the Blockchain application particularly smart contract in harmonizing data silos for a more secured, integrated, and trusted BIM and IoT environment. A simulated application was tested to gain a deeper understanding about the potential solutions or issues and informed judgment can be achieved.

3.1 Web Survey

The web survey findings highlighted in this paper reflect the participants thinking and perception in the Blockchain spaces and the potentials impact of the technology in AECO industry. The survey polled a sample of thirty AECO professionals in three countries twenty from Ireland, two from Qatar and eight from Malaysia with twenty-four represents AEC organization and six represents O&M department.

Findings from the survey suggest a promising digital transformation for many organizations. Thirteen participants implemented more than 50% BIM and IoT processes in either projects or their businesses process but have very low to no uptake of the Blockchain technology. The results indicate an improve use of smart devices in construction projects and Digital Twin for process automation during operation and maintenance phase.

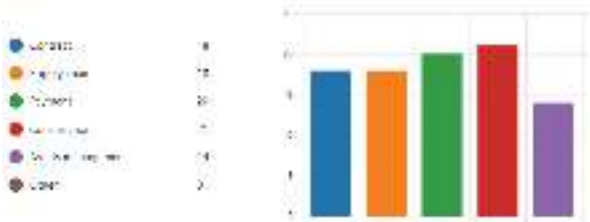

Figure 4 – Blockchain technology potential use cases in AECO industry

The findings also imply the respondents' optimism about the ability of the Blockchain to potentially play a role in BIM and IoT integration. Twenty-one participants agreed that the character of Blockchain properties could offer a massive opportunity for the industry to become more effective, transparent, productive, and sustainable. The Blockchain technology, BIM and IoT could be utilised for better interoperability in construction, supply chain, payment, contract, and procurement.

However, Figure 4 the twenty-one participants acknowledged, such integration requires a high level of knowledge and understanding of the technology. Though respondents are confident by eliminating old working culture, improve security and find suitable use case for businesses could lead to more take on Blockchain adoption and more impactful digital transformation in their organisation.

The respondents also believed that an integrated project delivered through an IoT-based BIM application secured by Blockchain technology would dramatically improve project visibility and data reliability. Such integration would allow the technology to exchange a structured database that can be shared for design and construction automation, energy simulations, fabrication, and the development of artificial intelligent (AI) thus increasing operational efficiency and enhancing risk analysis.

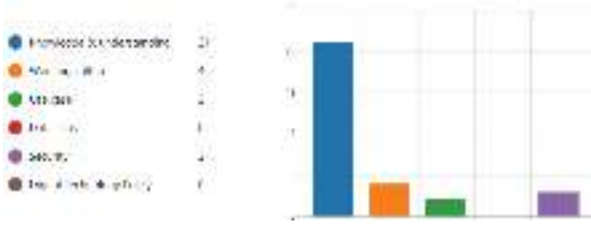

Figure 5 – Blockchain adoption obstacles in AECO industry

3.2 Action Research: A Simulated Application

This section presents the development of a Blockchain application to demonstrate the possible connection between BIM, IoT, and Blockchain. A simulated test was conducted to explore the various software packages used for Smart Contract developments. The objective of the test was to critically evaluate the value of the Blockchain characteristics in harmonizing BIM and IoT data silos. The test also served to demonstrate the potentials of the Blockchain-based applications, particularly Smart Contract and Distributed Ledger Technology (DLT) to be leveraged in creating a trusted Blockchain backed BIM and IoT cloud systems.

3.2.1 Methodology

A test of a simulated application, which allows data to be measured and evaluated, were conducted to achieve the objective of the study. The programmed application, a smart contract, was created to demonstrate the combined roles and functions of each technology in securing, distributing, and establishing trust in a shared data environment.

3.2.2 Overview

The smart contract serves to:

1. maintain historical data from an IoT device (see below) and BIM models in a distributed ledger
2. embedded the smart contract between the nodes in the system

3. provide hash-based security, verification of identity and provenance data ownership
4. provide consensus and agreement models for shared information, and
5. create a trust less data management

In this test, the smart contract provides information about a living quality scenario of a meeting room with a specific focus on the use of temperature and humidity information. For this purpose, an IoT device with a temperature and humidity sensors was installed in a meeting room to capture and provide data for the BIM model elements and DLT. This information serves to facilitate reliable data exchanges between the environments. With this information, several statements can be made for quality evaluation of performance or products of the measured room. These findings were derived from a process comprising the following four steps:

1. by defining the application (smart contract) parameters and requirements.
2. by designing a harmonised theoretical BIM-IoT-Blockchain framework.
3. by establishing an implementation approach.
4. by evaluating the results.

3.2.3 Define the Smart Contract parameters and requirement

The purpose of this section is to identify the parameters and requirements for the Smart Contract configuration metadata (source code). The configured source code defined the high-level workflow policies and interaction model of the Smart Contract.

Since Microsoft Azure only support Ethereum based blockchain, Solidity was chosen as Programming language deployed for this test. "Solidity is an object-oriented, high-level language for implementing smart contracts. Smart contracts are programs which govern the behaviour of accounts within the Ethereum state. In this sense, Solidity is a collection of code (its functions) and data (its state) that resides at a specific address on the Ethereum blockchain" [39].

```
pragma solidity >=0.4.25 <0.6.0;
contract AirQuality
{
    //Set of States
    enum StateType { Created, InTenancy, Compl
eted, OutOfCompliance}
    enum SensorType { None, Humidity, Temperat
ure }
```

Figure 6 – Solidity Smart Contract programming language

The configuration metadata contains application name, description and roles that defines the data ownership, permission control and security within the blockchain application. A set of distinct roles are defined based on functionality.

Name	Description	Parameter
Created	Contract has initiated and tracking in progress	
In tenancy	Tenant is currently occupying room	
Out of compliance	Indicates that the living space is not met H&S requirement	**Temperature** Min = 18deg Max = 23deg **Humidity** Min = 40% Max = 60%
Complete	Operation and maintenance have been carried out	

Table 3 – Smart contract States

3.2.4 Data harmonization Design methods

The architecture for the build, manage and deploy solutions for the Smart Contract application was first defined. This test was carried on Vendor-Locked solution due to the limitations of the Open-Software and Open-Protocols available during this study.

Microsoft azure platform was utilized as the common data platform for building, managing, and deploying solutions for the smart contract applications. Microsoft Azure also provides a cloud service such as IoT hub, virtual machines, SQL server, Blockchain Workbench etc. that can be used to automate data processing for a smarter and more efficient IoT and Blockchain data management.

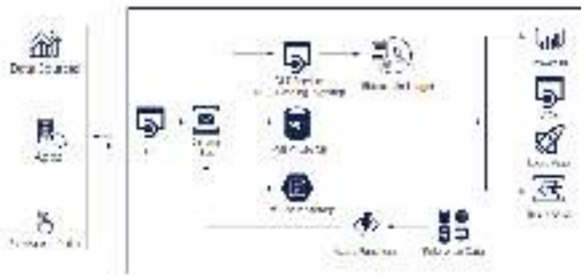

Figure 7 - Microsoft Azure IoT and Blockchain Architecture solution [40]

Harmonization of the system was evaluated across three environments:

1. A BIM environment which represents the project deliverables in terms of model element for both 3D and information contents (object properties). Interconnectivity between BIM model and the Azure platform was achieved via Autodesk Forge protocols.

Figure 8 – Virtual twin model represents IoT information

2. An IoT environment which "represents the actual delivery of the physical asset, goods, and services where IoT-based verification and authentication of the performance can occur" [32]. Azure MXchip IoT Devkit was used to develop and prototype the IoT solutions on the Microsoft Azure IoT hub. The Real-time data captured from these registered sensors for each space were published to an IoT hub and were forwarded to a Smart contract application on the Azure Blockchain Workbench.

Figure 9 - MXchip IoT Devkit

3. A Blockchain environment, which consists of a set of services that allow users to deploy Blockchain applications on the cloud. In the Azure platform, Blockchain Workbench provides the deployment solutions for the Smart Contract including blockchain stack, application templates, and support for IoT integration. This helps to simplify the development and ease experimentation with prebuild applications. The time taken to develop the Blockchain applications could be reduced significantly.

3.2.5 Implementation

With the established configuration metadata and framework design, the actual implementation can be carried out. The following diagram articulates the possible data flow harmonization across the three environments. A more detailed explanation regarding the application implementation workflow is outlined in the steps below and is shown in the sequence diagram in Figure 10.

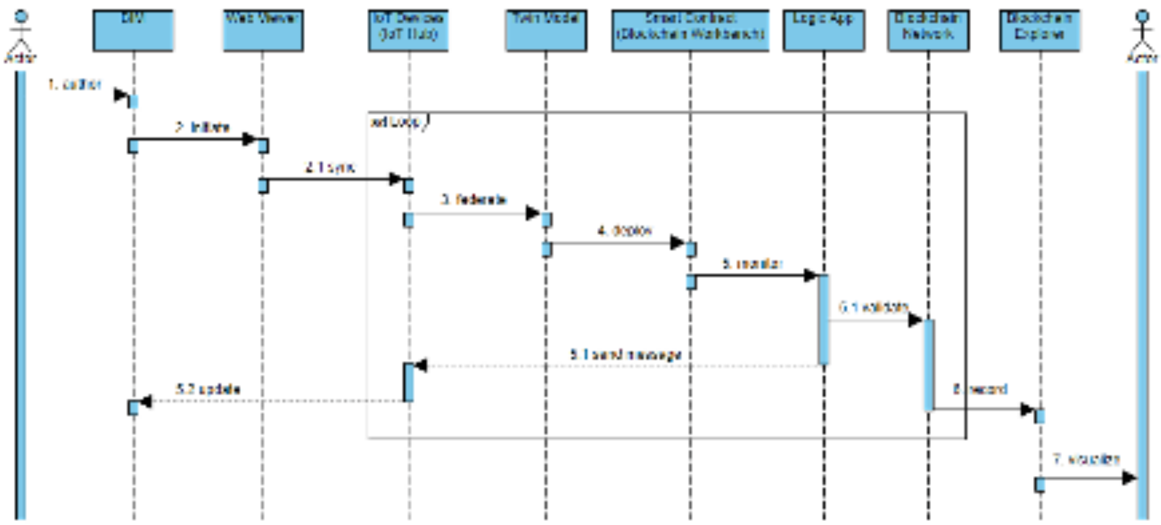

Figure 10 – A sequence diagram showing data harmonization across technological environments.

3.2.6 Workflow

Step 1 - The simulated application showcases an example of a smart contract process with BIM and IoT monitoring for health and safety compliance. The MXchip IoT Devkit with a temperature and humidity sensors was installed in a meeting room to capture and provide telemetry data. Set of parameter Compliance rules were specified and must be met for the room to be considered safe by the occupants. Acceptable range target parameter set as below;

Temperature
Min = 18deg Max = 23deg
Humidity
Min = 40% Max = 60%

Step 2 - BIM models were initiated to web viewer to host metadata from digital assets. BIM models that were authored in Autodesk Revit were used as a virtual twin to provide an accurate representation of geometrical data for web-based data monitoring and reporting. The Revit model were then translated into Serial Vector Format (SVF) via Postman; the collaboration platform for API development so that it can be rendered in the web viewer. The web app is used to visualize data captured from the sensor.

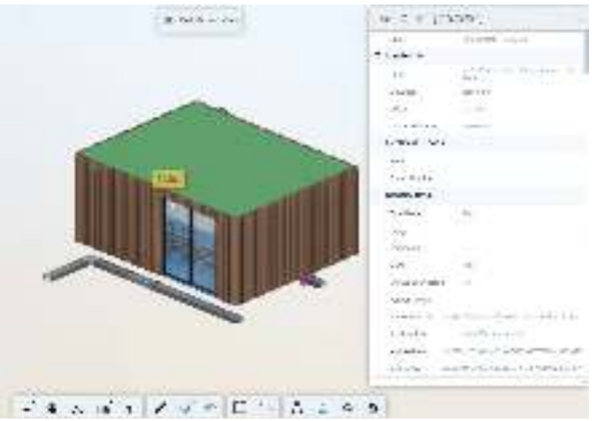

Figure 11 – BIM and IoT metadata in the web viewer

Step 3 – Data from IoT sensor were linked into the digital model in the web app via a call function coded in JavaScript. This brings all the 3D visualization to the IoT application in the Azure IoT hub.

Step 4 – With the web app setup, a smart contract then can be deployed. This contract enforced a specific function according to parameter specified earlier. The humidity and temperature rules measurement were specified by initiating counterparty and deployed to the Blockchain Workbench. The smart contact application was built to secure the transactions data between multiple counterparties at any given time. This contract collected telemetry information from IoT devices installed in a location and enforced contract specifics related to conditions during occupation. Specifically, receiving and evaluating temperature and humidity data against an agreed upon acceptable range. If the IoT device identifies that the telemetry is out of the acceptable range, the contract will shift into an out of compliance state and appropriate O&M action need to be carried out. The smart contract functions translated in the Figure 11 and Figure 12.

Figure 12 - Blockchain Workbench Smart Contract app

Step 5 – The monitoring process was automated by the Logic app which performs "two actions – one related to user creation and the other to delivering the telemetry data. The Logic app is then pointed at the Service Bus which is populated by the IoT Hub" [40].

The Logic app (Figure 13) by default is configured to get triggered every minute to process any new message that is delivered by the IoT hub. Upon finding a new message, the Logic app creates messages as appropriate for user creation or executing the "Ingest Telemetry" function [40] until the life cycle is completed.

Figure 13 – Logic App functions

Step 6 - The time-series events and activity were recorded inside the Blockchain distributed ledger validated by Ethereum Blockchain consortium. The DLT contained some data, the hash of the block and the hash of previous block. In this instance, each block stores the details information about temperature, humidity and occupancy. Once data recorded inside the Blockchain, details of the contract become immutable. This information can be viewed at any point in time in the Blockchain explorer (Figure 14).

Figure 14 – Blockchain Explorer

4.0 FINDINGS

The simulated application, though small in scale, was able to critically examine the ability of the Blockchain technology and its characteristics to harmonize BIM and IoT data silos.

Upon examination, a connected and distributed Blockchain backed system provides integrity for transacted information between BIM and IoT environment. Verified data received within the environments were validated, recorded, and registered in the distributed ledger by a network of computers. This offers a foundation for a more transparent, secure, and better data exchanges model. This underlying mathematical Blockchain consensus will not only allow appropriate access to verified data but also improved quality control over individual data element between technologies and gave maximum flexibility over what data is shared and how. Such a holistic view of a single source of truth among participants can be achieved when trust is distributed, and consensus is applied to transactions with no central point of failure. Thus, the proposed Blockchain based systems and applications have the potentials to change organization culture, encourage information sharing, and improve collaboration between a BIM and IoT environment.

Findings demonstrated that the automation in data processing improves validation speed and efficiency of the data sharing in a BIM and IoT environment. Faster processing will also reduce the overall operating cost. This is an excellent economic case for businesses and supply chains. Furthermore, the virtual models can be used for developing operator training simulation systems, troubleshooting, production optimization and failure diagnoses. This is a powerful application during the O&M stage.

Further examination finds that the underlying Blockchain verified time-series datasets from BIM and IoT devices are useful for predictive data intelligence in the built environment and, to obtain an accurate future prediction, ie; a sequence of day-to-day air temperature datasets can be used to forecasts the life expectancy of materials. The integrity and validity of information presents in the Blockchain network constructs a world of analytics potential for technology such as deep learning, machine learning (ML) and artificial intelligence (AI) to train and create a robust neural network [41].

The output results from the Smart Contract indicated that immutable proof established by Blockchain consensus created trust in data management. By establishing relationship, trust can build upon BIM and IoT environments. Connected data could prevent anomalies and eliminate information loss and fragmented communication between architects, engineers, contractors, and facility managers.

Blockchain integration could correspondingly pointedly minimise the overall costs in resolving reconciliation while mitigating errors and the build-up of unreconciled items at each stage of a project, which needs data authentication by automating trust. This ability will allow organizations to act timely consistent. Such a thought-driven process will promote ethical business and data governance between the parties involved. Without intermediaries, the smart contract enables a faster and efficient data models validation process. This multi-directional integration of smart contract and Blockchain applications in the BIM and IoT process will ultimately provide a value that can facilitate organisations improving their productivity, quality, and transparency in collaboration. This feature will revolutionise how contracts and processes are managed in the AECO industry in the future.

Furthermore, the Blockchain technology supported the standardisation of data by setting up a harmonised digital platform for BIM and IoT data accessibility. The combination between these technologies could offer greater data provenance and complete traceability of known events between multiple parties in the collaborative silos.

Perhaps by emphasizing Blockchain's potential role in promoting better collaboration and integration between BIM and IoT environment would reveal the real benefits of leveraging these technologies would finally be utilized. Harmonizing data silos encourages the AECO industry landscape to develop into a more collaborative, flexible, and creative environment, as the community promotes a transparent, interconnected, and distributed ecosystem that upholds trust. Originality and value of the building life cycle can be redefined.

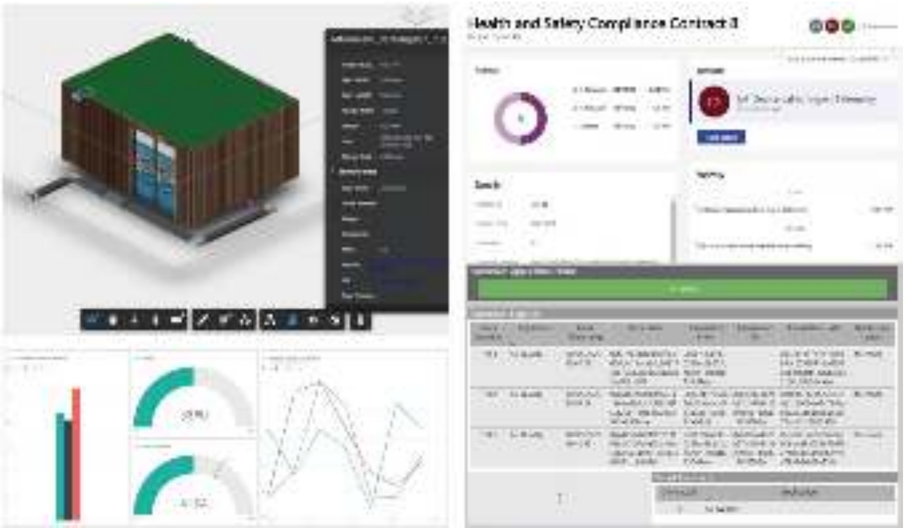

Figure 15 - Power BI dashboard.

5.0 Discussion

Blockchain technology implementations in the BIM and IoT integration promise many benefits for the AECO industry. However, this integration has shown various adoption challenges.

One of the major challenges in this integration is scalability. Gartner Inc. forecasts, about 25.1 billion IoT devices were estimated to be installed by 2021 [42]. Such massive number of connected devices require a larger network for transaction verification. Increasing block size limit in the Blockchain network can cause verification delay and will turn into an expensive transactions bottleneck [43]. This scalability issues put limits to how data can be processed in a decentralized application. This limitation of the current Blockchain technology must be addressed before it can become a fully mainstream solution for the BIM and IoT integration.

Scalability issue in the Blockchain network could be solved with a new consensus algorithm, but it requires altering the Blockchain code which will expose the Blockchain network into another security challenge. Security is imminent for any decentralized businesses; any technology breach or security threat can lead to substantial losses. For example, the Decentralised Autonomous Organisation (DAO) Attack on 17 June 2016 by unknown hacker has resulted in the loss of 3.6 million Ether, or worth more than 1.3 billion dollars in today's market. The only solution to fix the flaw code was to "hard-fork the Blockchain and revert it to the safe state. This remedy defeats the core values of Blockchain, such as immutability, decentralised trust, and self-governance" [44]. More emphasis must be placed on security policies, best practices, and intelligent security tools.

The absence of a suitable Blockchain-based platform for managing, creating, and deploying BIM and IoT services for AECO industry creates an interoperability issue and possibly new fragmented silos if implement. Therefore, future research should focus on developing a reliable blockchain network with a set of Open protocols and Open standards that promotes a community development and support all applications instead of introducing the application on specific networks. This will eliminate data lock-in by specific vendor and reduce vendor dominance in IoT market.

Numerous Blockchain projects have attempted to create solutions for every industry. The race of becoming the first and leading project has defeated the purpose of having a reliable Blockchain network, because such act simply recreates collaboration silos and has caused a tremendous amount of energy waste in the past decade. The economic challenge of Blockchain technology adoption must be evaluated carefully if not, this could be another waste for the AECO industry. Therefore, formulating regulations for economical, reliable, and accessible Blockchain network for the AECO industry is vital for the technology to grow and benefit our built environment.

The organizational challenge must also be considered. The lack of awareness and assessment in the AECO organisations is the major issue. Therefore, a strategic approach for accessing education, training, research, and development solutions must be planned. Yet such measures were understood as the common obstacles for any new technology to mature, and there are limitations as a result. Therefore, the continuation of learning and support from the industry is critical for these technologies to succeed.

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Integrating Computational Design into Structural Engineering Workflows to enhance Design Automation

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Abstract – Structural engineering consultancy firms commonly adopt one or more software solutions to develop structural engineering models for the purpose of analysis and technical design (e.g. Robot Structural Analysis Professional), while a different software solution is utilised to develop contract documentation (e.g. Revit). Where not explicitly linked, such workflows lead to duplication of effort and increase the risk of inconsistencies and inaccuracies in the contract documentation. In contrast, the increasing prevalence of three dimensional information centric models developed to align with Building Information Modelling (BIM) approaches, offer potential for computational design workflows that incorporate visual scripting. Incorporating such practices offer the potential for enhanced efficiencies and opportunities for structural engineers in developing design solutions. This paper explores the integration of computational design workflows in the structural design and documentation for a prototype building structure. The automation of a parametrically controlled analytical model & BIM model through the use of visual programming is presented. Dynamo, an open source visual programming language and add-in within Autodesk Revit, acts as the direct linkage between the structural analytical model developed in Autodesk Robot Structural Analysis Professional and the BIM Model developed in Revit. This integration has been found to reduce the time and effort required to create the BIM model, analytical model, drawings and schedules of quantities in the concept design phase as illustrated in the results section of this paper. A design science research methodology was employed which outlines as its core mission "to develop knowledge that can be used by professionals in the field to design solutions to their field problems" [3].

Keywords – Computational Design, Automation, Dynamo, Structural Engineering

I Introduction

Computational design is an approach whereby a designer defines a series of instructions, rules and relationships that precisely identify the steps necessary to achieve a particular design result and data [4]. It is the application of computer programming to the design process, which enables but is not limited to creating parametric relationships in design geometry and task automation. This paradigm shift approach amongst designers is becoming the prominent approach for leading Architectural and Engineering Practices involved in freeform design projects as the Industry continues to push the boundaries for such structures.

Computational design environments such as Dynamo for Autodesk Revit utilise a visual programming interface to assemble computer-programming language graphically rather than using syntax or text based script programming [5]. The emergence of such user-friendly computational design tools has led to an increased adoption of computational design within the Architecture, Engineering and Construction (AEC) Industry. The most common visual programming tools used for building design include Dynamo [5], a Visual Programming plugin for Autodesk Revit and Grasshopper a Visual programming plugin for Rhinoceros 3D [6].

While computational design has made its name in spectacular free form designs such as the museum of the future in Dubai [7], it also offers great opportunities for enhanced efficiency and automation in the traditional structural engineering workflow. Structural engineering consultancy firms commonly adopt one or more software solutions to develop structural engineering models for the purpose of analysis and technical design, while a different software solution is utilised to develop contract documentation or BIM Model. Such workflows lead to duplication of effort and increase the risk of inconsistencies and inaccuracies in the contract documentation.

Computational design is suited to a wide variety of structural forms, but is particularly suited to common structural forms such as elemental frame structures. For such structures, the rules defining the geometry of the building are easily defined parametrically in the form of design parameters such as frame spacing, height, width and secondary support member spacing's.

This research sets out to explore how utilising Dynamo, as the basis of a computational design approach, can assist in streamlining processes and providing enhanced efficiency in the structural engineering workflow. The paper aims to demonstrate how parametrically created geometry in Dynamo can be automated and utilised for structural analysis, technical design, production of contract documentation as well as quantification. The visual programming script that was developed builds upon an existing script developed by Tomasz Fudala [8] to include quantification. As part of a DSR approach, efficiencies that result are evaluated and feedback is sought from Industry professionals who may incorporate such an approach.

II Methodology

A design science research approach (DSR) was adopted for the research presented in this paper. Design science outlines a cyclical development and evaluation process which can firstly outline an issue in the built environment; propose that a new process or technology could solve this issue and subsequently evaluate if the new solution is successful for its intended users and in its intended environment [2]. The DSR process is illustrated in Figure 1. The fundamental principal in DSR is to develop industry-based solutions that can be adopted and applied in practice by professionals.

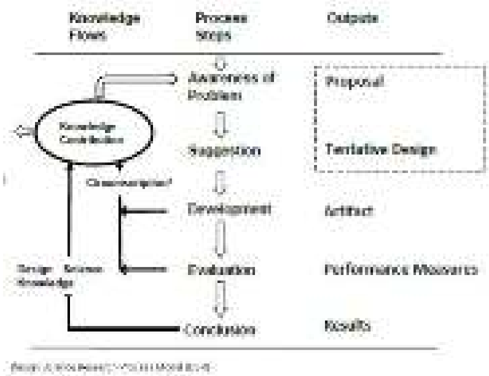

Fig. 1: Design Science Methodology [2]

To illustrate how computational design can enhance efficiencies and automation in the typical Structural Engineering workflow, Dynamo the visual programming plugin for Autodesk Revit was utilised. The workflow illustrated in this research expands upon the original design automation in structural engineering workflow developed by Tomasz Fudala [8] by programming a BIM model and steel quantification phase to the original workflow. The script highlighted in Figure 17 is based upon the original workflow developed by Tomasz Fudala to include BIM model automation and Figure 18 illustrates the quantification script that has been developed during this research.

III Overview Of Script Development In Dynamo

Dynamo contains an inbuilt library of out of the box nodes (OOTB), grouped under different headings to distinguish between the various functions the nodes are programmed to execute [5]. As Dynamo is a free open source programme, additional nodes can be sourced through the package manager within Dynamo in the form of packages. Two external packages utilised as part of the scripts developed for this research included "Structural Design" created by Tomasz Fudala and the "Structural Analysis" package. The aim of the script development phase was to:

- Demonstrate a script where parametric geometry/data could be automated and shared through the different phases of the structural engineering workflow from Structural Analysis/Design, to BIM Model development and quantification.
- In accordance with a DSR approach, build upon the original workflow developed by Tomasz Fudala to include quantification of the design.

The workflow is not fully autonomous and does require the user to input data at different stages of the process as identified in Figure 2.

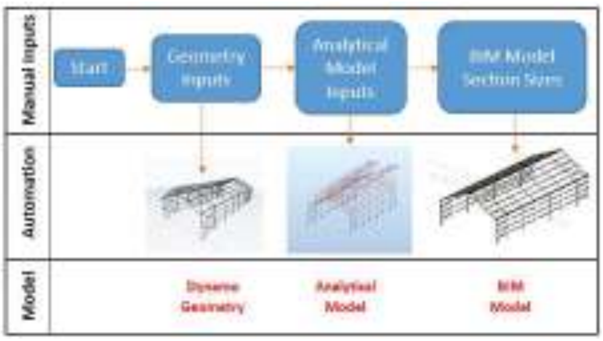

Fig. 2: Manual and Automated tasks

The final script as illustrated in Figure 17 was split into a number of groups to signify key phases or stages in the workflow, which include:

i. Creation of parametric geometry within the Dynamo Graphical User Interface (GUI).

ii. Conversion of the Dynamo geometry into a structural analytical model with associated parameters such as actions/loads and supports, release conditions, all of which are defined within the Dynamo GUI. Once the parameters are defined, the Analytical model is automatically created within Autodesk Structural Analysis Professional

iii. Following manual completion of the iterative Structural Analysis/Design process within Robot, the designed section sizes can be defined within the Dynamo GUI, which then automates the creation of the BIM mode within Revit for documentation.

iv. Finally the steel frame can be quantified and exported in excel format through the use of a separate script to automate the creation of a bill of materials.

IV Dynamo Script Development

a) Parametric Frame Geometry Parameters

The first phase of the script requires the user to define the geometry parameters for the structural frame using integer slider nodes as illustrated in Figure 3.

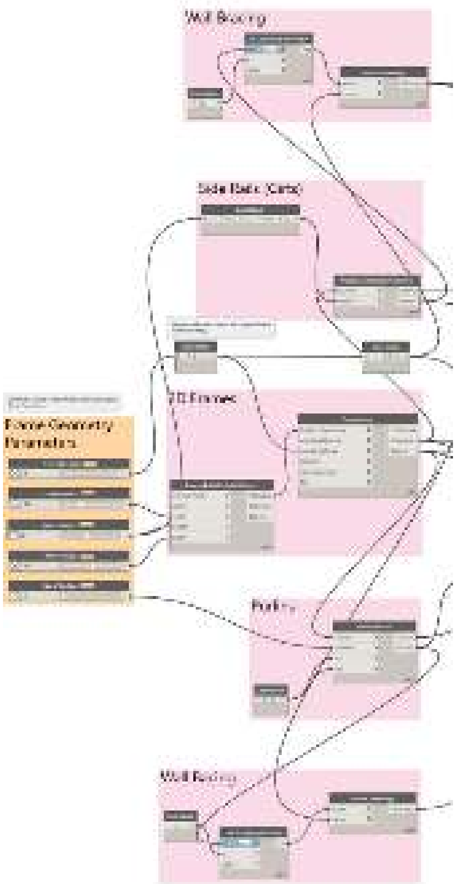

Fig. 3: Node group to create Dynamo Geometry

The nodes, as highlighted in orange include geometry parameters such as frame spacing, height, width and secondary support member spacing's.

b) Parametric Dynamo Geometry

With the geometry parameters defined via the integer sliders, nodes available within the "Structural Design" package such as *Frame.ByWidthHeightAngles*, *Frame.Purlins* and *Frame.XBracing* read the integer sliders to create the Dynamo "Stick Frame" Geometry. These nodes are highlighted in the magenta group in Figure 3.

Once the script is successfully "run", the geometry becomes visible within the Dynamo GUI as illustrated in Figure 4. The sliders may be adjusted and the script may be run again in an iterative process to "flex" the parametric geometry and to define the most suitable concept frame arrangement. The concept frame is then ready for the next processing phase of the script.

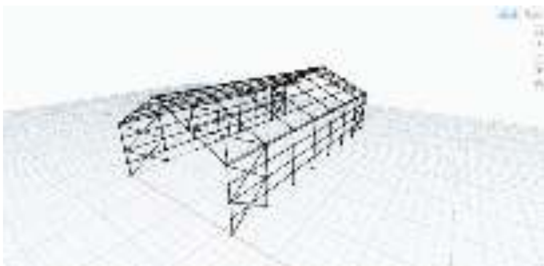

Fig. 4: Dynamo Geometry as viewed in Dynamo

c) Analytical Model for Structural Analysis & Design

With the Dynamo geometry created, the analytical model may be defined using nodes available within the Structural Analysis package as highlighted by the blue group in Figure 5. The *AnalyticalBar.ByLine* node may be used to convert each of the line elements of the Dynamo Geometry (2D Frames, Wall Bracing, Side Rails, Purlins & Wall Bracing) into analytical lines, which may be read by Autodesk Robot Professional.

Additional parameters to be defined for the analytical model include the cross sectional properties of analytical lines, the boundary conditions (supports) and end realeases, structural material and load/action cases. These parameters can all be applied within the Dynamo GUI via nodes avalable in the Structural Analysis package.

Cross section profiles are loaded by direct reference to the Robot Library using the *Bars.LoadSections* node for steel or timber sections. The sections that the user may intend on assigning need to loaded within the active Robot model in order for them to be applied to the model. When the sections are availble they may be assigned via the *AnalyticalBar.SetSectionByName* node.

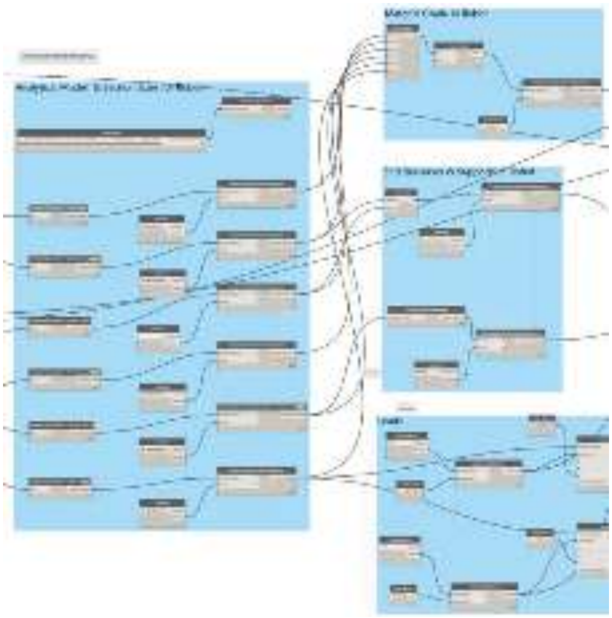

Fig. 5: Node Group to create Analytical Model

Definition of the boundary conditions including supports and end realeases has a significant influence on the overall structural behaviour that will be simulated within the Structural Analysis Model. The *AnalyticalNode.SetSupportByName* node may used to assign supports (fixed, pinned, etc) to specific nodes within the model. Similarly, the *AnalyticalBar.SetRealeaseByName* node may be used to apply "Pinned" or "Fixed" end restaints at the beginning and end of analytical line members.

Both load cases and load case combinations can be applied and defined within the dynamo GUI prior to running an analysis within Robot. Node, line and surface loads can all be applied to the model depending on how the structural engineer idealisies the load application whether that is through seconday members or applied directly to the primary members. For the script developed as part of this research, load cases and their associated line load magnitudes were defined in Dynamo with the combination cases to be defined within Autodesk Robot prior to running the analysis. The load case definition and applications of line loads were applied using the *LoadCase.ByNature* node and UniformMemberload.ByBars node. Figure 6 illustrates a view of the analytical model as viewed in Autodesk Robot Structural Professional GUI once the script has successfully run.

With the analytical model in place, running a structural analysis and subsequently carrying out the technical design can both be done within Robot. This is a cyclical process as illustrated in Figure 17 where preliminary members sizes may be changed within the Robot environment requiring the analysis to be "rerun" to calculate the relevant actions on each of the current members as the frame stiffness changes in line with the chosen section sizes.

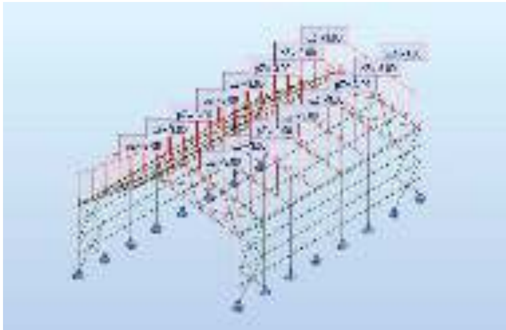

Fig. 6: Analytical Model as viewed in Robot GUI

d) Building Information Model

With the structural analysis and technical design process complete, exporting the final steel frame geometry to Autodesk Revit to create the BIM model may be done from within Dynamo GUI. To create the BIM model, OOTB nodes such as *StructuralFramingTypes* and *StructuralFraming.BeamByCurve* may be used to export the correct structural member sizes to Autodesk Revit, as determined during the technical design phase in Autodesk Robot. Figure 7 illustrates the typical nodes used as part of BIM model node group. The BIM model as viewed in Autodesk Revit is shown in Figure 8.

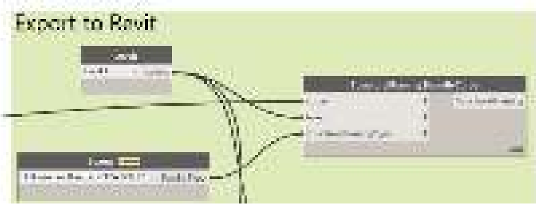

Fig. 7: Node Group to create the BIM model in Revit

Fig. 8: BIM model in Autodesk Revit

e) Qunatification/Bill of Materials

With the BIM model developed, the final task to complete the structural engineering workflow is to add a steel quantification element to the script. At the time of writing this paper, up to and including Autodesk Revit 2021, Revit Type Property parameters such as the nominal weight parameter are not available to be scheduled using the native scheduling function within Revit. Users are required to manually configure calculations within the schedule to extract the desired information or create a shared parameter for the nominal weight parameter so that it may be scheduled

Alternatively, as illustrated in this research, a Dynamo script can be developed; separate to the primary script which is to be run when the BIM model has been developed. The quantification script as illustrated in Figure 18, automates the process of extracting data for the structural steel frame from the BIM model and pushes the information to MS Excel to document quantities. The quantification script was split into a number of groups that include the "Discovery & Retrieval of Information" group as highlighted in green in Figure 9.

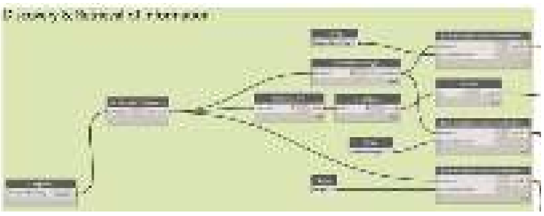

Fig. 9: Quantification Script – Information Retrieval

Utilising OOTB nodes such as *Categories*, *AllElementsofCategories, Element.ElementType and Element.GetParameterValueByName,* instance parameters and type property parameters such as Nominal Weight and Section Key Name can be accessed from within Revit. Once the data has been retrieved, lists may be used to sort the data and mathematical operators employed to quantify steel tonnages as illustrated by the grey group in Figure 10.

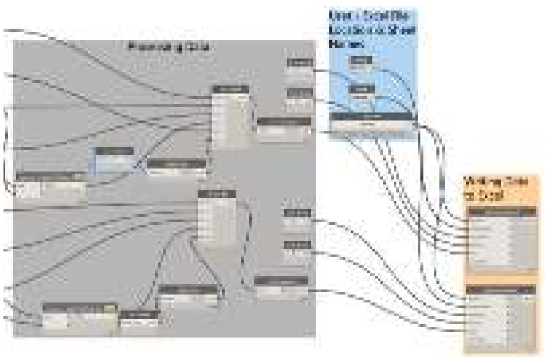

Fig. 10: Quantification Script – Information Processing and Writing to Excel

Finally, the data can be written to an open source file such as MS Excel using the *Data.ExportExcel* node. Amongst the advantages of such an approach, include the efficiency with which the process can be carried out as well as maintaining a consistent flow of information throughout the workflow. An exemplar output from MS Excel is shown in Figure 11.

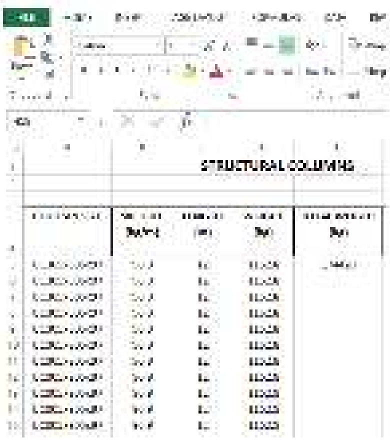

Fig. 11: Excel Output

V Results

The original script/workflow developed by Tomasz Fudala [8], which has been demonstrated and further developed as part of this research to include BIM Model development and quantification, greatly enhances the efficiency of structural engineers to analyse, structurally design, document and quantify their structural designs. In an attempt to quantify some of these efficiencies, the Authors recorded the time taken to manually create elements of the workflow that have been automated using Dynamo.

For the Analytical Model development in Autodesk Robot, the time taken for each of the typical manual analytical modelling stages for a steel frame structure were recorded. The recorded times (min) for each of the analytical modelling stages are illustrated in Figure 12.

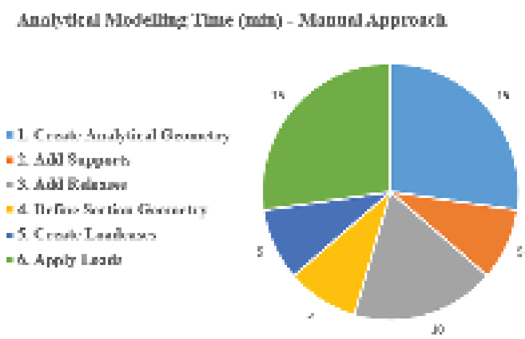

Fig. 12: Recorded time (min) to create the analytical model manually

The results of time taken to manually create the analytical model were compared to the time taken to create an identical analytical model using the visual programming script. The results are illustrated in Figure 13 with an overall time saving of approx. 50min.

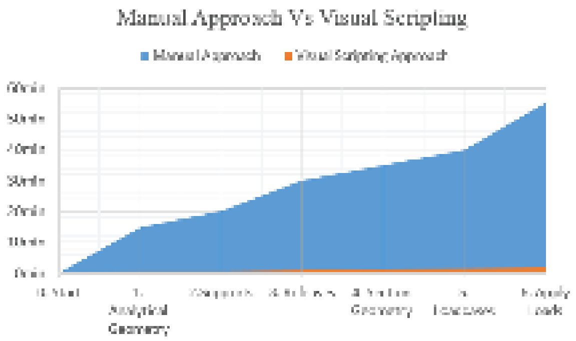

Fig. 13: Manual Approach Vs Visual Programming for Analytical Model Creation

For the BIM Model development in Autodesk Revit, the time taken to model each of the steel frame element types was recorded. The recorded times (min) for each of the Revit Family types is illustrated in Figure 14.

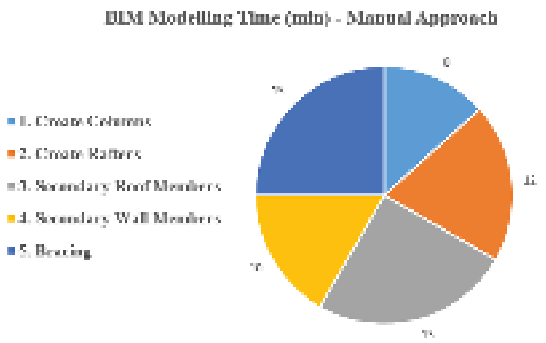

Fig. 14: Recorded time create BIM model manually

The results of time taken to manually create the BIM model were compared to the time taken to create an identical BIM model using the visual programming script. The results are illustrated in Figure 15 with an overall time saving of approx. 60 min.

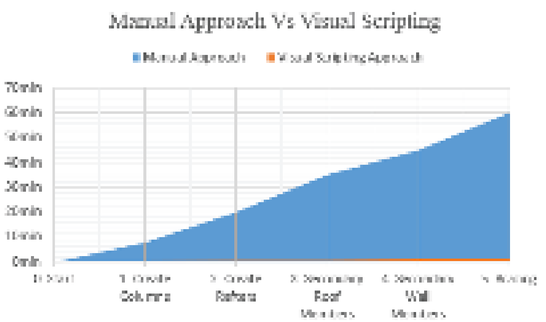

Fig. 15: Manual Approach Vs Visual Programming for BIM Model Creation

For the steel quantification script, the process of extracting the data from a BIM model using Visual programming is different to more conventional approaches such as utilising schedules within Revit. It was more difficult therefore to make direct step by step comparisons given the different steps involved in these two different approaches. However, the overall time to carry out the process using both a manual and visual programming approach were recorded. The overall time saving by using visual scripting was estimated to be in the order of 20min as illustrated in Figure 16.

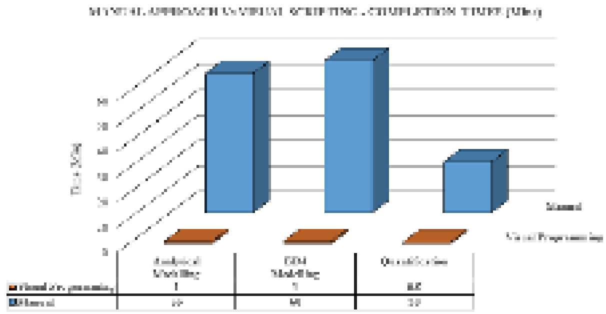

Fig. 16: Manual Approach Vs Visual Programming – Overall Comparison

VI Discussion

Visual programming, as part of a computational approach, offers great potential for enhanced efficiencies and automation in the structural design process. The results presented in this research show clear time savings where routine or repetitive design tasks may be automated within the overall design process. Such time saving opportunities will be of great interest to engineers looking to adopt such an approach. Like any new or novel approach, it is not without its limitations, which need to be understood if the greatest benefits of such an approach are to be realised.

There can be considerable time investment to develop and prototype innovative scripts. The development process will follow a cyclical process of testing and refinement before a final prototype script is realised. Like any new technology, there is also an initial learning curve to be overcome. It is encouraging to note however, that the increased usage of Dynamo for visual programming within the AEC sector has led to the development of many useful and purpose built "packages" which may be downloaded within the Dynamo GUI. Packages such as the "Structural Design" package for example as demonstrated in this research, enables amongst others for the rapid creation of frame geometry using purpose built nodes. Creating such frame geometry utilizing only OOTB nodes can be a more labor intensive tasks.

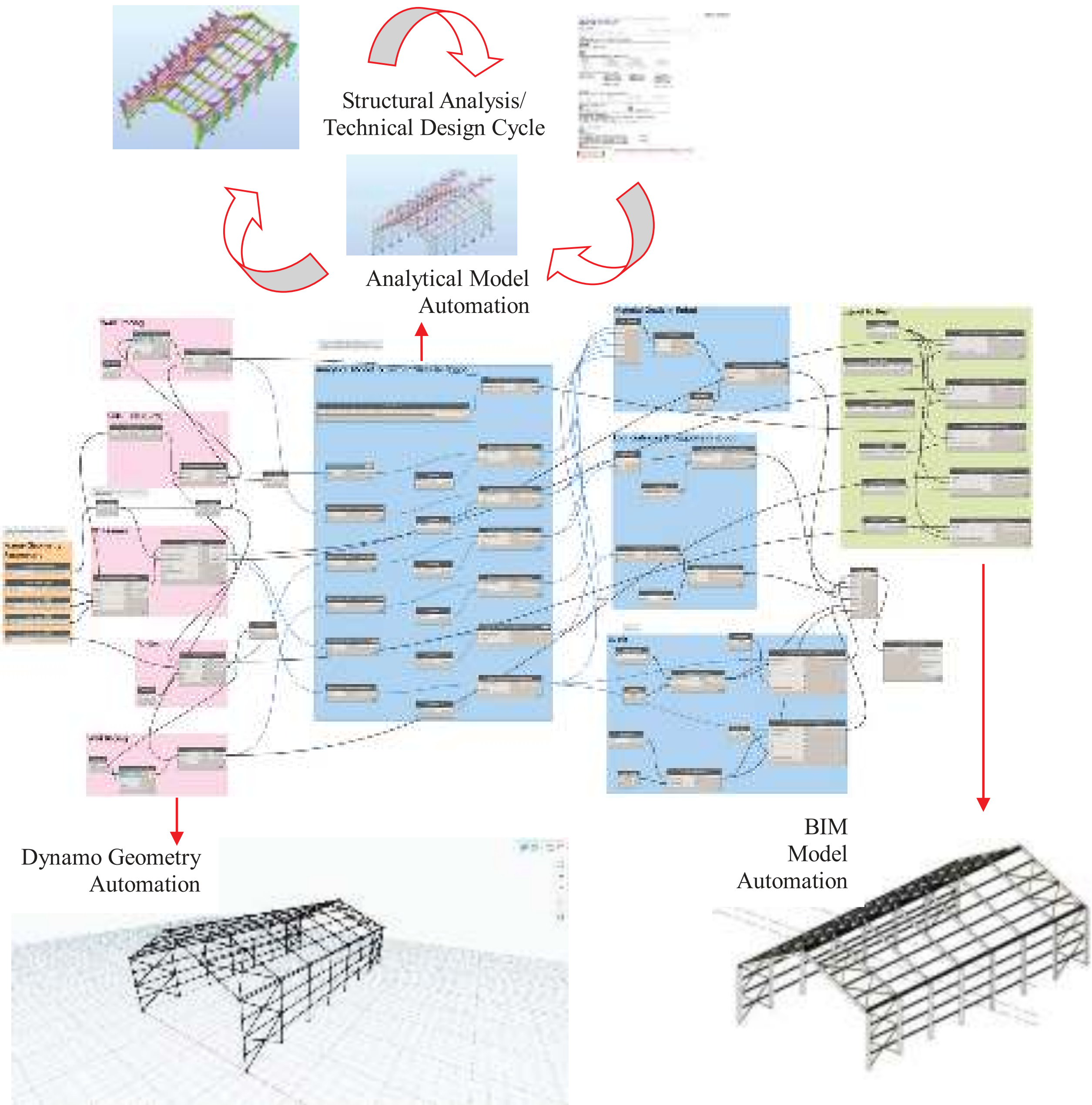

Fig 17: Script No 1 - Design Automation in Structural Engineering [8].

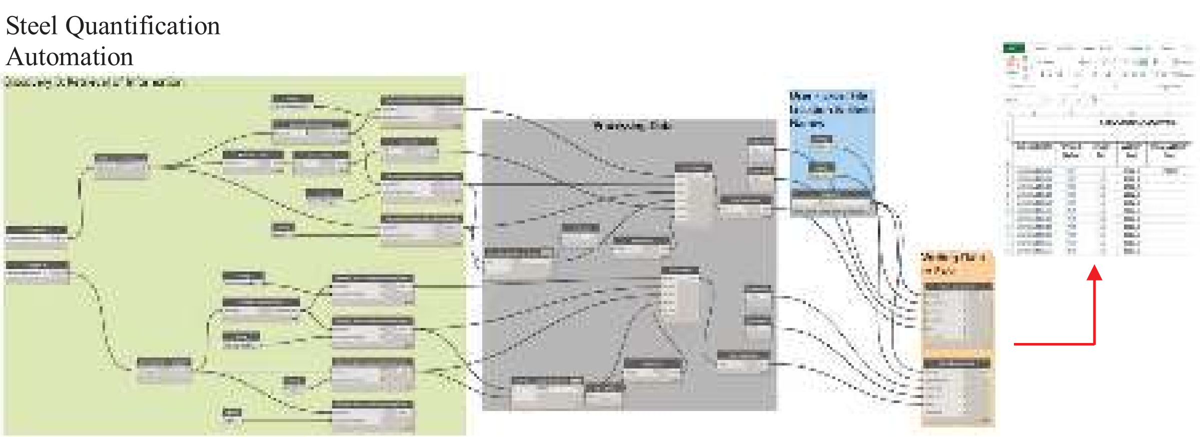

Figure 18: Script No 2 - Steel Quantification Automation.

Packages were utilised as part of this research to exemplify the benefits they can bring to the visual programming and script development process by facilitating more efficient scripting than may otherwise have been possible utilizing OOTB nodes only.

Amongst the greatest benefit however of adopting visual programming in the structural engineering workflow is the ability to maintain a consistent flow of design data from start to finish in the design process. There is no repetition in geometry creation and data such as loads, supports and the final BIM Model section sizes may all be controlled and defined within the Dynamo, the Visual Programming linkage between each of the software's.

VII CONCLUSION

This research paper set out to explore how computational design principles are being incorporated into the workflow of the structural engineer to assist with Design Automation. Dynamo, an open source visual programming language and computational design tool embedded within Autodesk Revit was used to shown how such an approach may be achieved. The structural design, documentation and quantification of a prototype steel structure utilizing a computational design approach has been presented. Amongst the advantages of adopting such an approach, include the ability to automate repetitive tasks such as the Analytical Modelling and BIM Modelling. However perhaps the greatest benefit of such an approach is the ability to access and extract the information rich BIM data and write to open source formats such as MS Excel.

This research has shown the clear and quantifiable efficiencies that may be achieved by incorporating dynamo into the structural engineering workflow. Automating tasks such as the analytical model creation, the BIM model creation and the quantification of the steel structure, can release the engineer for more creative and innovative endeavors.

Engineers are problem solvers first and foremost, who follow a logical sequence of steps, executed using specific sets of tools to create a considered and coherent output or data [9]. While the fundamentals of the profession have not changed, the engineering profession is constantly evolving. The fundamental steps, tools and data are becoming increasingly digitised offering increased opportunities and insight for the future engineer.

The future engineer therefore will be part software engineer capable of computer programming and part data analyst [10]. Such skills will enable engineers to develop analysis tools that transition away from exploring single solutions along linear design paths to being able to explore and optimize an infinite number of solutions in quick succession.

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The Digital QS

A Critical Review of the Requirements of Quantity Surveyors for Collaborative BIM Engagement and Success

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Abstract−This paper sets out to critically review the requirements of Quantity Surveyors (QSs) for collaborative BIM engagement and success. The paper has been set in the context of the Irish QS and their ability to actively and collaboratively engage in the 5D QS BIM process (5D –the fifth Dimension designated to QSs). A literature review was undertaken to establish the reasons for this lack of QS engagement. The data from these reviews was collected, analyzed, and distilled into the main challenges that required resolution to engage QS participation in the 5 D BIM process. A mixed research methodology based on the principles of Fourth Generation Evaluation was employed as this allowed for both Quantitative and Qualitative Analysis. The Focus group members were carefully chosen given their experience and knowledge of the barriers faced by QSs. Different stakeholders were chosen to get different perspectives and views on the problem and how these can be rectified. The paper outlines that the key challenge remains specifically around 5D QS MVD (Model View Definition). There is no universal QS MVD as this would require the adoption of a standardised approach to costing and different countries, disciplines and segments have their own unique approach to costing. The Irish QS needs to collaborate with other designers and software vendors to develop a QS MVD to harvest the full benefits of what BIM can offer. The future is full of new opportunities for the QS's who seek to embrace 5D BIM. This will lead to the delivery of new services, such as carbon and energy costing; cost data analytics and extend the QS reach into new areas spanning complete asset lifecycle.

Keywords − QS's, BIM, MVD, ARM4,QS Barriers to Uptake, BIM Mandate

I Introduction

This research paper sets to critically evaluate how Quantity Surveyors (QSs) engage with Building Information Modelling (BIM). It also sets out to establish what is required for the QS's to actively and collaboratively engage in the BIM process and resolve these issues for themselves in conjunction with the other design team members and if required software vendors. The literature review is used for data collection and analysis.

Today many Quantity Surveyors (QSs) execute their core functions in the same traditional conservative non–digital manner extracting quantities from 2D design drawings. For many technological advancements has been limited to onscreen 2D/3D Quantity Take off (QTO). There is a traditional mind-set engrained in both the QS discipline education and in the practice of Quantity Surveying not to embrace the greater potential of BIM. BIM has been described as a game-changing [1], however this change has generally not happened for the QS [2].

The traditional role of the QS is to provide the basic services of cost management of a construction project with regard to forecasting, analyzing, planning controlling and accounting [3]. Traditional services are at the heart of current Irish QS practices [4].

The QS has generally not engaged in the BIM process. This research sets out to examine the reasons for and possible solutions to this lack of engagement in BIM. The software vendor industry has concentrated largely on the designers largely ignoring the QSs who are main consumers of the design data.

II LITERATURE REVIEW

There were major concerns that the QS is not deriving adequate benefits from the typical BIM models that are currently produced by design teams [5].

There are a number of contributing factors to this problem [6], [7], [8], [9] such as

- designers not fully understanding the role of the QS in relation to 5D BIM,
- not knowing the level of detail and information required at specific stages,
- their belief in the myth regarding full automatic quantification and lack of understanding of costing software,
- Object detail versus cost detail.

The biggest barriers for QS firms adopting BIM were cited as the lack of client demand, training, application interfaces and software [10]. There is a BIM gap in QS training with a lack of QS application interfaces and fully developed and integrated QS costing software [11].

The RICS in their Information Paper "Overview of a 5D BIM project" [9] noted a number of issues (which posed their own risks and needed to be overcome) concerning the QS within a working BIM environment. Many QS barriers to collaboration in BIM have been identified and these are broken down into three areas namely, people, processes and technology.

QSs generally are not software/digitally literate compared to designers. The greatest value to a modern day QS "lies in their ability to be 5D literate and to be able to utilise electronic models to provide detailed 5D estimates and living cost plans in real time " [10].

There is now a realisation that the QS not only need to be proficient in 5D software but they will also need to be able to understand and utilise designer software if they are to sort out software compatibility/ interoperability issues, as well as facilitating the interrogation of the models, to push and pull data as and when required and function fully in a 5D BIM collaborative environment.

In Holzer's paper "BIM's Seven Deadly Sins" exposed seven prevailing practices that affect the uptake of BIM for Designers, which are also relevant for QSs [12]. These include technocentricity; ambiguity; elision; hypocrisy- the IPD excuse (integrated Project Delivery); delusion- asking for 2D while requiring 3D; diffidence - denying the need for process change and mono-disciplinarity - design exploration in professional silos, these are further addressed in Sections IV and V.

The quantity and quality of information entered into the model and collected in the model during the design phase has a big impact on Bills of Quantities (BoQs). Furthermore, the information within the model affects the success of the construction project and consequently significantly influence the costs of the construction works [6].

Some companies have been hesitant to invest in BIM simply because the traditional method has worked for so long; and it is always risky to invest time and money into a new method that has not been tested and proven [5].

There was also a fear and mistrust among QSs of what automatic quantification might mean due to the knowledge that automation in its current state was approximately 61-80% (at best) BIM enabled and ,therefore, clunky and flawed [5].

Furthermore, neither discipline - design or QS fully understood or are prepared to rectify existing software deficiencies within their respective software requirements, particularly as they did not fully understand each other's requirements. Put simply, QSs are not designers. While designers think in pictures, QSs think in numbers. This accounts for some of the difficulties in relation to communication and collaboration between the disciplines.

There is a great lack of 5D case studies [9] from which to learn from others, to evaluate the findings, to stress test and learn lessons. Coupled with this, the UK Government in its level 2 BIM mandate (UK mandate 2016) only stated that this level of BIM ***may*** utilise 4D construction sequencing and /or 5D cost information. In sharp contrast to this the forthcoming level 3 BIM mandate states that 4D, 5D and 6D project lifecycle management information must be used.

Research and analysis on several leading market BIM-based cost estimation software program concluded that one of them suited the Polish market [13]. The authors set about devising their own costing system, specifically for the Polish Situation called the BIMestiMate and the BIM vision browser. The authors identified a number of flaws in their software including a lack of automatic simplified cost estimation and the inability to organize and save quantities by different classifications, such as Omni class or Uniformat. The authors hoped that their system would be evaluated as appropriate and applied in the Polish BIM-based cost estimation. The opportunities and solutions offered by the Polish application seem to have made a significant contribution to software development for QSs. However, this software has three major drawbacks namely quantities can't be organised and saved by different classifications such as Omniclass and lack of automatic simplified cost estimation and data can't be saved from cost estimate to the BIM model different which makes it unsuitable for universal adoption by QSs.

Current research identifies the problems but does not give the solutions [14]. The authors outlined similar QS issues with BIM but they did not chart a clear way forward or a workable solution to the problems. They showed that great strides been made in trying to make 5D BIM fit for purpose. However, they acknowledged that there are still inherently many software and interoperability issues for the 5D BIM QS.

Measurement ontology stated that, for generations, the process of cost estimation has been manual, time-consuming and error prone [15]. Emerging BIM modeling can exploit standard measurement methods (SMM) to automate cost estimation process and improve inaccuracies. Structuring SMM in an ontologically and machine-readable format for BIM software can greatly facilitate the process of improving inaccuracies [16]. The authors discussed the process that was undertaken, presented its limitations and successfully tested the core ontology on Navisworks. The authors stated that as part of a future study, this ontology would be tested on other BIM software systems such as Autodesk QTO. They expect that other end users can adapt or transform the complete ontology in this study to meet their various needs.

Smith explored the necessity for project cost management professionals to be integrally involved across all construction project phases and to embrace the 5th dimension. These adaptations would enable QSs to become key players in the BIM environment. He concluded that the greatest value to the modern day QS lies in their ability to be 5D literate and to be able to utilise electronic models, provide detailed 5D estimates, and living cost plans in (almost) real time [10].

The Irish Government has not as yet mandated Level 2 BIM (although it is imminent - OGP mandate for Band 5 Projects in Q2 -2019, followed by OGP mandate for Band 3 Projects for Q2 2020). Therefore, BIM is not presently a requirement for Public Procurement Works.

The proposed papers proposes to fill some of the gaps that were identified. The main findings from the Literature review has been to establish what are the barriers that are preventing QS's from actively and collaboratively engaging in the BIM process. These have been summarized as:

1. People - who operate in a cultural discipline silo mind-set where BIM is not currently mandatory.
2. Process – there is a lack of awareness, interest and QS expert knowledge in the BIM/5D BIM process.
3. Technology – there is a lack of suitably developed integrated 5D QS BIM software availability. Put simply there is no universal QS MVD (Model View Definition).

III METHODOLOGY

A mixed research methodology based on the principles of Fourth Generation Evaluation (FGE) was employed. This allowed both quantitative and qualitative analysis to be used [17].

The stakeholder interview members were carefully chosen because of their experience in the sector and for their interest in engaging with and advocating BIM to the highest standards. They had first-hand knowledge, of the barriers faced by QSs. and had examined many issues, claims and concerns but took the view that QSs must "stop sitting on the fence" and should instead engage proactively with other professionals to find solutions to the problems which when examined, were actually design collaboration, QS, process and technology problems.

These individuals were and are actively involved in different capacities in various BIM working groups (both nationally and internationally) and are at the forefront in advocating for the use of BIM. These QSs recognise that they are best placed to fix their own QS problems themselves. They recognised the need to adapt, upskill and collaborate and thus they have transitioned from the non-BIM to BIM -based environments.

See Fig 1 for the steps used in the mixed research methodology.

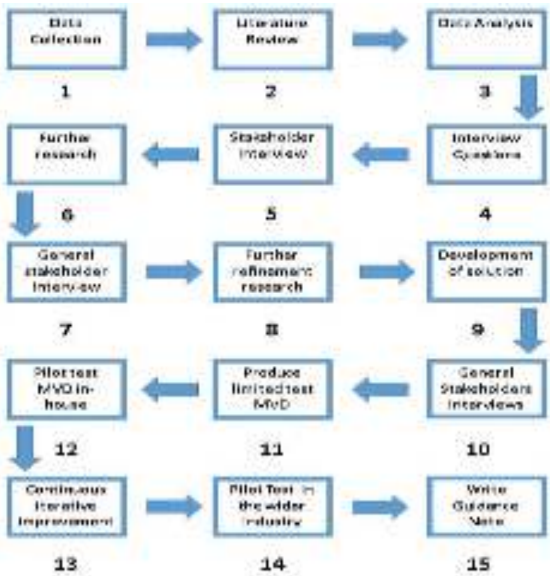

Figure 1: Steps used in Mixed research Methodology
(Source: Author)

Please note that steps 13, 14 and 15 are currently outside the scope of this research.

The literature review was used to research, analyze and distil the issues that QSs have in BIM adoption. This analysis was then used to produce interview questions, which in turn was used to elicit responses from the stakeholder group to the research question.

Different stakeholders were chosen to get different perspectives and views on the problems, as well as proposals on how the problems might be rectified. Some of the main stakeholders were interviewed numerous times, by either face-to-face interviews or telephone conversations to further develop and tease out the issues and the proposed solutions.

The main stakeholder group were interviewed numerous times using a combination of different interview techniques. The focus group comprised of 10 participants, 5 of which were QSs, three of the QSs were from the private sector, one from the public Sector and one from academia. Two of the other participants were structural engineers, one private sector and one public sector, two of the participants were software developers and vendors. The last participant was a public sector BIM architectural technologist. The general stakeholder group had three additional QSs for broader analysis of the issues and clearer refinement of the solutions, as well as two other design professionals.

IV QUANTITATIVE ANALYSIS

The desk study revealed a myriad of reasons for the lack of QS engagement in the BIM process. This quantitative data was then collected and analyzed under three main sections headings as illustrated in Figure 2.

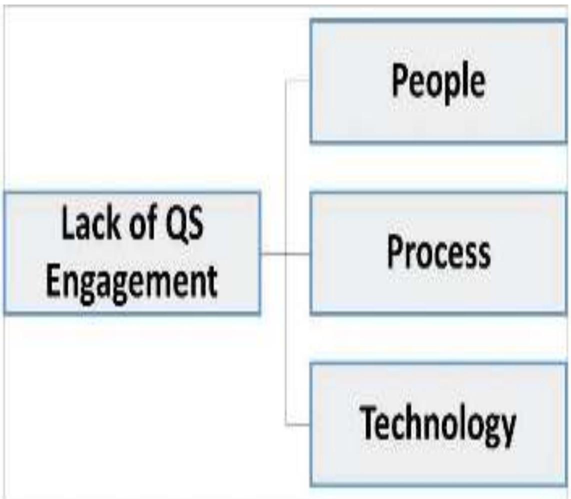

Figure 2: The three main reasons for lack of QS Engagement in BIM (Source: Author)

Under each of these 3 headings the problems encountered was listed and the author proposed solutions for discussion with and evaluation by the interviewees. The feedback received from the main stakeholder group informed the Interview questions in sown in figure 3.

1 People Problems

Problems encountered	Proposed Solutions
Traditional working still does the job, is within comfort zone and is low risk.	Raise awareness of the benefits of 5D QS BIM.
Silo discipline education.	Interdisciplinary modules in Undergraduate QS Degree Courses.
QS's are not designers, basically number crunchers	Need to understand how designers operate and collaborate with them.
Not mandated by the Irish Government.	Mandate BIM to drive change.
Need for cultural change- Mind-set 90% of issue.	Awareness campaigns by Professional Bodies. Seminars/ Workshops
No buy-in from management.	Show Return on Investment.
Myths about what BIM is – Still perceived as 3D CAD and clash detection.	Awareness campaigns, seminar/workshops by Professional Bodies.
Brexit seen as more imminent risk.	Government needs to include BIM within its priorities.
5D BIM not mandated within the UK level 2 (2016) mandate therefore QS's assumed not particularly relevant to them, thus slow uptake.	Raise awareness of the benefits accrued to 5D BIM uptake.
No exemplar 5D BIM Case Studies to learn from.	Exemplar 5D BIM studies required best provided by Academic Institutions.
5D BIM in its present state not a perfect solution – Too many inherent issues, so why bother?	Inherent issues are resolvable with collaboration from the Design Team.
5D Exemplar Case Studies difficulty to accrue owning to Client insistence on confidentiality, particularly in the Private Sector.	Adopt American system of using percentages Instead of numbers. Academic Institutions & Public Sector provide where possible
Not incentivized to engage or collaborate within the 5D BIM Environment.	Clients need to actively engage consultants for their professionalism in the 5D BIM Area. The Government needs to take the lead and mandate for Public Sector Projects.
Not paid for 5D BIM services.	Fees need to be restructured to include any additional 5D BIM services.
Lack of suitable integrated courses for the training of 5D BIM QSs or (short courses) for upskilling of existing working QSs.	Academic institutions need to restructure courses including continuous modules on ICT skills and on interdisciplinary collaboration.
Peoples anxieties – Fear of the unknown Being made redundant. New roles – new projects team configuration. New responsibilities. Changing work practices.	Leadership/management need to acknowledge and cater for these anxieties by providing training and resources together with meetings, informal evenings etc. explaining the new changes and allowing for question and answer sessions.

BIM Acronyms – With widespread use of this terminology it causes confusion & is off-putting.	Glossaries provides at all times with plain language explanations.
Difficulty in recruiting BIM -enabled staff and cost of training existing staff.	Invest in upskilling current staff – invest in delivering via Academic Institution BIM specific modules tailored to needs of the business.
Please note that the list of people problems is not exhaustive but are a result of this research.	

2. Process Problems	
Problems encountered	**Proposed Solutions**
Lack of QS expert knowledge in the BIM/5D BIM Process.	Awareness campaigns by the Professional Bodies- education gap for the Academic Institutions.
Industry not ready for "full blown BIM" e.g. planning process not transitioned to digital planning process.	Implement E-planning to accept BIM models while concurrency also accepting traditional planning applications.
Intellectual property (IP) and copyrights.	OGP (office of public procurement) are researching this with recommendations for Best Practice & eventual implementation.
Discipline roles not fully agreed and defined – Who is responsible for what role.	Roles need to be defined without ambiguity within the Construction Sector. The new roles need to be created Officially within the Public Sector – The Government BIM Mandate will accelerate this process.
IPD (integrated project delivery) BIM Maturity in Ireland is not there yet.	This requires substantial buy in from many stakeholders but most particularly from the Government and private sector clients.
Lack of specific definitions of distinct QS 5D BIM related activities/distinct BIM services as they are emerging in practice.	Need defining by the professional bodies showing added value of specific services – with associated spectrum of fees.
PI (professional indemnity insurance) and insurances generally relating to the construction industry have not fully integrated BIM within their provisions. There is lack of uncertainty regarding responsibilities, risk and legal status.	The professional Bodies, the Insurance Industry, the Construction Industry and the Government need to engage and collaborate on the resolution of these issues.
Sharing of risk fairly amongst Clients, Professionals , Contractors etc.,	The professional bodies, the Insurance Industry, the Construction Industry and the Government need to engage and collaborate on these issues. Look at the use of Integrated Project Insurance Models as one possible solution
Most SME Contractors not yet fully adapted for full BIM integration.	Overhaul of contracts required for early contractor involvement and integrated team BIM inclusiveness. Review and revision required by the GCCC Contract Committee
The integration of early contractor involvement – is a major mind-set change from the long established traditional method of design for designers, clients and even contractors.	Changes requires to contracts and procurement to allow for this. Suspicion over early contractor involvement will eventually be resolved by emerging standards and rules.
Lack of both budgets and expertise in setting up 5D BIM libraries and templates and for the training of staff in the use there in.	The professional bodies need to give guidance, develop and procure standard templates as well as involve the supply chain and technology vendors in the process.
Incomplete model audit trails	Rectified by ICT technology
Unclear standards – New ISO standards ready for usage with further new ISO standard evolving to replace the PAS Standards – in transition period.	Currently in a transition period where all the required Standards cannot be fully integrated into the Irish BIM process as yet, owing to uncertainty because of Brexit and continual evolvement of standards.
Naming conventions – causing some confusion and reluctance to use correctly – mind-set.	Education and awareness of benefits of proper naming convention as well as utilizing software to where possible automatically name.
Public sector in a vacuum when trying to agree & implement BIM Processes, SMP's etc. universally on large Public Sector BIM Projects as BIM not yet mandated by Irish Government	Ongoing process and discussion within Public BIM, an Alliance of Public Sector Bodies , trying to align Public Sector Processes
Unsuitability of ARM4 (agreed method measurement as not digitized, and not suitable for automatic quantities - Also outdated – Last revised 2009 pre- BIM.	A Working Group has been established to review and update in line with International Best Practice, modern construction methods and BIM integration
Classification used within ARM 4 currently under review as NSBE (An Irish System) no longer fit for QS's working internationally.	A Working Group has been established to review and update in line with International best practice & proposed adoption of ICMS Classification System
Clients not asking for 5D BIM service	Offer to Clients as a value added service

3. Technology Problems	
Problems encountered	**Proposed Solution**
Perceived cost (rather than investment) of software licences and cost of upgrading computer hardware and network capabilities.	Show significant savings through return on investments. The cost of software & ICT Maintenance should have a budget allocation In the business plan –the cost BIM should be an extra over ICT requirement.

Substantial cost of training staff in ICT.	Show the negative cost of not training and upskilling staff.
Lack of budgets.	Need to make case for investment and show pay back.
Different methods of modelling by different design professionals even within the same practice.	Adoption of standard approach of modelling (SAM). Similar to the Modelling Standard used by Hong Kong Housing authority.
Object detail verses cost detail.	Designers need to be educated regarding QS requirements.
Items not modelled.	Need linked schedules.
Items missing entirely.	Rely on QS Expertise.
Rogue items.	Rely on QS Expertise.
Items incorrectly labelled or modelled.	ICT issues with different software's.
Please note that the list of technology problems is not exhaustive but are a result of this research.	

Figure 3: The reasons for the lack of QS engagement in the 5D BIM process

Six key over-riding themes emerged from the interviews.

1. QSs had very little faith in the data in most current BIM Models, as they were incomplete, generally of poor quality and not modelled to a level suitable for the QS automatic quantification. All stakeholders saw this as the greatest barrier to QS BIM engagement.
2. In general, design teams had insufficient understanding of the role of the QS in relation to 5D BIM. This lack of understanding was a viewed as the second most significant problem by Stakeholder.
3. No QS MVD is available that allows for automatic Quantification. This was viewed by the stakeholders and the stakeholder as the single biggest advantage of BIM to the role of the QS in construction i.e. increased speed and accuracy of QTO (Quantity Take off)
4. There was a shortage of suitably skilled 5D BIM QSs who fully understood the BIM Process as well as having the necessary digital skills for interrogating models, pushing and pulling cost rich information.
5. BIM was not yet mandated by the Irish Government and was therefore not a requirement. This however has been categorised as a short-term problem by the author as the government mandate is imminent.
6. The BIM protocols, Standards, Contracts etc. were adopted from either the UK or pre BIM without being fully integrated into Irish BIM context. There are issues around IP (intellectual Property), copyrights, insurances, the legal status of the BIM model, and so on. This was further complicated by Brexit. However, this was seen more as a problem and an issue common to all the professionals than just a QS item.

V QUALITATIVE ANALYSIS

In the second phase of this research, the secondary stakeholder group was used to further refine issues articulated by the main stakeholders and expand the solutions presented with additional information from further research for their consideration. It was during this phase that opportunities for development and education arose and there was general consensus on both the issues and the possible solutions.

This was an iterative process and as the process was distilled, a number of stakeholders were interviewed numerous times. These personal interviews were advantageous as the participants spoke freely about their experiences, how they overcame issues and what insights they had gained and what could be improved upon on hindsight.

A very important insight from the research was that the QSs need to be realistic and pragmatic in their expectations and realise that BIM is not a perfect digital solution but an imperfect digital advancement with great potential. QSs in the traditional world accepted less than perfect un-coordinated drawings, frequently resulting in well- documented overruns in terms of time and cost. There is always some quantifiable data even in bad models and QS's need to know how to navigate the model and articulate their requirements by collaborating effectively with designers to acquire the information in a useful format.

a) BIM Process Challenges

The desk study review revealed issues with the BIM Process:

- Such as contracts and procurement not BIM aligned
- No Irish SMP's in place
- No proper BIM protocols in place
- Transitioning difficulties from the PAS standards to ISO standards
- What standards to use where no ISO standards in place
- Use of Uniformat or Omniclass
- The legal status of the BIM model
- The legal and practical implications of Brexit and so on.

The stakeholder groups were less concerned by the BIM process challenges revealed through the desk study. Since the National BIM Council (NBC) had produced a Roadmap to Digital Construction for Ireland's Industry 2018-2021 with timelines, funding and resources in place for resolving these process issues. The Irish Government recognized that these transitioning process issues pose significant barriers to the proper implementation of BIM and delivery of the Government's promise of a 20% reduction in project delivery programme, 20% reduction in capital costs and 20 % increase in construction exports [18].

These process problems were also common to other design professionals, contractors and clients and were part of the bigger BIM picture and not exclusive to QSs alone. The stakeholder group took the view that the mandating, implementing and practicing together (maturing) the BIM process would eliminate these problems through iterative revisions overtime. However, the main concern of the stakeholder group was that QSs proactively engage in those working groups so that QS voices are heard (cease distancing ourselves from the BIM process as we have traditionally been doing) and their needs articulated and catered for in the future solutions to BIM problems.

The stakeholder group also recognised that a number of the process problems could be eliminated by the QSs themselves,

- Becoming properly informed of what BIM is?
- Understanding the production and delivery of information
- Understanding team/data exchange formats and information drops,
- Having their QS requirements comprehensively incorporated into the BEP,
- Recognising when data or drawings are not complying with the BEP (BIM Execution plan).

These process problems can be addressed by the QSs fully engaging and upskilling in the BIM process, which, prior to now, was a question of lack of awareness and education and engagement.

b) Skills Shortages

The literature review revealed that QSs have a skills shortage particularly in the 5D QS BIM area. This is widely acknowledged within the QS Profession. A recent comprehensive report by Dr Roisin Murphy (2018) on "Employment Opportunities and Future Skills Requirements for Surveying Professions 2018-2021, predicted shortfall of 1,652 (taking a Median 3% growth) QS Positions spanning from Director to Graduate level to the year 2021 [19].

This news is hardly surprising following a deep and prolonged recession where numerous QS's emigrated and at the same time there was a large fall off in students entering the QS profession.

The predicted shortfall of 1,652 QS professionals is a concern when one considers that currently the total number of QS's (from Graduate to Director/Partner level) within the Irish Construction Sector stands at 4,327. The report states that if the pessimistic predicted growth of 2% should occur, the expected shortfall will be 898 QSs at all levels. On the other hand, should the optimistic prediction occur there will be a shortfall of 2,558 QSs (at all levels), and this will have consequences for the medium to long-term implementation of 5D BIM [19].

The desk study concurs and is consistent with the views expressed by the 5D BIM QSs stakeholders in this research. The large 5D BIM QS practices are actively recruiting QS graduates, who leave college with a promise of an immediate career progression.

c) Creation of a QS MVD

One of the major findings revealed through the interviews and Fourth Generation Evaluation was essentially a major malfunction between processes and software. This was attributed the lack of a readily available QS Model View Definition (MVD). The designer software has inherently built into their functions a Design MVD for the specific requirements of the designer. Such a function does not exist within capabilities of QS Software typically used in Ireland. Such a QS MVD would enable the automatic quantification of quantities (Thus the commonly held fictional "push button myth" associated with automatic take off would evolve into a virtual reality) linked to an international classification system that was commonly used by all designers linked to an agreed Method of Measurement.

The stakeholders QSs believe that the greatest benefit to them is the increased speed in QTO. The next biggest benefit is the increased accuracy of the QTO and a very desirable benefit is 5D BIM and live cost plans.

The solution to the QTO problem is the creation of a QS MVD. This is a major task. However, a simplified version would still create massive time savings until such time as industry evolves to create a fully integrated information exchange. The desk study has shown that various QS MVD's have been developed and tested in different jurisdictions but all have their limitations and all require further research and development.

V1 Further Study

The author has demonstrated that a QS MVD is achievable for practical use within the Authors' work place and that it will be developed for long-term use. The author does however recognize that it is an imperfect solution and that it has its limitations in its current state. However, these are greatly outweighed by the long-term ROI in time and resources. The author acknowledges that there is a cost and time frame involved in the development of this QS MVD but due to advantages accrued from similar type repetitive work and the setting up of a 5D BIM Library and Templates as well as the on the job practical training for the 5D BIM QSs it is a worthwhile endeavor.

V11 Conclusion

Due to lack of maturity in 5D BIM there is presently limited experience and knowledge amongst professionals. This contributes significantly to the challenges facings QS's and of implementing 5D BIM. From the significant list of challenges, which were articulated through the mixed methodology research, none of these impediments were deemed insurmountable. Some will involve greater time-frames and resources than others.

The mandating of BIM by the Government in line with NBC Roadmap to Digital Transition – For Ireland's Construction Industry 2018-2021 will assist with resolving many of these which cover the core areas of leadership, Standards, Education and Training and Procurement.

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Re-imagining Quantity Surveying

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Abstract—As with all major global events, life will never be the same. The Covid pandemic has created the opportunity for us all to engage in new way of working. For most this has meant a rapid transition to digitalisation for all key aspects of our work.

Timing will be everything for those students newly graduating, in the next few years, from professional built environment programmes. Why so? Industry 4.0 - Society has accepted the digital future.

Accepting the digital future is going to challenge the age-old way of producing buildings ranging from design, to procurement, to construction and then delivering a built asset to clients/end users as well as managing the built asset throughout its life cycle. However, the biggest challenge will not be the attainment of a new skill set, but more importantly it is about creating a sense of identity.

This sense of identity nexus permeates all aspects of society, from reimaging our cities, to workspaces to homes and communities. Therefore, must we re-imagine our professional roles, not within the industry but within society.

Societies emerging post pandemic will be influenced in part by the physical and built environment. These physical and built assets will be shaped, in part, by new emerging clients. Clients such as Google and Amazon where technology is intrinsic with their being, together with the drive for sustainable resilient cities and high streets, ergo creating a global and digital industry in which our profession must compete.

Yet the focus should not be on technologies but on a re-imaging, what is going to impact on society first. Thinking, behaving, and acting beyond our traditional construction industry remits creates an opportunity for diversification. The construction industry's role within society means that the professional will require diverse skills sets beyond those of traditional technical competencies. This creates challenges for providers of construction professional programmes. Initial challenges will be to ensure programmes are instilling the broader adaptable skills including digitalisation, data driven competencies and flexibility.

This study considers these wider skills sets of undergraduate quantity surveying students at Ulster University. The study seeks to determine the student perception of their role within societies emerging post pandemic and their readiness to embrace Industry 4.0.

Keywords—Industry 4.0, Quantity Surveying, Digitalisation, Profession

I Introduction

Industry 4.0 (I4.0) originated in Germany, in a 2011 project about high-tech strategy promoting the computerisation of manufacturing. High-tech has also been advancing the construction industry. The adoption of digital tools has transformed many of our practices in the industry. As the technology advances, data driven solutions develop to enhance industry performance and client satisfaction, have become increasingly important. However, there are many difficulties to embracing I4.0

Some industries are embracing the changes whilst others are experiencing difficulties, particularly in relation to recruiting competent and high-quality staff. This is a key challenge to the construction industry, particularly the professional sector. The lack of commitment to attaining I4.0 diverse and digital skills will result in a 'have and have not' sector within the construction industry. The professionals who embrace a more diverse and digital skill set will work in a without boundaries industry, not in the geographical sense, but in relation to traditional professional boundaries. Diversification brings growth, through increased opportunities in new markets, with new clients in new and emerging industries.

Those with the I4.0 skills will succeed and those who do not attain I4.0 skills will fade. The aim of our research is to examine the current levels of diverse and digital skills attained by graduating students on the BSc. Hons Quantity Surveying programme at Ulster University (UU). This study examined four distinct areas of diversification and digitalisation, namely soft skills, mind skills, process skills and technology skills. In doing so this research seeks to understanding how UU provides graduates, from the programme, an I4.0 professional identity.

II Soft Skills

According to Durkheim (1992), the term professional originates from the guilds in Ancient Rome that existed as a tribe or big family engaging in a particular industry. The Oxford English Dictionary (2008), concurs and defines professionalism as "belonging to a profession, worthy of a professional person; skilful or competent". Thus, the term professionalism can be applied to persons with a particular competency, which can be further refined by their affiliation to a specific profession.

Furthermore, the ideology of professionalism, according to Carr-Saunders (1933), 'is the application of a specific skill competently delivered by highly educated people'. Construction industry clients depend upon this service and the quality of the service has a direct impact on project performance, (Ling, 2002). These specific skills and knowledge pertaining to professional quantity surveyors include understanding costs and construction technology, managing projects and ascertaining risks, measurement, procurement and contracts. These skills are considered technical competencies by the professional body, the Royal Institution of Chartered Surveyors (RICS). However, to deliver a project successfully requires competent soft skills. Soft skills are essential as according to RICS (2020) the best quantity surveyors are not just technically competent, but they are good leaders who are able to challenge the design teams constructively. They must also be able to communicate, and report clearly and accurately, with both informed and less-informed clients. Traditionally the key skills of a quantity surveyor (QS) are construction, economics and management and controlling of costs within projects, involving the use of a variety of management procedures and technical measurement tools. However, the work of the quantity surveyor also includes making sure that projects are completed on time, coordinating all the people involved and acting as a link with the client and the other design team members (Hardie *et al.,* 2005, Temple, 2006 and Ashworth and Hogg, 2007). Badke (2006) cautiously concludes that although quantity surveyors currently are seen as indispensable to construction and strategic advisers, but they will need to keep reinventing themselves to continue to provide high value services to meet the evolving needs of clients.

Therefore, the soft skills competencies of quantity surveyors are considered essential in providing a professional service to clients. Soft skills refers to a broad range of people with personal communication attributes, such as leadership, teamworking, decision making, problem solving, motivation and negotiation.

III Mind Skills

Mind skills refers to a collection of professional character attributes which are concerned with the ability to adapt, commit and act with integrity and to be accountable for your actions. These mind skills represent the very best of all the professional competencies. Quantity surveyors are 'governed by a controlled entry within a code of ethics and a monitor of self-discipline', (Jeffers, 1999), which enhances their ability to successfully deliver a professional service. However, the practical application of ethics in the business context is 'the degree of trustworthiness and integrity with which companies and individuals conduct their business'. Essentially these skills are required to protect the client who is viewed as vulnerable in the client – professional relationship and for quantity surveyors to do as they say they will.

IV Process Skills

Process skills refers to enhancing solutions through robust predictions of risk. The construction industry requires modern professionals to be flexible, lean and efficient which is contradictory to the "paternal, hierarchical and conservative" construction industry identified by Smith and Love (2001). Shohet and Frydman (2003) add that the management of complex construction projects is less of an architectural and engineering issue and more of a managerial one. Smith *et al.,* (2004) suggest that construction professionals are required to have design functionality combined with management and technological skills, which are now considered as 'critical determinants of successful professional practice', (Le Roux et al, 2004).

Managing ever increasing complex projects requires quantity surveyors to demonstrate their ability to be creative and innovative. This can be construed as finding solutions to economic, environmental and social value pressures.

V Technology Skills

I4.0 is a digital revolution. The advances in digitalisation and technology will forever change the way we live and work. I4.0 will impact on the professional role of quantity surveyors, who will have to acquire new skills and competencies pertaining to a range of digital tools and practices. This rapidly advancing revolution requires quantity surveyors to be proficient in the application of robotics, data analytics, BIM and cloud-based remedies to provide clients with high quality services.

According to McKinsey (2020) BIM will transform the construction industry in three key ways namely, *Collaboration, Forecasting and Safety.* The acquirement of these technology skills embeds resilience into the quantity surveying profession. Given that projects require collaboration, the digitalisation of the project will improve productivity by enhancing the quantity surveyors' ability to make decisions, assess and mitigate risks, reduce waste, improve performance and ultimately contribute to a more sustainable society.

The benefits of the digital revolution will be great, but also challenging. For Quantity surveyors, whilst putting these new skills to practice is important, what is vital to the success of digitalisation is a shared commitment to changing the approach.

I4.0 will change the skills profile of quantity surveyors as it presents them with an opportunity to diversify into industries such as pharmaceutical, automation and digital. However, the challenge for training providers and learning institutions is to provide an underpinning knowledge, understanding and application of the new and emerging digital skills. This will secure the future and relevance of the profession and attract diverse talent.

VI Research Methodology

A quantitative approach was adopted using an electronic survey to elicit data from graduating students on the BSc. Hons Quantity Surveying Programme at Ulster University. The survey was issued to 65 students, during the final month of their study at the university. A pilot survey was conducted, and no issues were identified. The survey consisted of four closed ended question. Each of the four questions, examined the students perceived ability pertaining to soft skills, minds skills, process skills and technology skills. Students were asked to rank their abilities for each question on a five-point Likert scale, with 1 representing having No ability, 2, having Basic ability, 3- having the ability to Demonstrate, 4 – having Proficient ability and 5 – having Expert ability. The results of the survey are presented as follows.

VII Tables

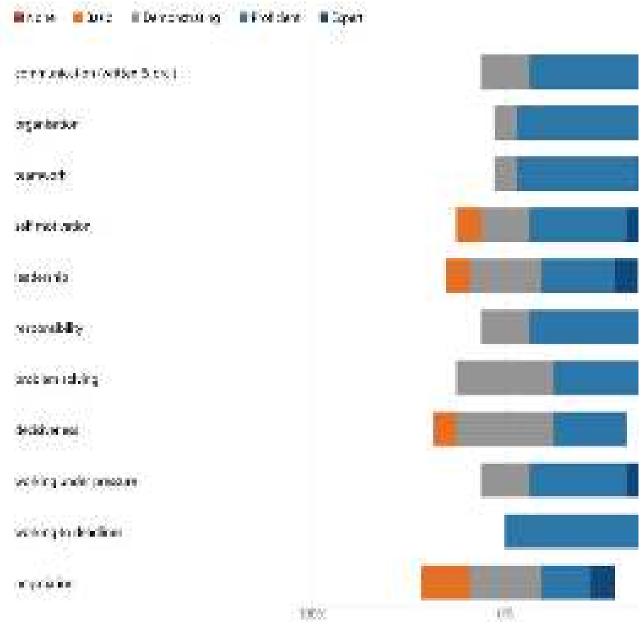

Fig. 1: Students' perception of Soft Skills ability

With regard to the soft skills of communication, organisation, teamwork and the ability to accept responsibility and to also solve problems the majority of respondents indicated that they were proficient with the remainder indicating an ability to demonstrate these skills.

The ability to work to deadlines recorded a proficient ability level from all respondents, but the closely linked soft skill of being able to work under pressure generated a more mixed response. Again, the majority of respondents recorded that they had proficient ability, but a small proportion of respondents indicated that they had expert ability and a slightly larger proportion indicated that they considered only having the ability to demonstrate this skill.

The other soft skills of self-motivation, leadership, decisiveness and the ability to negotiate generated a mixed response. Once again, the majority of respondents indicated that they had a skill level that was proficient or they had the ability to demonstrate these skills. However, it was interesting to observe that a small number felt they possessed expert ability, but correspondingly a small proportion felt that they had only basic ability in these skills.

This indicates varying levels of confidence and self-determination across the respondents as these would be seen as very important skills in leadership, management and engaging with others.

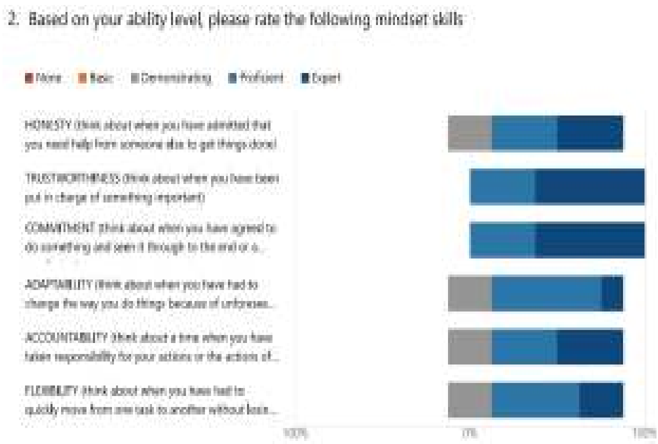

Fig. 2.0 Student's Perception of Mindset Skills

The responses to abilities in mindset skills recorded that the majority of respondents indicated that they were either expert or proficient when it came to commitment. In contrast the responses to abilities in trustworthiness and honesty were more mixed with trustworthiness generating responses of either being expert or proficient whereas honesty had a number of responses indicating that they only had the ability to demonstrate this skill.

This was similar to the responses to the ability to demonstrate adaptability, accountability and flexibility, although the majority of responses indicated proficient ability in terms of adaptability and flexibility in particular there were a number who felt expert, but also a number who indicated that they only had the ability demonstrate each of these skills.

This is significant as the quantity surveyor of the future will need to embrace the need for continuous improvement and widening their skills and expertise through being adaptable and flexible in their approach. This includes the adaptability and flexibility to move to other sectors such as pharmaceuticals, oil and gas, renewable energy, automation etc as well as working in other jurisdictions and geographic locations.

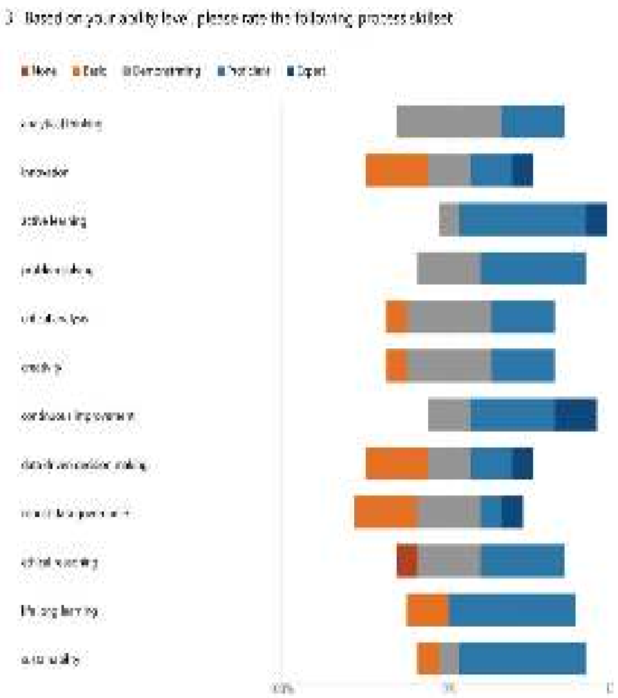

Fig. 3.0 Student's Perception of Process Skills

The responses to abilities in process skills generated a wide range of responses in many instances. The responses to analytical thinking indicated that a majority felt that they only had the ability to demonstrate this skill whereas the remainder felt proficient.

With regard to active learning, problem solving and continuous improvement the majority of respondents felt proficient with the remainder indicating only an ability to demonstrate this skill. The process skills of critical analysis, creativity and sustainability again generated responses indicating an ability to be proficient or to simply be able to demonstrate these skills, but there were a small proportion who indicated that they considered they only had a basic ability.

However, when questioned about the process skills of innovation, data driven decision making, robust data governance and lifelong learning an increasing number of responses indicated that they felt that they had only a basic ability. In the response to the question on the process skill of ethical reasoning, despite the majority indicating either being proficient or simply having the ability to demonstrate this skill a number of respondents surprisingly indicated having no ethical reasoning skills.

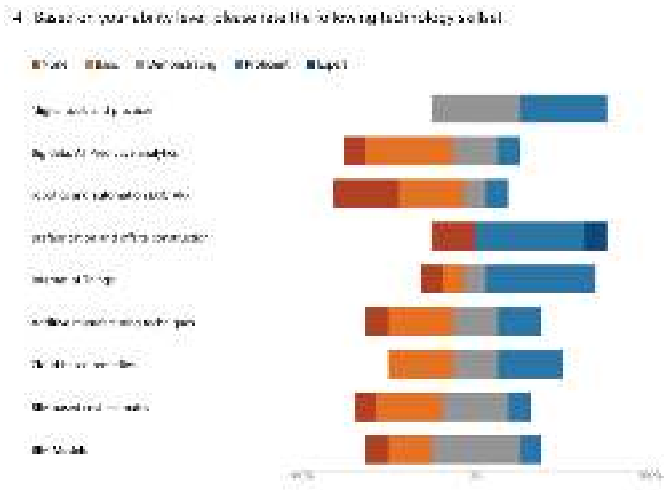

Fig. 4.0 Student's Perception of Technology Skills

The final section of the survey examined technology skills. Interestingly the ability in using digital tools and practices generated responses indicating proficiency or the ability to demonstrate these skills.

With regard to big data, artificial intelligence and predictive analysis, robotics and automation, additive manufacturing techniques as well skills in producing BIM based cost estimates and BIM models there was a wide range of responses ranging from being proficient, to the ability to be able to demonstrate, to a basic ability level, to those who indicated no ability in these skills.

Prefabrication and off-site construction responses ranged from those indicating expert ability, to the majority of respondents indicating a proficient ability with the remainder surprisingly recording no ability in these skills.

Ability in the internet of things generated responses indicating a majority having proficient ability with the remainder of responses spread evenly across ability levels of being able to demonstrate, having a basic ability and having no ability.

The remaining technology skill of cloud-based remedies indicates that the vast majority of respondents have only a basic ability in this skill or consider that they are proficient with the remainder indicating an ability to simply demonstrate this skill.

IX Conclusions

In conclusion as construction continue to move into the digital age with the digitalisation of all processes it will necessitate the development and provision of new knowledge-based competencies in quantity surveying programmes to attain these skills. Thus, we must commence the reimaging of quantity surveying education if we are to embrace I4.0. We must produce graduates with a greater breadth of mind and process skills as well as digital skills , whilst not reducing the provision of soft skills learning.

Therefore, education also needs to adapt to meet the evolving changes with greater emphasis on providing learning to develop digital skills and challenge students to develop creativity and innovation as well as adaptability and versatility. If this doesn't happen, potentially the role of the quantity surveyor and their professional contribution will diminish.

Tertiary education providers need to work in collaboration with industry to enhance these graduate skills and attributes to embed this in learning. In so doing they must also attract students from diverse backgrounds creating opportunities not only for school leavers but for graduates from other sectors, arts and sciences to bring their learning and skills as well their diversity of knowledge and experience.

The survey indicates that respondents generally feel confident about their abilities in the soft skills and mindset skills, but this still needs to be improved, but there appears to be a greater range of abilities in process and in particular the skills associated with the application of technology. This clearly shows a general lack of confidence and in many instances indecisiveness and lack of self-motivation to continually improve, diversify and ultimately embrace I4.0

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Creating Opportunities for Successful Adoption of BIM solutions for Estimators and Quantity Surveyors

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Abstract – The paper looks at three different groups of estimators and quantity surveyors in the UK & Ireland based on their use of BIM solutions. For those who currently use BIM solutions, we identify the type of solutions they use, explore reasons for investment and then offer ideas to facilitate expansion. For those who do not, we explore the problems they are trying to solve, understand key adoption barriers and suggest ways to overcome them. 'Improving productivity' and 'Reducing risk' come out as the top reasons for investment for the group already using a solution. 'Cost' and 'No time to get up to speed' are the main deterrents for those who have considered a BIM solution in the past. The third group is waiting for BIM models with cost relevant data to be more widely available before they decide on adopting a solution.

Keywords – estimators, quantity surveyors, BIM, productivity, collaboration, risk

I INTRODUCTION

The paper looks at a specific audience and where they are with BIM solutions (estimators and quantity surveyors in UK & Ireland).

The objective was to explore their opinions on benefits of BIM solutions as it relates to their work. If there are any adoption barriers, what are they? And, if that gives us insights into short and long terms options to overcome these barriers?

The paper focuses on three different sub-groups.

- individuals who are currently using a BIM solution
- individuals who don't use a BIM solution but have considered using one in the past
- Individuals who don't use BIM and haven't considered using one in the past

For the first sub-group (referred to as 'Use BIM'), we assess if they are satisfied with their BIM solution.

For the second sub-group (referred to as 'Have considered BIM'), we explore reasons for not investing in a solution. Also, if this group would consider a BIM solution in the future and the reasons behind it.

For the third sub-group (referred to as 'Have not considered BIM'), we try to understand what is required for them to consider one.

a) Results

The results bring out the differences in motivations for BIM adoption for these sub-groups.

The first sub-group is more aware of BIM solutions and their benefits because of the first-hand experience either within their department and/or a different department.

The second sub-group lists 'Cost' and 'No time to get up to speed' as the main deterrents to investing in a BIM solution. However, it can proactively make a strong case in front of management as they understand the key problems they are trying to solve.

The third sub-group is waiting for suitable BIM models with cost relevant data to be widely available and will benefit from an external push by the client.

II METHODOLOGY

An online survey was sent out to estimators and quantity surveyors in UK & Ireland, which got 39 responses. There were a handful of responses from outside this region (3 of them).

The survey was a mix of multiple-choice, rating scales and open-ended questions. The open-ended questions were included for respondents to offer explanations for their responses.

About 87% identified themselves with the construction sector. A handful of other respondents were from the Civil and MEP (mechanical, electrical and plumbing) sectors.

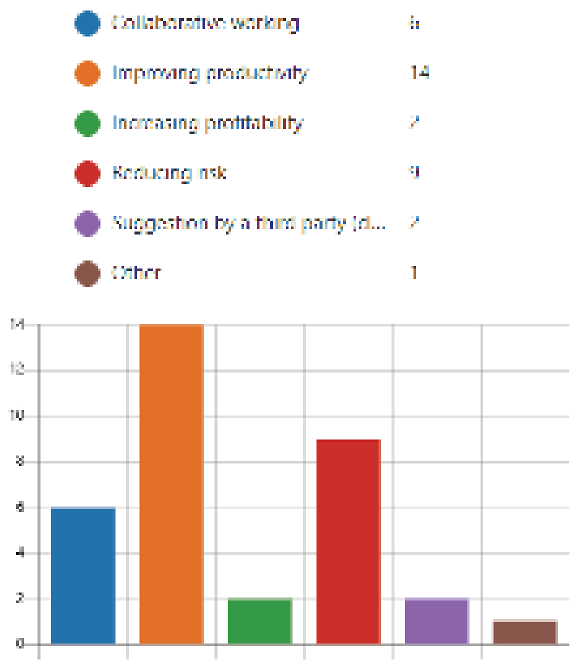
About 4/5th had experience spanning 10 years or more, which makes the study biased towards experienced professionals.

In terms of company size, just above 50% of them identified with companies having 200+ employees. Other company sizes were almost evenly represented (1-10 with 8 respondents; 11-50 with 6 respondents; 51-200 with 5 respondents).

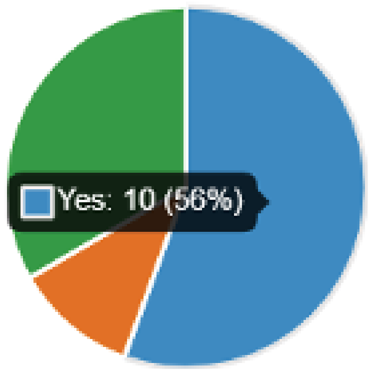
III Diagrams and Tables

Graph 1. Use BIM

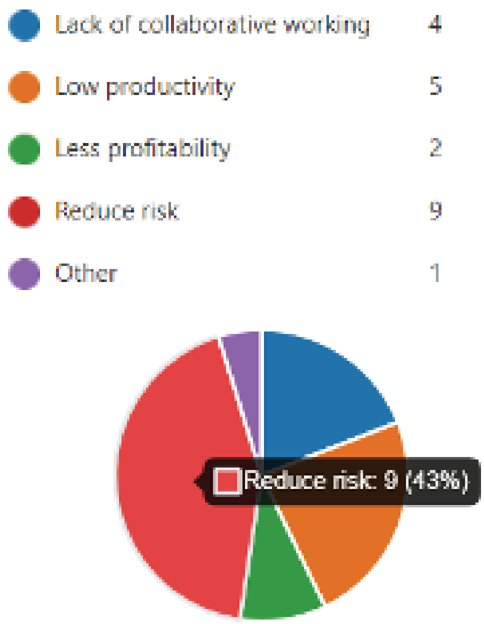
(reasons for investing)
'Improving productivity' and 'Reducing risk' come out as the top reasons for investing in a BIM solution for this group



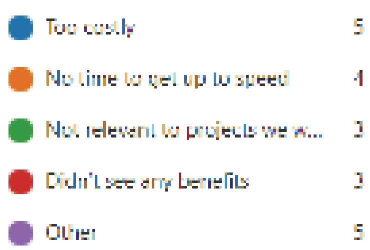
Graph 2. Use BIM
(if it was your decision, would you continue with it?)
The majority of users would choose to continue with the BIM solution if it was their decision

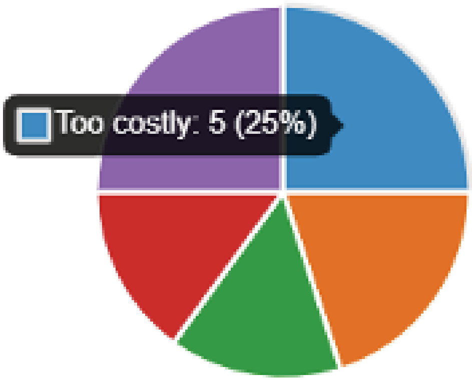


Graph 3. Have considered BIM
(problems to solve)
'Reducing risk' and 'Low productivity' are the top two problems this group wanted to solve through a BIM solution

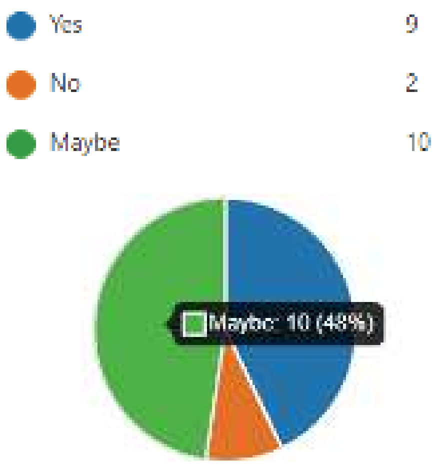


Graph 4. Have considered BIM
(reasons for not investing)
Cost is the primary hurdle to investing in a BIM solution for this group





Graph 5. Have considered BIM
(consider using a solution in the future)
Most respondents are ambiguous about using a BIM solution in the future



IV Results

a) Use BIM

BIM solutions related to take-off/estimating are mentioned the most, which is expected. Design solutions are mentioned next.

This shows that the group feels that they are invested in BIM solutions even if they are not end-users. They may relate to the benefits of such solutions as they see other teams take advantage of them. In that case, they may be more open to using a work-specific BIM solution, if it is introduced to them.

'Improving productivity' is cited as the top reason for the management to invest in a BIM solution. The users can benefit from quantifying productivity figures for their teams. Hours saved per person/money saved per person are a couple of metrics they can track. With these numbers, they can better predict the resources required to complete a project or tender using the BIM solution.

This will also help them build influence over their management in a couple of different situations - 1) for expanding the use of current BIM solutions for their team 2) purchasing new digital solutions in the future.

It is no surprise that 'reducing risk' is cited as the second most important reason. The survey does not capture the types of risks. But, these may relate to a) risk of avoiding costly mistakes b) reputational damage or c) risk of regulatory non-compliance.

The fallouts from any of these risks far outweigh the advantages of improving productivity or collaboration for a contractor. They can lose out on projects, suffer from poor margins, take years to recover from reputation loss or be blacklisted from tendering for certain projects. The estimators or quantity surveyors may lose their jobs.

If they can build on the message of using BIM solutions to 'reducing risk for the management' and translate it to 'reducing risk for the client', they will be able to differentiate themselves. The management will also feel content about the return on investment (ROI) of digital technologies through access to new commercial assignments.

The participants seem to be satisfied with their current BIM solution (average rating of 3.83 on a scale of 1-5 with 5 being most satisfied).

Within this group of users, there are two sub-groups. Those who influenced the choice of BIM solutions and those who didn't. Interestingly, they have slightly different levels of satisfaction – an average score of 4 for the 'influencer' group as compared to 3.72 for the 'non-influencer group'.

Users, when they join a new company, do not have a say in the choice of BIM solution/s. If they have had previous experience, it is easy for them to get up and running with the incumbent solution. If the new users do not have any experience, the existing users can help them with the uptake with a bespoke training and onboarding plan. This will ensure that they learn to use the BIM solution quickly. With regular use, they will also see the benefits for themselves and the company. And, develop similar satisfaction levels as their peers over a period of time.

The response to the question "if it was your decision, will they continue with it" is slightly titled towards YES (56%).

Some users have said that they will not continue as they feel that there are better alternatives available. If that is the case, they should be proactive in getting their colleagues and management to think about using this alternative and its advantages. A trial or short-term subscription may be a suitable first step.

The undecided users cite reasons like 1) not having a choice as it is client-driven 2) not sure if the overall team is satisfied with the use 3) current solution not able to interconnect 2D & 3D results.

These users may influence their management to consider other BIM solutions by 1) pointing out drawbacks with over-reliance on a single customer 2) taking an internal survey to understand the low satisfaction levels of the team and find ways to address them 3) explore solutions with better 2D – 3D coordination through trial or short-term subscription.

b) Have considered BIM

The motivations for companies to use a BIM solution are similar to the 'Use BIM' group. But, for this group, 'reducing risk' takes the top slot.

The paper has already highlighted the potential risks that contractors face and the related fallouts. Could it be the case that the groups' employers have suffered in the past? Or, are they in a position where they may face an adverse outcome if they don't manage a certain risk?

If the group members can quantify the losses suffered or expected losses, they can make a strong case in front of their management for investment in a BIM solution. The solution will then pay for itself.

The challenge here is that if the team does not have any previous experience with a solution, they will take time to build proficiency with a new system. To overcome this, in the first few months, they can use the services of an external party with the intention of building skills over a period of time or hire someone with the relevant technical skills.

Although the members related to the company motivations either fully or partially, the management chose not to make an investment.

'Cost' and 'No time to get up to speed' are the main deterrents. Is it possible that the members were hesitant in making a strong case for the BIM solution in front of their management to justify the upfront cost? So, if the management approves it and the team is not able to invest enough time in learning the tool, they will be to blame.

To overcome the 'cost' barrier, the members can quantify the benefits associated with reducing risk, improving productivity or improving collaboration. And, then pitch 'cost' as an 'investment' which will bear a positive return.

'No time to get up to speed' is a tricky problem. With the current workload, the members may struggle to learn a new solution from scratch.

There are a couple of ways to deal with this. Either, strategically hire someone with the skills. Or, appoint an 'internal BIM solution champion'. This champion can undergo training first and then train his/her colleagues to make the best use of the team's time. This will also help the management to make investments in stages to align with the team's training.

Some of the members highlighted that they are open to using a BIM solution in the future or recommending it to their management, if a) more BIM models became available b) BIM models had cost relevant data attached to them.

If this group can get the management buy-in and go ahead with a solution at a limited level, they can market themselves as a forward-thinking organisation. BIM savvy clients are sure to take notice and approach them in due time.

c) Have not considered BIM

This group has not considered a BIM solution in the past. However, they are open to adopting a BIM solution in the future if certain conditions are met.

These conditions relate to a) tender requirements b) availability of BIM models c) cost relevant data within these BIM models

Another interesting observation by this group was the problem upstream with design. If the designers do not factor in cost relevant data in their models, they become irrelevant to estimators and quantity surveyors down the line.

Could clients play a pivotal role in this situation to improve BIM adoption? Firstly, by ensuring that their design team develops models including cost data. Secondly, by making these BIM models widely available to different contractors tendering for a project. Lastly, by giving the contractors an opportunity to have back and forth communication with their design team for any clarifications.

V CONCLUSIONS

a) Use BIM

This group is aware of the benefits of BIM solutions available to them. It can influence the management to expand the use of the existing solutions by quantifying the productivity benefits or developing a message around risk reduction for the clients.

By having an onboarding and training plan for new users, they can ensure that these users develop the same satisfaction levels as existing ones.

If the users feel that an alternative BIM system can offer better results, they should try to make a case for a trial or short-term subscription for this solution. An internal survey would help to establish if such an experiment is necessary.

b) Have considered BIM

This group appreciates the benefits that a BIM solution can bring to them and their employers. However, for them to get the nod from their management, they need to quantify the 'risk reduction' potential of this solution and pitch it as an investment.

They can show their commitment to using the solution through a new hire or an internal 'BIM champion', requesting investment in stages.

By marketing their BIM credentials, they can attract new 'BIM savvy' customers.

b) Have not considered BIM

This group is sitting on the fence waiting for suitable conditions before considering investing in the appropriate BIM solution.

An external push by the client may help this group get on the BIM ladder if not an internal one.

VI Survey

Link - https://bit.ly/3gTkTub

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CitA BIM Gathering **Proceedings**

Getting BIM and Off-Site Production to Work Hand-in-Hand

Can Ireland deliver the stable quantum to sustain a viable volumetric off-site industry?

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Abstract – Moving towards an off-site model for construction in residential development, in particular volumetric off-site construction, will significantly alleviate the skills shortage in the industry. It will also improve quality, programme, predictability and cost certainty. This paper will look to reaffirm these benefits with the focus on Ireland's market size and scale. It would be futile to put forward a solution if it is not commercially viable in the market. This paper will seek to prove or disprove if the Irish modular construction market is mature enough and has the requisite predictability to facilitate a commercially viable volumetric construction market with competition in the space. Experience gained by the lead author in working in the volumetric off-site space and delivering over 650 units over the past few years with Modern Homes Ireland (MHI) gives an insight into the industry. The knowledge in the space in Ireland is still limited and it is seen as a niche market. However, Ireland is very well placed, given the sheer volume of units that must be built and also the demographics and continued demand for residential construction, to be a world leader in the rapid provision of both public and private housing.

Keywords – DfMA, Housing, Modular, Off-site, Volumetric

I Introduction

Mark Farmers seminal works on the state of the Construction Industry in the UK and globally in general [1] and his most recent collaboration with Mike D'Ath; Build Homes, Build Jobs, Build Innovation [2] clearly points towards off-site manufacturing as a critical enabler to unlock the rapid delivery of new homes in Ireland.

This will make house construction; more predictable, more efficient, safer, give more cost certainty, reduce programmes, reduce finance costs, make construction more environmentally friendly and provide resilience to future pandemics such as the current COVID-19 virus.

There are other tangential benefits, such as the ability to attract a more local workforce and coupled with the increasing importance of digitalisation will lead to the formation of a new business eco-system in Ireland's construction industry, one leading to a smarter, more innovative and productive business sector.

Currently Property Industry Ireland (PII) and the Construction Industry Federation (CIF) are developing separate reports into the increasing role of off-site construction in the Irish construction industry.

An early review of these reports both identify the benefits articulated earlier and further reinforce that off-site manufacturing is the future of our industry. The reasons for moving to industrialised construction or off-site construction are clear. The intent in the industry is also clear in Ireland with some of the largest contractors, such as BAM Ireland, John Sisk & Son, Mercury and Jones Engineering investing significantly in off-site manufacturing space.

If the intent and business benefits are there, can it be done at the scale required to really make an impact in Ireland?

II INTERNATIONAL PERSPECTIVE

The key players in the Japanese volumetric housing industry are not traditional house builders with the likes of Sekisui, Toyota Homes and Panasonic's Pana Homes the major players in this market. These businesses are coming from a manufacturing industry and not burdened by the traditions of construction. These companies have the most knowledge and experience in volumetric off-site manufacturing, in a country where the seismic activity creates significant issues, even for low-rise residential units. These companies are now starting to move into the UK and European markets with Sekisui working with Homes England and

Daiwa starting to work with Jan Snel in the Netherlands and the UK.

Technically it can work, and it can work to a considerable level of automation and across Europe and the UK there is a market. The question is, in Ireland can it work given the capital investment and the nature of our house construction market both from a size and also cycle perspective i.e. the market is small in comparison and the house building industry is very cyclical with significant boom and bust cycles.

III Why Move to Off-Site

When looking at the reasons for moving to off-site we can segregate these into; labour, safety, programme, environmental, cost, predictability and resilience to pandemics. A brief overview of these elements is included below and further supported by statistics.

a) Labour

The availability of labour to deliver work on sites is difficult to come by, as identified by the McKinsey Global Institute (2017) "*Globally, construction sector labor-productivity growth averaged 1 percent a year over the past two decades, compared with 2.8 percent for the total world economy and 3.6 percent for manufacturing. In a sample of countries analyzed, less than 25 percent of construction firms matched the productivity growth achieved in the overall economies where they work over the past decade. Absent change, global need for infrastructure and housing will be hard to meet.*" [8]

The CIF states that "*In 2015 the value of turnover in the construction industry was around €13 billion, representing 6.2 per cent of economic activity (GNP), down from almost one-quarter of the economy at the height of the last boom. There were 136,900 persons directly employed in Q2 2016, 6.8 per cent of the total employed workforce. The severity of the construction recession saw the numbers working in construction decline by almost 180,000 by Q1 2013 to just 35 per cent of the numbers employed at the peak (2007).* [3]

There are a number of key skills that are in significant shortage. The National Skills Bulletin 2019 states that "*11 occupations relevant to the built environment, were identified as being in short supply in 2019, namely: Civil Engineers, Construction Project Managers, Quantity Surveyors, Carpenters, Glaziers, Steel Erectors/fixers, Curtain Wallers, Scaffolders, Pipe Layers, Electricians and Construction Site Drivers*" [9] All of these activities are reduced when moving to off-site. The move to volumetric off-site manufacturing will alleviate some of the pressure on the rest of the industry.

b) Safety

The statistics show that, from a quantum of fatalities perspective, construction is a dangerous working space to be involved in. In 2019 Health & Safety Authority (HSA) published the level of fatal injuries in the construction sector in comparison to other sectors. Having a safer working environment is certainly grounds for considering moving to off-site. Figure 1 illustrates the volume of construction fatal accidents against other sectors and manufacturing [4]. It demonstrates that construction has 6 times more fatal accidents than manufatcuring

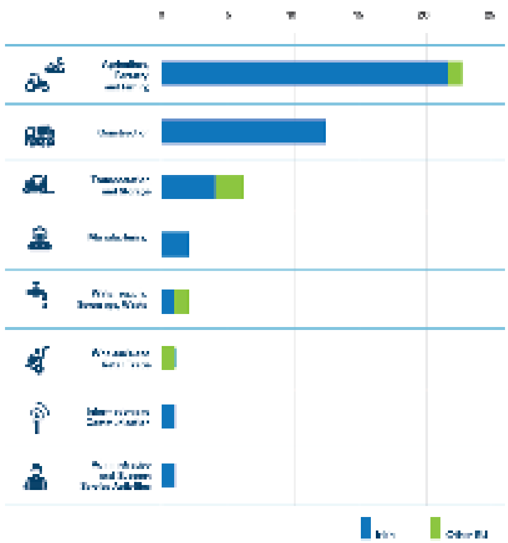

Fig. 1: Number of fatal accidents by NACE economic sector and nationality, 2019 (HSA)

The US Bureau of Labour Statistics identified an increase in construction fatalities over the period 2015 to 2019 from 937 to 1061 whereas during the same period the workplace fatalities dropped from 353 to 0 in manufacturing.

There is a clear correlation in the numbers across borders leading to the assumption that off-site manufacturing will make construction safer which will improve the possibility of attracting skilled labour to the space.

c) Programme

When we look at programme we need to consider the entire process. In later sections we will explore the lead in times and focus on the specific duration of construction / manufacturing. We then look at the construction of a volumetric house to give a micro view at the scope and then to the duration of a high-rise apartment building to identify the minimum and maximum savings in programme.

When looking at volumetric off-site manufacturing it takes between 12 and 17 days to manufacture a house to 90% completion (Modern Homes Ireland statistics). Therefore, once design is complete one has a 2–3 week period to prepare for installation. The off-site manufacturing working concurrently with the civil and infrastructural works there is no delay to the programme i.e. your site programme begins on the first day the modules are delivered to site. Taking a standard 3 bedroom semi-detached house it will come in 6 modules, two ground floor, two first floor and two roof modules (Figure 2).

Fig. 2: Shows modules as they are being installed, two on the ground floor to the right, 4 modules in the centre and all 6 modules complete on the left

Installing each module takes approximately 40 to 50 minutes. To install a standard 3 bedroom home would typically take 4 to 4.5 hours which means a home is 90% complete in half a day with all of the structure complete with external insulation, the restraint for the external leaf installed, the building weathertight with the windows and roof in position including all of the internal finishes, sanitary ware, kitchens, plastering, tiling, 1st and 2nd fix joinery, all doors, 1st and 2nd fix mechanical and electrical works including all storage units, radiators and heat pumps.

This speed in low-rise residential is at minimum 75% faster than the nearest off-site panelized solutions. However, the overall benefit is mitigated as the units can generally only go as fast as the groundworks is progressing so the ultimate benefit is generally a 50% faster build time. With some solutions like screw piles and brick slip facades this may improve closer to the maximum efficiency.

When looking at a high-rise buildings a good example is the world's tallest modular project developed by John Fleming's Tide Construction and Vision Modular. This 44-storey building was constructed using 1524 modules which were installed at a pace of 50 modules per week giving a 30-week modular programme. The overall superstructure programme was reduced by (a conservative estimate) 60%.

There are many benefits to the local communities and the developers in this instance. The local communities have a reduction in construction traffic of 80% and a reduction in people working on site and issues such as parking. The works are also quiet, installing modules is much quieter than large concrete, precast or steel frame structures.

d) Environmental Benefits

Another significant benefit of off-site manufacturing is the reduction on the carbon footprint. The construction industry should be seen to play a larger part in reducing the impact of building on our planet.

Eurostat state that construction accounts for 36% of all waste generated in the EU. Construction is by far (almost 10%) the biggest generator of waste. When you consider that all households in the EU generate 8.2% of all waste it shows the stark reality of that quantum. Most main contractors and construction companies generally are working hard to reduce this number but it requires a dramatic change to shift these statistics as improvements on current processes will not be sufficient to reduce this to an appropriate level. Fig. 3 below illustrates the significant volume of waste generated by construction

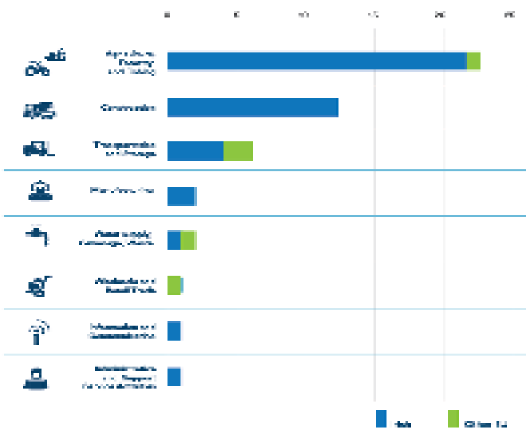

Fig. 3: Eurostat information on waste generation by industry [5]

Mark Farmer and Mike D'Ath in their work Build Homes, Build Jobs, Build Innovation [1] have stated that the research has shown that off-site manufacturing can reduce the quantum of waste generated by up to 80%. The lead authors experience of working with a volumetric modular business this is at least accurate and the saving may be greater. They also state that the embodied carbon can be reduced by 40% – 50% by utilizing off-site techniques.

e) Cost

One of the significant benefits of off-site manufacturing is the reduction in preliminaries on site manifesting in a reduction of the staff and plant associated with a project on the site, as well as the accelerated programme. There is also the significant reduction in project finance costs which can be very high on large scale modular projects.

Typically, the cost of running a project is similar between volumetric construction and traditional methods, when you look at the fact that the work in the factory is faster, more automated and more efficient (therefore it is cheaper). However, the savings in the efficiency in the factory are generally balanced by the fact that units are structurally overdesigned i.e. the modules are designed for the lifting process where they do more work while being installed that they will do in situ, so there is more steel to make them more rigid. There is also a more significant logistics cost in modular with delivering modules and installing them.

Internal exercises that we have completed have identified savings or an overall reduction on the cost of low rise and high-rise projects when they are designed for modular – using the minimum number of modules to complete a project with the minimum amount of site work. However, there is a price increase when the designs do not suit modular. The price range is -2% to a +2%.

The Irish House Building Association (IHBA) 2021 in their recent publication "Product Inflation Tracker & Cost Impact Assessment May 2021" [7] identified an 8% inflation on the price of a standard 3-bedroom semi-detached house of €12,075 of which €7,100 was attributed to the increased cost of timber. In a similar time, the price of Light Gauge Steel (LGS) has also soared from €900 / tonne to €1600 + per tonne, assuming the volumetric house is built in LGS the likely uplift in price might be €4,500 to €5,500 / home. However, the attributable increase in cost due to labour inflation has not increased significantly in factory work whereas it has on sites (that is where the staff are available). Therefore, the more stable space, from a cost perspective, is in volumetric construction.

f) Predictability & Quality

When working in a factory all of the modules are at ground level, all of the units are being made by the same skilled workers with the same tools and techniques. There is no difference project to project, there is no learning curve on the site or orientation inefficiency i.e. people taking time to get to know a project. The materials are always at the workstation. These are the inherent benefits of building in a factory. The process is a Factory Production Control process which is audited by the National Standard Authority of Ireland (NSAI) which has a 48-step quality checking procedure for every module that goes through the factory. This level of checking is commercially impossible in a traditional job site setting.

The Certification also requires significant testing of the systems, so all walls, floors and ceilings are tested for fire and acoustic performance. This testing regime is over and above any of the typical details that are generated on traditional designs, as each element is tested individually.

This ensures that the units when they get to site perform and the level of predictability is far in excess of what can be achieved with on-site construction.

With off-site you can also automate more tasks and work with precision engineered automation which is better and more certain that manual operations.

g) Resilience to Pandemics

Covid-19 has certainly had a significant impact on all industries. One key aspect of volumetric off-site manufacturing is that when you are building / manufacturing you are doing it in a controlled environment away from the unpredictable Irish weather. During a pandemic this has an added value in that the process can either continue or stop. If it has to stop the modules, regardless of layout, design or finish are protected from the elements. This is not possible in traditional construction without roofing the project.

IV The Timing of Orders: The Lead-In Time Required

The timing of modular is key to the efficient operation of the factory or manufacturing facility. Early involvement means that the process can operate at its most efficient. There are ideal scenarios and then some sub-optimal options that we can run through to demonstrate feasibility and timing.

When an order is placed for a modular project the initial items to close out on will be the long lead in items so potentially; glazing, tiling, unique kitchen equipment or sanitary ware (assuming the raw material be it Light Gauge Steel, Hot Rolled Steel or Timer is in sufficient rolling stock)

The overall design element, depending on complexity, will take 12 to 16 weeks which includes the approval of materials, drawings, layouts, M&E coordination, connections etc. Assuming that the longest lead in items can be procured during that 12 to 16-week period then the project can go to the factory floor assuming there is a production slot available. Once the production slot is available then the project can work in behind the next project and progress through the production process. The production process in the MHI factory takes 15 days on average. Post starting on the production line 15 days later complete modules will be taken off the end of the line fully complete.

V The Timing of Orders: The Impact of Delays

The ideal scenario outlined earlier takes a project from agreement to the factory floor and on to site in 15 weeks. Given that almost all projects will have that level of groundworks which can work concurrently, there is a huge saving.

In a less ideal scenario the process can all work but have no production slot. The project will have to wait to get a production slot or run to night shifts which can impact on the cost. Equally less than ideal is that the project happens and progresses quickly but the site is not ready, then the modules have to be stored in a temporary situation. This is not ideal and requires moisture bags to be placed in the units to combat moisture build up, because the units are so air tight with limited ventilation.

To take a theoretical factory of reasonable scale with a turnover of €52,000,000 and include an overhead and operating cost of €5,200,000 per annum (for ease of calculation) outside of project costs. That means for every week a client might be late will lose the company €100,000. If the company runs at a profit of 2% to 3% that means that for every project that is delayed by 1 week the company loses approximately 10% of its profits. This is not sustainable because it both makes a loss but also makes the overhead cost a larger percentage of the turnover, which in turn further increases the loss. This demonstrates the criticality of having the factory busy and at maximum capacity through the full 52 weeks of the year.

VI The Timing of Orders: The Typical Lead-In Time in Construction

Depending on the type of construction tendering process the lead in time can either be extremely challenging or take a long time due to complexity. This might be the difference between a private developer on a housing scheme who conducts the evaluation quickly or a longer more complex process like a PPP Contract. Both of these can cause an issue for the volumetric construction space as the fast solution will be dependent on having production slots available quickly and the longer procurement methods can take too long as the decisions can be pushed back by weeks or months. The positive in the second scenario though is that when you become the preferred bidder you would still have time.

The variety and uncertainty around success makes traditional procurement techniques extremely difficult to manage in a volumetric factory scenario. This is one of the reasons many of the most successful volumetric operators globally have their own development wings because they can fill any gaps left due to projects being delayed or push back their own projects to facilitate clients.

VII A New Type of Procurement in Construction

There needs to be a new type of procurement offering to ensure that there is a more balanced and predictable approach. That can come via having set designs and procuring production slots as opposed to projects. If Rebuilding Ireland in partnership with the Royal Institute of Architects Ireland (RIAI), Society of Chartered Surveyors Ireland (SCSI) and the Construction Industry Federation (CIF) agreed a suite of internal house types with guide pricing then an agreed set of modules could be designed. These could look like anything externally and be configured in different ways to give variety. The base modules could be detail designed by those in the off-site industry. This would mean that key players in the residential development space could procure production slots as opposed to particular projects. The flexibility in the design would mean that there would be no planning issues or implications, once the pre-determined layouts are being followed. There are a number of parties who could procure a large volume of production slots; the Approved Housing Bodies (AHB’s), the large residential developers, the Land Development Agency, county councils etc.

This is a change from the long-standing procurement types in Ireland but agreeing cost parameters based on agreed designs will make the industry significantly more efficient at a time when the industry is in a very difficult position with significant price inflation.

We are seeing some great work being done in the UK with new innovative thinking with Homes England creating a Joint Venture with Sekesui and Ilke Homes which will no doubt deliver a significant volume of badly needed homes in the UK.

VIII The Current Volumetric Modular Industry in Ireland

There is a very limited volumetric modular construction industry in Ireland in residential construction. PII report (2021) *"Innovation Increasing Supply"* [6] identifies some of the key off-site manufacturing businesses which includes volumetric off-site modular manufacturing businesses ESS and MHI who can deliver approximately 500 units each if they were to dedicate their capacity to residential developments. Cumulatively the likelihood is that the industry has a current capacity to deliver approximately 2,000 modular units. The current latent demand is 100,000 units or homes and the population increase will add another 30,000 per annum as identified in Davy's Special Report 2021 "The Irish Housing Market – Where Next?" [10]. If you take the PII estimate at 35,000 units then the current capacity of modular factories / companies will only fill a maximum of 5% of the required homes to built in the country per annum. A key point here is that the vast majority of modular construction in Ireland is being procured by private clients. Some may end up as social housing but the developer is almost always a private individual or company. There are some exceptions with Dublin City Council and Clúid proposing volumetric projects but they are in the minority and the volume as a percentage does not register to a full decimal point in a given year.

IX The Target Growth of The Modular Industry Internationally

Looking at the contraction in availability of skilled staff and all of the benefits outlined above then a move to modular is a necessity. Mark Farmer and Mike D'Ath in their work Build Homes, Build Jobs, Build Innovation [2] have requested that the UK Government commit to delivering 75,000 new home via modular construction by 2030. Which would equate to between 25% and 30% of the overall demand in the UK. If we were to mirror this in Ireland we would be looking at between 8,750 and 10,500 modular homes per annum by 2030. This is a realistic and feasible target.

If we look at the metric provided by Farmer and D'Ath "*each factory operating at a capacity of 2,000 homes per annum would create on average 600 jobs"* in Ireland this would be at minimum 5 new factories which would create 3,000 jobs. Looking at the precedence set by prior off-site businesses these are most likely to be rural and remote locations. Using their economic principles that is likely to generate 3,750 jobs in the related supply chains, including in manufacturing equipment supply so a cumulative of nearly 7,000 jobs in rural locations.

The target must be ambitious if we are to hit our climate goals and sustain the delivery of the quantum of homes needed in the country.

When assuming a base level of 8,750 homes per annum then this production capacity would have to be guaranteed to get the very best value for money i.e. the more a factory produces the more cost effective it becomes and the ultimate client or end user gets the best price possible.

X Conclusion

The preconceived notion of prefabs and old modular solutions should be dispelled at this point. The reality is that modular volumetric construction can provide more robust quality checks and processes providing a superior product, that is more environmentally friendly, faster and more predictable. When we look at the availability of staff and the ageing workforce in construction it is going to be a necessity to move to off-site.

Fig. 5: Images of modular units courtesy of MHI

In summary modular construction is not that panacea to the housing crisis however it should certainly be part of the solution. To generate a market there needs to be cooperation between all of the key actors and the modular businesses and these key actors; the Land Development Agency (LDA), the Approved Housing Bodies (AHB's), County Councils, Re-Building Ireland, significant Developers etc. all need to commit to booking production slots over a long period and not trying to make one off small individual projects work. The larger the commitment the better the price will become for the units and ultimately make modular cheaper than traditional methods of construction.

The procurement method needs to change and move from traditional procurement to booking production capacity. This is a key in unlocking the potential of the sector. Finally, for the sector to flourish the government need to commit and provide incentives for these pioneering businesses to move forward and assist in delivering the type of quality stock that people need.

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Modern Methods of Construction:

A driver for increased levels of output in the Irish Residential Market

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Abstract – The Irish construction sector is still recovering from the 2008 financial crash and subsequent economic recession. Productivity rates are amongst the lowest in the Irish economy. The sector is struggling to achieve the levels of housing supply required to meet demand. Modern Methods of Construction (MMC), which include offsite manufacturing and onsite techniques, have many reported benefits over traditional building methods including improved productivity, environmental sustainability and increased levels of health and safety. The overall goal of this research was to examine the current use of MMC in Ireland and to evaluate the potential for increased MMC adoption to improve construction productivity and accelerate the delivery of housing.

Findings confirm that MMC can accelerate housing delivery. However, current adoption rates are relatively low with several barriers to full adoption prevalent. The primary recommendation is that overcoming the barriers requires education and upskilling across the industry. Governmental supports for this, combined with policy changes, would improve the adoption rate of MMC, enhance productivity in the sector and increase the supply of housing.

Keywords–MMC, Offsite Construction, Prefabrication, BIM, Digital Construction, Lean

I Introduction

Ireland is in the midst of a housing crisis following the global financial crash of 2008 with a 75% drop in housing unit completion numbers between 2006 and 2019 [1], [2].

On the backdrop of this, the COVID-19 pandemic has added high levels of economic uncertainty, disruptions to supply chains and more critically, increased risks to the health and wellbeing of workers. This is likely to result in the already suffering industry struggling to keep pace with output demands.

Modern Methods of Construction (MMC) is a broad term used to describe offsite manufacturing and onsite techniques that provide alternative construction methodologies to traditional building methods [3]. MMC have been shown to deliver both residential and commercial projects to a faster construction programme through productivity improvements [4] while achieving many additional benefits including improved environmental sustainability, delivered quality and improved site safety and health and wellbeing [4], [5], [6], [7]. As such, MMC have been described as being key to addressing the demands of high output levels in the housing market [8], [9], [10]. However, several barriers to MMC adoption have been identified including skills; knowledge and experience; cost control; and supply chain capacity [11], [12], [13].

The UK Government is driving a change in innovation culture through policy and regulation. Digital design and delivery through BIM has been mandated for publicly funded projects and crucially, delivery of 180,000 homes under the Affordable Homes Programme (AHP) 2021-2026 is linked to the UK Governments wider objectives for MMC [14]. In contrast to this the Irish government has yet to develop fully collaborative project procurement methodologies or construction strategies that specifically target use of MMC. Similarly, a national roadmap to BIM adoption, developed by the Irish national BIM council in 2017 [15] has also yet to be adopted into national procurement policies. BIM is a transformative technology [16] which enables the virtual design and coordination of a building prior to construction [17].

Digitisation of the industry facilitates collaboration between designers and contractors improving productivity throughout the project life cycle. However, a recent survey [18] found that globally, 60% of respondent companies operating in the construction industry are only starting out in their digital transformation journey. Despite the slow progress in changing attitudes and cultures at the sectoral level, several firms/contractors have embraced MMC and are driving change.

The aim of this research was to gain an understanding of the issues surrounding the current use and adoption of MMC in the Irish construction industry through direct engagement with those operating in the sector. Here we argue that MMC can accelerate housing delivery. However, current adoption rates in Ireland are relatively low with several barriers to full adoption prevalent. We outline a way forward for the industry through a set of recommendations which can be taken by Governmental policy makers and industry.

II Research Objectives and Aligned Methodology

The research focused on the Irish residential construction sector. The aim was to investigate the current use of MMC in Ireland and to evaluate the potential for increased adoption to improve construction productivity and accelerate the delivery of housing through three key objectives:

1. Analysis of the current residential property market focusing on relative volumes of property types.
2. Assessment of the current rate of MMC adoption
3. Evaluation of the challenges/barriers to MMC adoption

The research methodology incorporated both qualitative and quantitative methodologies.

Residential Housing Market Analysis

National data on numbers and types of housing completions and planning consent applications was analysed. This data was obtained through the Central Statistics Office (CSO).

Online Questionnaire

An online questionnaire was developed and disseminated to the design and construction sector including architects, engineers, building contractors, manufacturers and residential development procurement bodies.

104 complete responses were received in total. Using a confidence level of 95%, the margin of error of the questionnaire was calculated to be 9.6%.

Quantitative responses were in the form of ordinal data based on a 5-point Likert-type scale. Individual responses were aggregated and sorted into the predominant respondent groups. The groups included clients, architects and contractors. For the purposes of the analysis, main-contractors, sub-contractors, and product suppliers were combined under the 'contractor' heading as all three disciplines deal directly with construction activities. Data was then tabulated both within and across groups. The ordinal data was initially analysed based on the median value of responses.

Analysis of the frequency of use of each listed MMC category was carried out using the Frequency Index (FI).

$$Frequency\ Index\ (FI) = \frac{\sum_{i=1}^{5} \boldsymbol{b_i d_i}}{\boldsymbol{5D}}$$

Where b_i is the weight assigned to each response (1 to 5); d_i represents the frequency of each response given to each factor; D is the total number of responses.

The Relative Importance Index (RII) was used to analyse the order of importance of benefits and barriers to MMC usage.

$$Relative\ Importance\ Index\ (RII) = \frac{\sum \boldsymbol{W}}{\boldsymbol{A * N}}$$

Where W is the weight given to each factor by the respondents (1 to 5); A is the highest weight (5); N is the total number of responses.

For specific questions where median response values varied between subgroups of respondents, statistical significance of these differences was determined by non-parametric, rank-based Mann-Whitney or Kruskal-Wallis tests. The Mann-Whitney test compared outcomes between two independent groups while the Kruskal-Wallis test was used for comparisons of more than two groups.

Interviews

Semi-structured interviews generated qualitative data which was used to triangulate the quantitative data generated through the online questionnaires.

The interviewees were chosen from the Irish design and construction residential sector and represented a wide cross section of stakeholders: procurement bodies e.g., private developers, corporate and public bodies; designers (architects); contractors.

Twelve interviews were carried out (4 per stakeholder group). Interview data analysis was based on the observations of the research participants and identification of key aspects in the research topic [19]. Thematic analysis was carried out on all collated data [20].

III RESEARCH FINDINGS AND ANALYSIS

Housing Market Analysis

An analysis of the housing sector was undertaken incorporating data from the Irish Central Statistics Office (CSO) for the numbers of planning permissions and housing completions to ascertain what housing typologies are being planned / built and to what volumes.

As shown in Figure 1, a 96% fall in the number of multi-development units granted planning permission was recorded between the years 2005 and 2012.

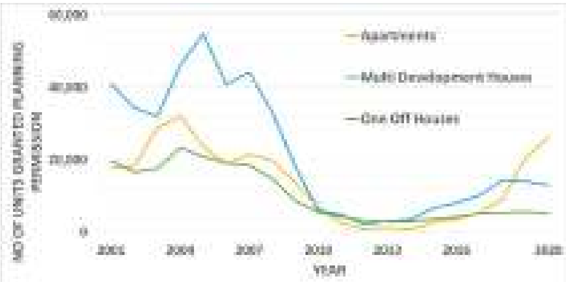

Figure 1. Planning Permission Numbers by Property Type Permission by Type and Year.

A similar decline of 97% was recorded for apartments between 2004 (peak) and 2012 (lowest). Over the period between 2001 and 2018, multi-development housing was the predominant residential building typology being granted planning permission. In 2019, unit numbers of apartments granted planning permission exceeded those of multi-development houses for the first time over the reporting period of 2001-2020. Of interest, the Irish government brought forward legislation to regulate the private rental sector in 2019 [21] which has attracted international investment firms in that sector.

While completion numbers for apartments over the same period were lower than multi-development houses the rate of increase was significantly higher. In terms of completion numbers for apartments, 2019 saw a 5.27-fold increase in comparison to 2015 (Figure 2).

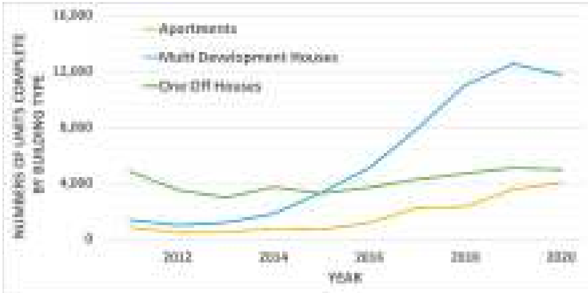

Figure 2. Housing Unit Numbers Completed by Type and Year.

Online Questionnaire

A total of 104 respondents completed the survey representing a cross section of the construction industry from client / procurement bodies, design disciplines and contractors (Table 1).

A gender imbalance was evident across the respondents with 82% of all respondents identifying as male and 17% as female. Of the 18 Female respondents, 72% were from the architectural design field with only 1% working with a main contractor.

Table 1. Online questionnaire respondent breakdown.

	Total (n=104)	Architecture (n=42)	Contractor (n=37)	Client (n=4)	Other (n=21)
% of total		40%	36%	4%	20%
Gender	85 Male 18 Female	28 Male 13 Female	35 Male 2 Female	4 Male 0 Female	18 Male 3 Female
Age	18-29 (n=9) 30-44 (n=57) 45-64 (n=36) 65-74 (n=1)	18-29 (n=6) 30-44 (n=24) 45-64 (n=10) 65-74 (n=1)	18-29 (n=1) 30-44 (n=21) 45-64 (n=15) 65-74 (n=0)	18-29 (n=0) 30-44 (n=3) 45-64 (n=1) 65-74 (n=0)	18-29 (n=2) 30-44 (n=9) 45-64 (n=10) 65-74 (n=0)

a) Use of MMC

Respondents were asked if they had ever used MMC on projects. Depending on their answer, they were then asked to what extent they routinely incorporated MMC on projects, or in the event they had never used MMC, to indicate how suitable/amenable they felt a predefined list of building typologies would be to incorporation of MMC.

Where respondents had used MMC, responses were given against a 5-point Likert scale where 1 represented ‘never’ and 5 represented ‘always’ and where they had never used MMC, 1 represented ‘not at all’ and 5 represented ‘ideal’. For those who had previously worked on projects using MMC, residential apartment developments were the building typology which respondents identified as having the greatest extent of MMC incorporation, with a median response of ‘4-Often’.

This was true for all three categories of respondents examined – architects, contractors, and clients (Table 2). Similarly, amongst those respondents who had not incorporated MMC on projects previously, ‘residential apartment developments were the building typology identified as being most suitable/amenable to MMC.

Of note, a comparison of male versus female respondents showed a significant reduction in the use of ‘offsite components’ and ‘on-site process improvements’ by female respondents ($p=0.0092$ and $p= 0.0101$ respectively by Mann-Whitney test)

b) Benefits of MMC Adoption

Respondents were asked if they agree or disagree that MMC leads to a predefined list of benefits based on a 5-point Likert scale where 1 was “Strongly Disagree” and 5 was “Strongly Agree”. Increased levels of early design coordination achieved a median value of 5 across those who had previously used MMC.

The relative important index for each benefit of MMC is shown in Table 3. ‘Increased levels of early design coordination’ is the category ranked most important across all groups. It should be noted that the number of clients with MMC experience responding to the questionnaire was low.

c) Barriers of MMC Adoption

Respondents were asked to what extent they felt that items on a predefined list acted as a Barrier to the adoption of MMC based on a 5-point Likert scale where 1 was “Never” and 5 being “Most of the Time”. ‘Levels of client awareness’ of MMC and lack of incorporation at design stage both achieved a median value of ‘4-Often’ across those who had previously used MMC.

Both architects and contractors ranked ‘lack of incorporation at design stage’ and ‘client awareness’ as the top 2 barriers to MMC adoption (Table 4). Conversely for clients the leading barrier was seen to be ‘procurement methodologies’ which ranked 3rd for architects and even lower for contractors.

Table 2. Frequency Index for usage of MMC components on residential construction.
*Represents terms jointly ranked in terms of frequency index within that category of respondents

	Overall		Architecture		Contractor		Client	
	FI	Ranking	FI	Ranking	FI	Ranking	FI	Ranking
Offsite Components	0.737	1	0.714	1	0.789	1	0.700	1*
Non-Structural Assemblies and Sub-Assemblies	0.635	2	0.576	2	0.714	2	0.700	1*
Structural Panelised	0.596	3	0.562	3	0.665	4	0.500	5
On-site Building Material Improvements	0.590	4	0.490	4	0.676	3	0.600	3
Volumetric Modular	0.500	5	0.429	6	0.605	5	0.300	6
On-site Process Improvement	0.488	6	0.433	5	0.551	6	0.550	4
Additive Manufacturing	0.312	7	0.262	7	0.389	7	0.200	7

Table 3. Relative Important Index for benefits of MMC adoption.
*Represents terms jointly ranked in terms of frequency index within that category of respondents.

	Overall		Architecture		Contractor		Client	
	RII	Ranking	RII	Ranking	RII	Ranking	RII	Ranking
Increased Levels of Early Design Coordination	0.880	1	0.859	1	0.915	1	0.933	1
Improved Productivity	0.859	2	0.837	2	0.897	2	0.867	2*
Accelerated Delivery	0.841	3	0.830	3	0.873	4	0.733	6*
Better Quality	0.832	4	0.822	4	0.879	3	0.867	2*
Increased Levels of BIM Adoption	0.827	5	0.807	5	0.861	5	0.800	5
Increased Levels of Site Safety	0.805	6	0.778	6	0.842	6	0.867	2*
Improved levels of Environmental Sustainability	0.729	7	0.711	7	0.764	7	0.733	6*
Lower Costs	0.620	8	0.607	8	0.648	8	0.600	8

Table 4. Relative Important Index for barriers of MMC adoption.
*Represents terms jointly ranked in terms of frequency index within that category of respondents.

	Overall		Architecture		Contractor		Client	
	RII	Ranking	RII	Ranking	RII	Ranking	RII	Ranking
Lack of incorporation at design stage	0.798	1	0.763	1	0.836	1	0.733	3*
Level of client awareness of MMC	0.739	2	0.741	2	0.709	2	0.733	3*
Skills Shortage	0.717	3	0.696	4	0.685	4*	0.733	3*
Project procurement methodologies	0.690	4	0.719	3	0.673	6	0.800	1*
Low levels of Virtual Design and Construction (VDC) adoption	0.666	5	0.615	6	0.691	3	0.733	3*
Increased construction costs	0.651	6	0.630	5	0.685	4*	0.800	1*
Manufacturing / Supply Chain capacity	0.622	7	0.585	7	0.618	7	0.667	7
Planning permission system	0.524	8	0.444	9	0.558	8	0.533	8
Reduced design quality	0.495	9	0.504	8	0.497	9	0.333	9

Interview Data Analysis

The main respondent groups for the questionnaire were architects, contractors and clients. These categories were selected for more in-depth analysis through semi-structured interviews. Four interviewees were selected from each of the three groups.

a) Benefits of MMC

Several benefits of MMC were reported by the interviewees. Of significance to this study, 100% of the interviewees reported that MMC helps drive a faster programme. Other benefits identified included increased quality (75%), reduction of onsite labour (50%) and improved site logistics (50%) (Figure 3). While all participants identified a faster programme as being the predominant benefit of MMC, the breakdown of the remaining benefits identified, varied across the disciplines. All architects (100%) reported increased quality as a benefit compared to 75% of contractors and 50% of clients. Interestingly, the least reported benefits were those of improvements to environmental sustainability, quality of life, and health and safety.

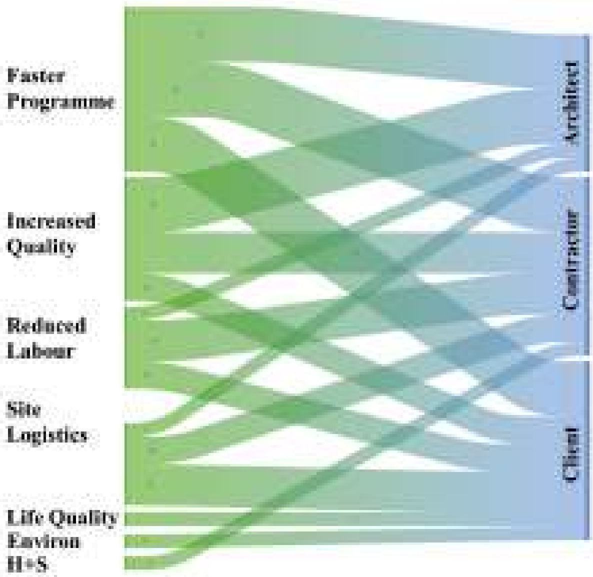

Figure 3. Benefits of MMC Indicated

b) Barriers to MMC Adoption

The barriers to adoption of MMC most frequently identified were: lack of knowledge and experience (100%), capital cost (75%) and supply chain capacity (41%). A contractor at manger level argued that adoption at early design stage: ***"comes down to the architect's familiarity with offsite methods and what their understanding of it is"***. One Associate level Architect acknowledged this, noting that ***"I think it's probably just a lack of knowledge of a certain product or system"***.

It was acknowledged that the capital cost of MMC typically is more than that of traditional forms of construction, and 100% of the contractors and architects interviewed felt that this proved to be a barrier to increased adoption. However, only 25% of clients had a similar view.

c) Drivers of Adoption of MMC

Three drivers to adoption of MMC were identified through the interview process (Figure 4). Early contractor engagement was seen by 58% of the interviewees as the main driver to increased adoption. An Associate level Architect identified the benefits of collaboration with contractors during the early design stage: ***"There's huge potential here for more cooperation with the contractor … often that relationship is adversarial and can be fraught, but if they are brought on at the right stage and as part of a team, their expertise is utilised"***. This view was shared by a Contractor at Manager level: ***"what's happening is that we get designers designing things without talking to the contractors. And contractors seem to build things without talking to the designers and we need to have an awful lot more integration between the two"***.

A third (33%) of all participants see governmental policies as a driver and a quarter (25%) of all interviewees identified environmental sustainability as a driver. it is also worth noting that all of those who identified environmental sustainability as a driver were clients

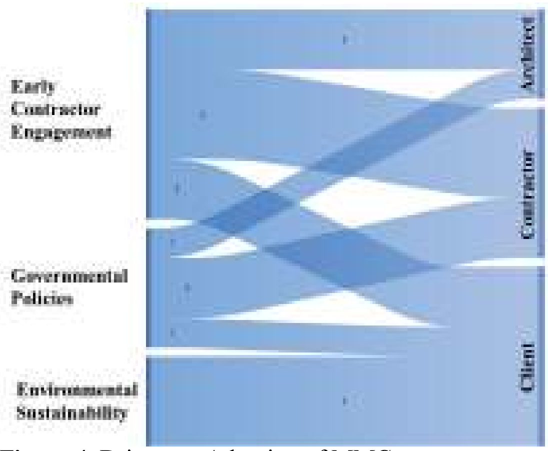

Figure 4. Drivers to Adoption of MMC

Through the interview response analysis, five main themes were identified: Adoption, Barriers, Drivers, Benefits and Categories of MMC used. Several sub-themes were coded under each of the main theme headings (Figure 5). There was a variance in the occurrence of the sub-themes across disciplines, for example, 100% of all contractors and architects saw capital cost as a barrier to increased adoption compared to 25% of clients, however several sub-themes were very prominent across all disciplines.

A lack of knowledge and experience was seen by all interviewees as being a barrier to increased levels of MMC adoption. Similarly, all interviewees felt that incorporating MMC into projects benefited the construction programme helping to deliver the project faster than if traditional methods of construction were used. Over half of interviewees saw contractor engagement at design stage as a driver of MMC adoption.

IV Discussion

Quantifying accurate adoption rates of MMC within the Irish residential market is difficult due to the lack of data on construction methodologies being used. A report commissioned by the Irish Government in 2002 [22] found that 15% of housing that year was constructed using timber frame prefabricated elements indicating that at that point the industry had begun to adopt MMC within the residential sector. However, as the housing market analysis indicates, housing output levels dropped significantly following the financial crash of 2007 resulting not only in severe supply chain fragmentation, but also a loss of skills and knowledge in the workforce.

The housing market has now begun to recover with numbers of residential units granted planning permission and being completed rising year on year. This represents an opportunity to enhance the adoption of MMC.

Developing the current level of MMC awareness in the Irish construction sector is critical to its successful adoption. There is a particular need to increase innovative thinking and awareness of the full potential beyond the current MMC adoption maturity levels. This has proven difficult within Ireland to date. While stakeholders can see benefits, the relatively minimal levels to which MMC have been incorporated mean that the full potential benefits in terms of productivity and accelerated programme delivery have not been realised, in turn making it more difficult to build the business case for MMC.

This research has established that a lack of skills, knowledge and experience is seen as a significant barrier to higher levels of MMC adoption followed by supply chain capacity issues. If adoption is to

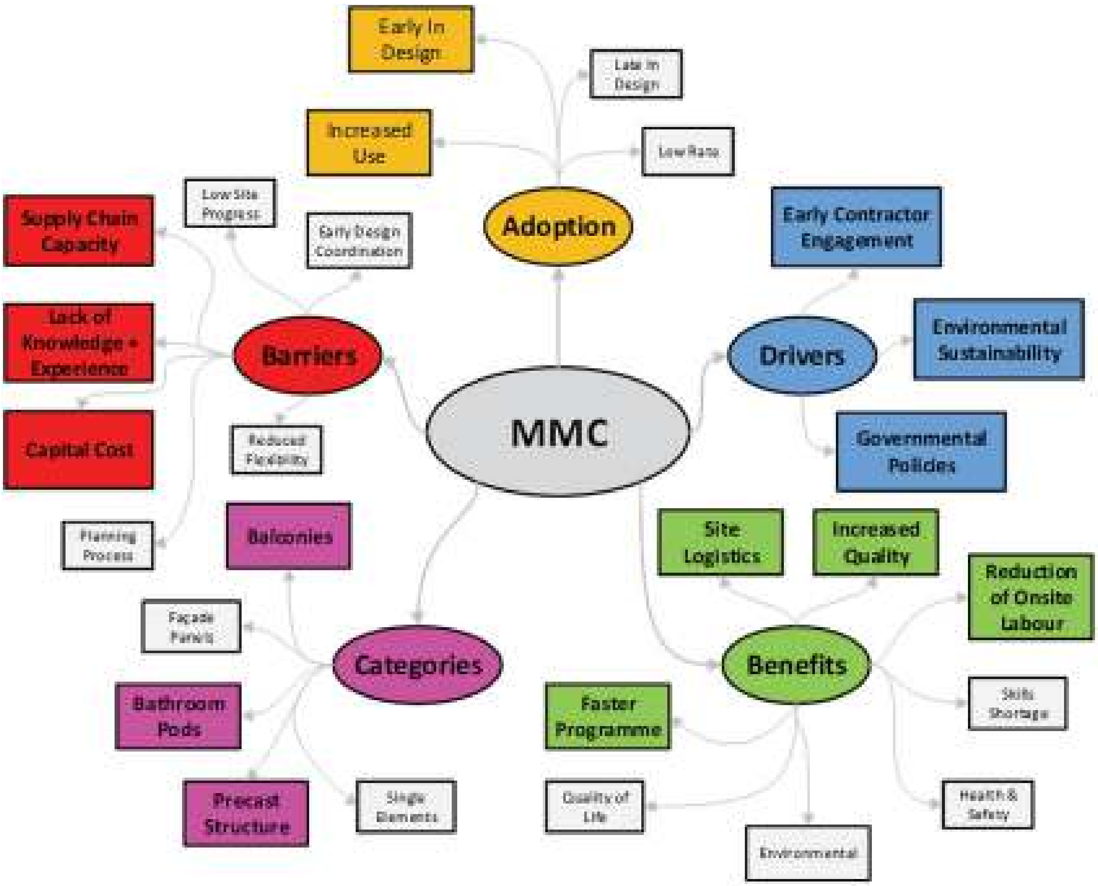

Figure 5. Interview Response Thematic Analysis Chart

increase to a level where it will positively improve residential construction productivity, then these barriers will need to be addressed by the industry.

Overcoming this will initially require an increase of knowledge of MMC across the entire industry. Significant training would be required for this to be achieved. To be effective at a national level this would require support from the Irish Government and considerable collaboration with academic institutions.

The Farmer report [4] called for government intervention in the housing sector by incentivising the use of MMC on the private rented sector (PRS). While this would certainly increase the level of MMC adoption in Ireland, especially with such a high volume of apartments being planned, it could lead to an acceleration of the fragmentation of the residential market. Housing outside of the Dublin region is mainly owner-occupier multi-development units, developers would be incentivised to develop housing mainly in Dublin potentially leading to supply issues in rural settings.

However, other governmental incentives could undoubtedly help to drive productivity improvements in the construction sector. The Danish government have streamlined the planning process and mandated the use of BIM across the sector. The Danish economy is a world leader in eco-innovation [23], [24]. National policies for circular economy thinking, waste reduction and recycling [25], and energy efficiency in both new build and renovation forms of construction have been implemented. Productivity levels within the Danish construction sector are higher than the EU (27 -2020) average while Ireland is below the EU 27 average.

Policy alone, however, is not sufficient to drive a change in construction culture to improve productivity. At the start of the industrialisation of construction in Denmark, the government established the Danish Building Research Institute in 1947 [26] to provide support and guidance on the implementation of new building technologies, while the productivity commission [27] was established in 2012 to help drive productivity improvement across the economy. This has led to certain forms of MMC being considered standard construction methodologies in Denmark while they are only beginning to be adopted in Ireland.

Policy development backed by governmental support mechanisms would help to incentivise the construction industry to embrace the change in culture required to improve productivity. These combined with a knowledge and realisation of the benefits of MMC would act as a driver to greater adoption rates across the construction sector.

A Construction Sector Group focusing on innovation and digital adoption has been formed by the Irish Government to identify and develop a roadmap for improving productivity in the construction industry. This group have identified seven actions on innovation and digital adoption including MMC, BIM, a new Digital Build Centre of excellence to be developed, a new Construction Technology Centre by Enterprise Ireland, and other innovations on construction technology and planning application digitisation to help streamline planning permission processes.

The outcomes from this group will be key in developing the skills, knowledge and capacity for full MMC adoption across the construction industry.

The cynical nature of the construction industry in terms of demand, investment and skills pose a challenge for factory-lead manufacturing processes [6]. It has been argued that supply chain capacity and security is the Achilles heel of MMC adoption [28]. Manufacturing and construction sequencing are critical for the success of MMC. As seen recently, geo-political events such as Brexit and global health concerns make supply chain security critical for the operation of the construction industry.

The fragmented nature of procurement in the industry restricts its ability to build economies of scale which benefit the factory line type production processes that many forms of MMC embody.

Developing procurement at scale either at project or central Government level will help build supply chain capacity resulting in increased competition within the market and help reduce capital costs and as such the cost of construction.

This research has found that one of the potential benefits of MMC least identified through both the online questionnaire and interviews is that of improved environmental sustainability. This is perhaps linked to the barrier of skills, knowledge and experience identified. The Irish Governments Climate Change Bill, 2021 commits to reducing greenhouse gas emissions by 51% over the next decade.

Achieving this goal will require a step change in the construction industry in order to embrace a decarbonised sector. MMC aligns with circular economy thinking in all facets of its concepts and methods. This whole lifecycle approach reduces raw material usage, energy consumption, carbon emissions from efficiency in logistic planning and offers the potential for re-use and recycling of building elements / components at demolition or re-adoption stages of construction projects [7], [29], [30].

V Recommendations

The findings of this research indicate that increased adoption of MMC would improve construction productivity and increase delivery of housing. To achieve this, the following recommendations are put forward to address the barriers to MMC adoption identified:

1. Develop the business case for MMC adoption through the creation of an innovation hub to develop skills, good practice guidance and disseminate knowledge sharing across the industry. This should be carried out in partnership with academic and Governmental institutions.

2. Identify the current skills base and map this against the future skills needs of the industry required to transition to increased levels of MMC adoption.

3. Development of more collaborative forms of building procurement which promote contractor engagement at an early design stage and the adoption of a national BIM mandate.

4. Updating and development of more cohesive governmental policies related to construction which facilitate increased levels of productivity within the construction sector and allow for the benefits of MMC to be realised. For example, through the digitisation and streamlining of the planning permission process and incentivising more sustainable forms of construction through policies such as circular economy thinking and energy efficiency

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Notes

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