Proceedings of the 9th International congress on architectural technology (ICAT 2022): digitally integrated cities: closing the chasm between social and physical, 19-20 May 2022, London, UK.

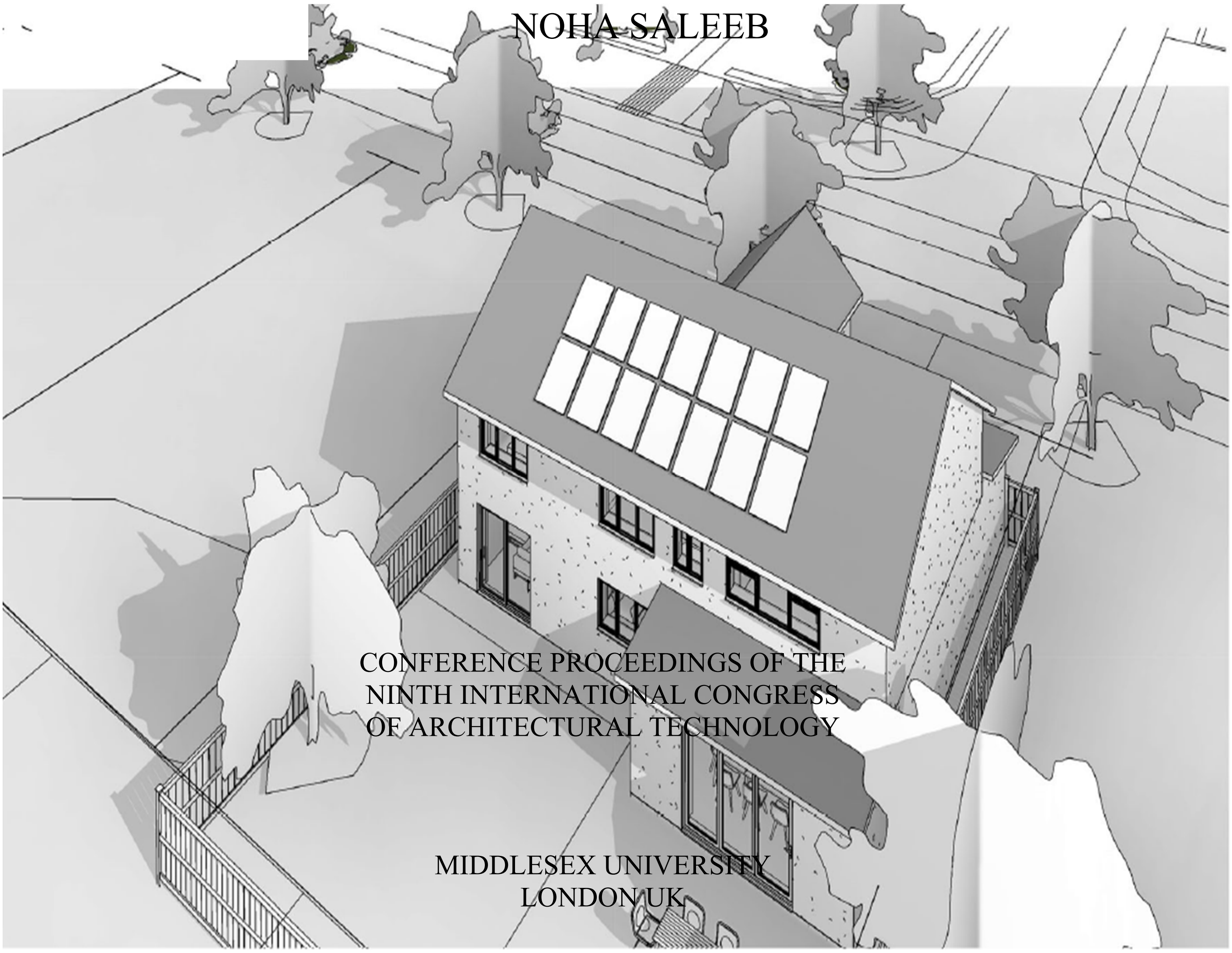
KOUIDER, T. and SALEEB, N. (eds.)

2022

DIGITALLY INTEGRATED CITIES: CLOSING THE CHASM BETWEEN SOCIAL AND PHYSICAL

ICAT 2022

TAHAR KOUIDER
NOHA SALEEB



CONFERENCE PROCEEDINGS OF THE
NINTH INTERNATIONAL CONGRESS
OF ARCHITECTURAL TECHNOLOGY

MIDDLESEX UNIVERSITY
LONDON UK

DIGITALLY INTEGRATED CITIES: CLOSING THE CHASM BETWEEN SOCIAL AND PHYSICAL

ICAT 2022

TAHAR KOUIDER
NOHA SALEEB

CONFERENCE PROCEEDINGS OF THE
NINTH INTERNATIONAL CONGRESS
OF ARCHITECTURAL TECHNOLOGY

MIDDLESEX UNIVERSITY
LONDON UK

Robert Gordon University

Garthdee House, Garthdee Road Aberdeen
UK: https://www.rgu.ac.uk
Tel.: +441224263522

Edited by: Tahar Kouider & Noha Saleeb

ISBN: 978-1-907349-22-5

Cover Images: J Smolarz (RGU)
A Biddulph (RGU)

Proof-reader: Tahar Kouider

ICAT
INTERNATIONAL CONGRESS OF ARCHITECTURAL TECHNOLOGY

ROBERT GORDON UNIVERSITY ABERDEEN

Middlesex University London

Board Members

International Scientific Committee

ACKNOWLEDGEMENTS

The International Congress of Architectural Technology (ICAT) would like to express their thanks and gratitude to all those who helped and contributed to the organisation of the ninth conference and the production of these proceedings:

- The authors who contributed papers and presentations
- Middlesex University London for hosting the conference and associated events
- Members of the ICAT Board
- Members of the Scientific Committee
- Dr Noha Saleeb for chairing the conference and coordinating its logistics during the difficult
- COVID-19 lockdown period
- Tahar Kouider for editing and printing the proceedings

` ` `

` ` `

FOREWORD

It is an honour for me to be able to welcome all delegates to ICAT 2022 in Middlesex University, London UK. It is the ninth time the conference is held, online this time due to the COVID-19 pandemic, and it is every time enlightening, thought provoking and filled with innovative experiences presented by selected authors.

Challenges are emerging within the construction industry, causing diversification of roles, workflows and educational transformations. This has resulted in unifying and integrating the built environment on city, country, and global levels due to the Internet of Things, Artificial Intelligence, cloud computing and big data analytics.

Architectural Technology is at the centre of the construction industry where the relationship between these factors creates many interfaces. Academics and Professionals associated with Architectural technology are best positioned to enhance the design, delivery and performance of integrated buildings within cities at large.

This congress will be a vehicle to disseminate research, education and practice related to this theme investigating both social as well as physical, technical, operational and strategic effects on Digitally integrated Cities.

Welcome to the 9th ICAT Conference

Dr Noha Saleeb, Conference Chair
Middlesex University, London UK

```

**DISCRETISATION DESIGN STRATEGIES**
strategies to integrate design and fabrication through discretization

ERFAN ZAMANI AND THEODOROS DOUNAS
*e.zamanigoldeh@rgu.ac.uk*
*t.dounas@rgu.ac.uk*

**Abstract.** In the present paper, we introduce a classification system, for discretisation strategies, based on the procedural differences. This paper has a particular focus on strategies explicitly positioned towards an integration between digital design, robotic fabrication and robotic assembly. In the first step, the paper introduces and analyses previous methods from the literature and built case studies and proposes a classification for discretisation approaches. This classification is based on three basic designing strategies: Top-Down, Bottom-Up and Hybrid, in a parametric design manner. The second step defines a general parametric framework for each approach based on the classification analysis. Due to the specifications and functions, these approaches can be synced and combined with other parametric design tactics, such as panelising, subdivision, or generative design. We describe and analyse the possibilities of connecting other parametric features with our discretisation definitions in each category. In the end, this paper introduces several alternative implementation avenues for each category, including a logical design strategy, without considering any specific software or tool.

Keywords: Discretisation, Digital Design, Robotic Fabrication, Parametric Architecture, Geometric Complexity.

## 1. Introduction

Computer-aided design tools bring new opportunities to produce complex geometric shapes with minimum mathematical inputs. Correspondingly, this progress has affected the architecture field, and digital modelling is becoming increasingly popular proportionately with other industries (5). In tandem, there has been a shift in architectural design representation from ortho-plane and regular shapes toward the forms that are often associated with more geometric complexity and design flexibility (9). Not only, this aesthetic revision poses a challenge in design stage, but it also demands an adjustment in the manufacturing and construction procedure (1).
The present paper assumes discretisation as a step-by-step design procedure that could simplify the complex geometry into simpler geometries by dividing it into understandable roles and relations (9). Discretisation can be used to break down an architectural volume or surface into smaller and buildable pieces (14) or can be used to generate a 2D or 3D volume (30).
Additionally, discretisation can bring new features to design. For instance, in discretisation, we can start the design process from the module instead of the overall geometry. This feature gives the designer enough flexibility and opens new possibilities to integrate the digital file with fabrication machines.
```

This paper proposes a classification system for discretisation strategies in architecture by reviewing the existing discretisation methods. This study scrutinises case studies to find digital procedural differences and similarities. Due to the specifications and functions, the proposed strategies can be synced and combined with other parametric design tactics, such as panelising, subdivision, or generative design. In each category, we describe and analyse the possibilities of connecting other parametric features with our discretisation definitions.

2. Literature Review

Kolarevic in (10) discusses design data digitalisation and integration of design, analysis, manufacture, and assembly. He explains how this integration optimises the construction time and reduces human errors.
Currently, buildings constructors and designers are working in two fragmented sectors and designers are not getting involved in the construction process after the delivery of the documents (31).
However, during a discretisation process (as a digital design strategy), by using analytical methods, designers can consider and generate a lot of fabrication and assembly options, such as interlocking joints, modular orientations or even picking and placing strategies (5). This feature brings designers the possibility to come over into both design and construction stages (10).
In (9), authors explain discretisation as a reverse engineering process in a parametric manner. In their proposed framework, a non-orthogonal/free form first parametrically delineates and readjusts the surface. Secondly, the parametric surface can be discretised (9). Katrin & Penn introduce a discretisation method using subdivided surfaces. This method enables designers to produce an "approximation" of the freeform surface and break it into a family of discretised elements.
Some studies, like (9) and (14), have considered discretisation as a solution to manage free form's geometry complexity by digitally re-formulating the surfaces and evaluating them down into smaller components.
However, discretisation can be used as a general digital design strategy to fulfil the requirements for fabrication and assembly (13). In (32), different subdivision schemes have been analysed for semi-regular geometries, and the discretised units have been applied to the form by point mapping controls. Similar method has been used in (33), where authors, propose geometric calculations for wave-shape formats based on cross-ratios of identical tasselling parts.

Another approach to discretise a surface is to apply a curvature network on it. This technique can be manipulated with different geometric meshes like conical or hexagon shape; like (12) or (25). There have been more studies on conical meshes and curvature network techniques. The articles (16) and (17) study and extend the previous knowledge of quadrilateral meshes and their functionality to discrete large scale-free forms. In these papers, the researchers examine the possibility of a relation between circular and conical meshes with other parametric capabilities (e.g., offsetting tools) (17). Also, their research can validate the glass multilayer buildings design and categorise the construction elements (16). Likewise, another geometric approach is proposed in (14) to discrete double-curved surfaces based on the intersection of tangent planes.

3. Methodology

This study develops a classification system, for discretisation strategies, based on the procedural differences. This paper has a particular focus on strategies explicitly positioned towards an integration between digital design, robotic fabrication and robotic assembly. This classification makes a comprehensive basis for a deep procedural understanding of current discretising methods in architectural design toward generalising our methods for a wide range of structures.

In the first step, this paper introduces and analyses the previous discretisation approaches. These analyses lead us to elicit each case study's logical and algorithmic specifications. In the second step, the methods are classified according to their design logic and conceptual and procedural differences (Figure 1).

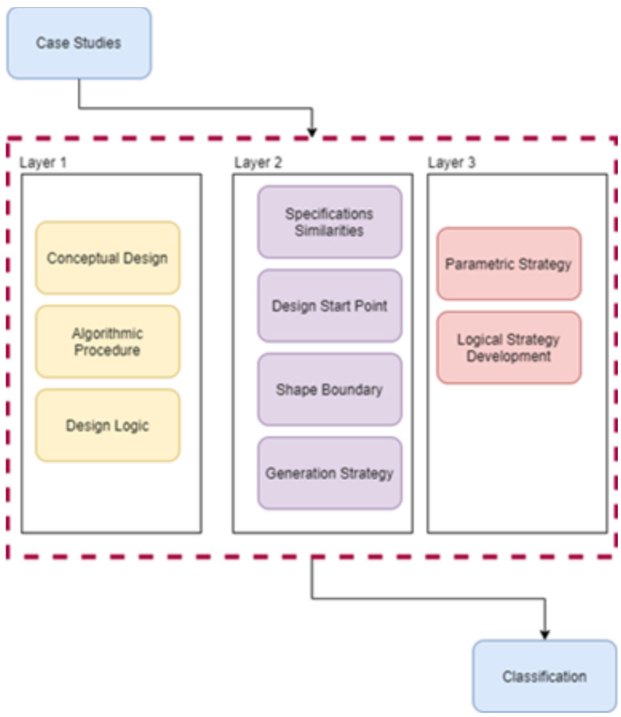


Figure 1 Methodology Layers

4. Case Studies

This paper first reviews several discretisation cases studies from the literature and built structures and secondly, re-checks their parametric design mechanisms and assort the algorithmic steps.

4.1. LITERATURE CASE STUDIES

In the table below, 14 discretisation related case studies/papers are introduced (Table 1). This classification is used to generalise the discretisation methods and generate a parametric framework for each category.

Table 1 Literature Discretisation Case Studies, Credit by Erfan Zamani

Paper	
1	Geometric modelling with conical meshes and developable surfaces
2	A parametric strategy for free-form glass structures using quadrilateral planar facets
3	Ornamental Discretisation of Free-form Surfaces
4	Generative Agent-Based Design Computation
5	Meso-Scale Digital Materials: Modular, Reconfigurable, Lattice-Based Structures
6	Project DisCo: Choreographing Discrete Building Blocks in Virtual Reality
7	Aggregated Structures: Approximating Topology Optimized Material Distribution with Discrete
Paper	
Building Blocks (**Error! Reference source not found.**)	
8	Interlocking of Convex Polyhedra: towards a Geometric Theory of Fragmented Solids
9	Topological Interlocking Assemblies
10	A generalized framework for designing topological interlocking configurations
11	Geometry as Interface: Parametric and Combinatorial Topological Interlocking Assemblies (
12	A Model for Intelligence of Large-scale Self-assembly (
13	Voxelcrete - Distributed voxelized adaptive formwork
14	Discretized Fabrication of Geometries Generated with Cellular Growth Simulations

4.1.1. Planner Surface/Mesh & Curvature Network

Liu and his colleagues in (12) and (25) propose a dynamic strategy based on curvature network and planer mesh. In their methodology, the quad mesh may be recognised either as planer or conical. This feature makes it possible to optimise the mesh and combine it to other parametric settings such as subdivision or panelising (12). Their research was updated in 2009 for hexagonal shape meshes. They proposed a top-down approach to approximate a surface and evaluate it to be broken down into discrete hexagons (25).

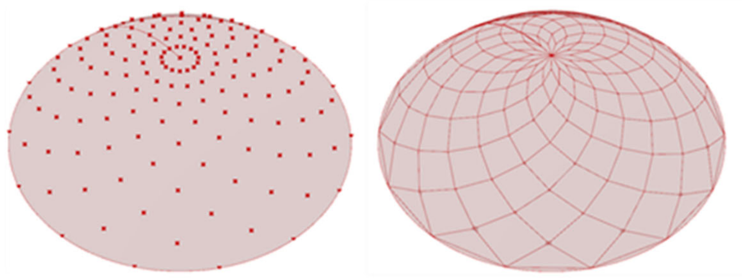


Figure 2 Curvature Network, Credit by Erfan Zamani

The other similar relevant example is (26) worked particularly for glass roofing structures. This paper uses the proposed method to bring the necessary geometric principles in a parametric framework. The parametric tool, CATIA, approximates the given structure format and generates discretized quadrangular meshes in a double-curved surface (26).

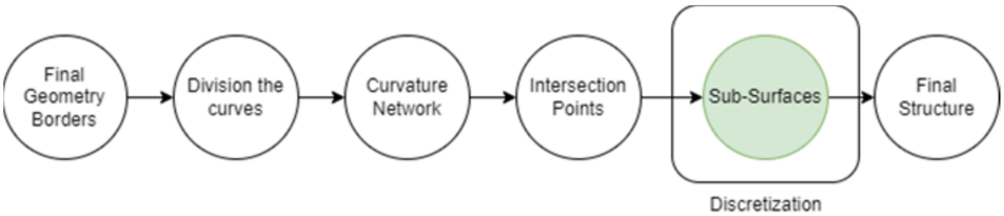


Figure 3 Curvature Network Parametric Logic, Credit by Erfan Zamani

4.1.2. Intersection of Tangent Planes

There is another top-down geometric approach to discrete double-curved surfaces based on the intersection of tangent planes. The paper (14) explores the possibility of two-dimensional mapping points over a 3D shape and generating planes by these points. By changing the tangent of these planes (the angle between planes and freeform), different shapes would be generated that result from the confluence of planes (14). Baharlou and Menges (1) follow the same method in the manner of "Constrained Generating Procedures "(GCP's), considering fabrication constraints. In their method, complex patterns can be used for planner locating and have more generated options (1).

Figure 4 Intersection Validation, Credit by Erfan Zamani

4.1.3. Algorithmic Growth

The new developments in fabrication methods, for example, 3d printers, bring more options for the modular designs based on generative and bottom-up approaches (7). The Project DisCo (Discrete Choreography) made a foundation for spatial aggregation modelling with beam shape modules in Virtual Reality (VR). This methodology is mainly proposed for gaming, and the discretised elements use sensorial physical/gamer body interactions to instantly assemble the structure (27).

The current digital design approach is mainly used to bridge the gap between digitalisation and fabrication to take advantage of novel and progressive production techniques. This digital to analogue translation needs to consider the natural geometry and specifications of the modules (19). Cubic modularity because of its simple geometry can streamline the process.

Rossi & Tessmann developed the tools WASP to explore different computational generative strategies to generate and assemble a mass of discrete elements from a manual designed module. Their methodology enables the designer to define a diverse variety of rules for modules to grow. This bottom-up aggregation can be transferred into digital design workflow and can be synced with robotic assembly systems (19, 20,21,24).

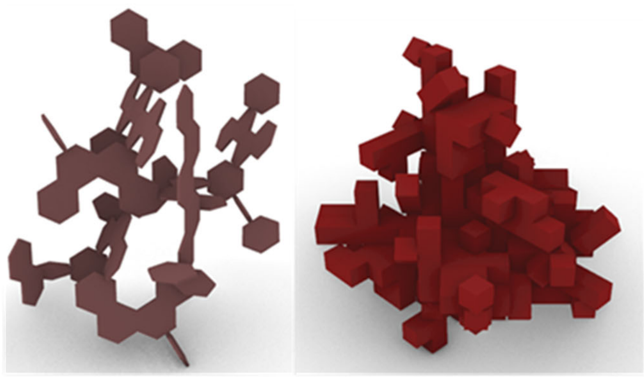


Figure 5 Algorithmic Growth, Credit by Erfan ZamaniGoldeh

4.1.4. Moving Cross-Section Procedure

The cross-section methodology had been presented in (8), based on polyhedron shapes. This model includes a network of planner square grides and polyhedron modules in which each edge of square grids plays the leading role to define modules' placement. This process that named "Moving Cross-Section Procedure" (8) & (15) can translate the planners into the modules by defining the modules' side angle. The pair of parallel sides of each square gride specifies the module's side locations. In this method, polyhedron modules are not predefined, and they are constructed along and in harmony with panner grides. Although cross-section is based on angle and pattern, the resulting modules are still controllable.

Tessmann (23) validates the "Cross-Section" method with an assembly system for topological interlocking blocks. In this interlocking validation that has been examined as a part of the research design studio, tetrahedron shape modules can fill a predesigned planner or curvature. Although the design of the modules might be varied, they can still be categorised as tetrahedron families.

The modules' dimensions and sides' geometry can bring new options for interlocking joints. This method constructs the base of (15) research. Their research simplified Tessmann's methodology by making a pattern of square grids on a surface and aligning tetrahedron modules to it. Then, they developed this method by applying hexagonal shape modules on a predefined cells network.

Bejarano and Hoffmann, in (2) generalised "Moving Cross-Section Procedure" by a "Topological Interlocking Configuration" (TIC). Their configuration is an assembly system based on the repetition of single modules on tasselling surfaces or mesh. The angular surfaces are still critical, but by analysing the modules' structural behaviour, the authors add central point and height values that make the modular parametric control more flexible. These behaviours include rotation, movements and slipping to the front, back and sides.

The Cross-Section method generally makes a topological structure in which each module is surrounded by several neighbours, depending on the number of modules' sides (1) & (15) & (25). The modules should be designed to prevent X and Y motions. To keep the entire structure, the designer may need to design the supporting frames or different designs in the border parts (2). This modular volumetric support and resulting interlocking system bring a high structure resistance that counteracts the external and internal forces (34) & (8).

The digital and software technology progress brings new features to the Cross-Section and tasselling-based methods such as more complexity in overall form and modular shapes. Also, there is more variety in the designs of the modules and interlocking joint options that enable us to consider different types of fabrication and assembly alternatives. In the figures below, we explored the Cross-Section Method.

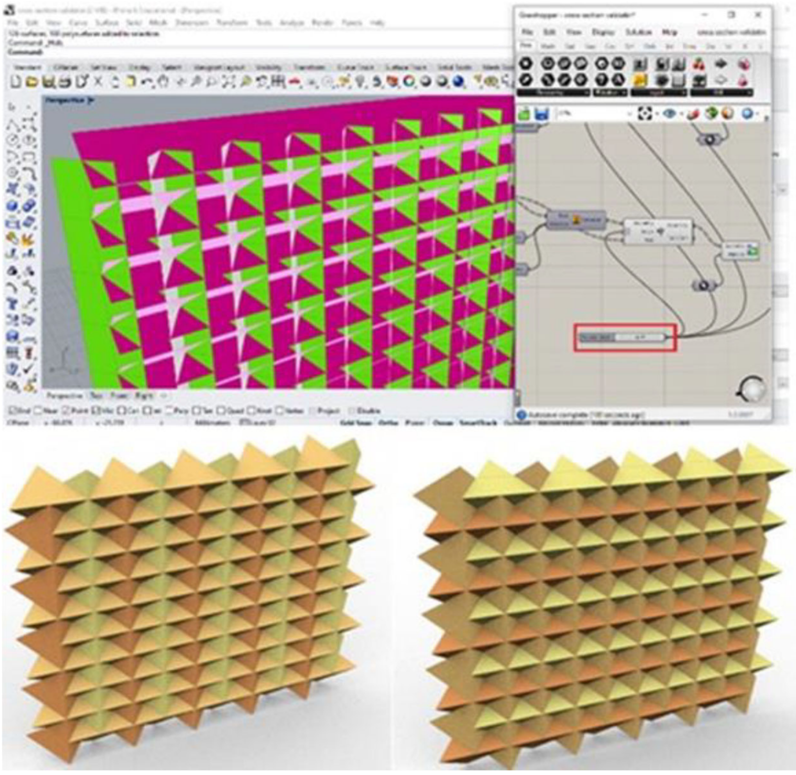


Figure 6 Cross-Section Validation, Credit by Erfan Zamani

4.1.5. Aggregation and Interlocking System

Rossi and Tessmann (20) propose a spatial assembly approach for an architectural formation aggregated by discretised modules. This aggregation can be resulted from the relation of the module with itself or with surrounding modules. They advance an aggregation model in 3Dimension based on the growth method (19). In this method, the 3D outline of the final geometry specifies the boundary of a modules' density. This reversible procedure can integrate the complexity of modules' shapes with their geometry relations and specifications. This method enables the designer to manage or even define the attribution of the modules and bring new options for fabrication and assembly levels. Their developed plugin WASP can link the discretised digital model and physical worlds.

Another example of modular aggregation configuration is (11) in which authors present a method as coverage for non-standard concrete structures with dodecahedron shape modules. The modules can be assembled to make a closed form for concrete to be cast. This temporary structure can be disassembled, and modules can be reused. Due to its nature and the high number of sides, Dodecahedrons can be constrained among several same shape neighbours and brings more interface options (11).

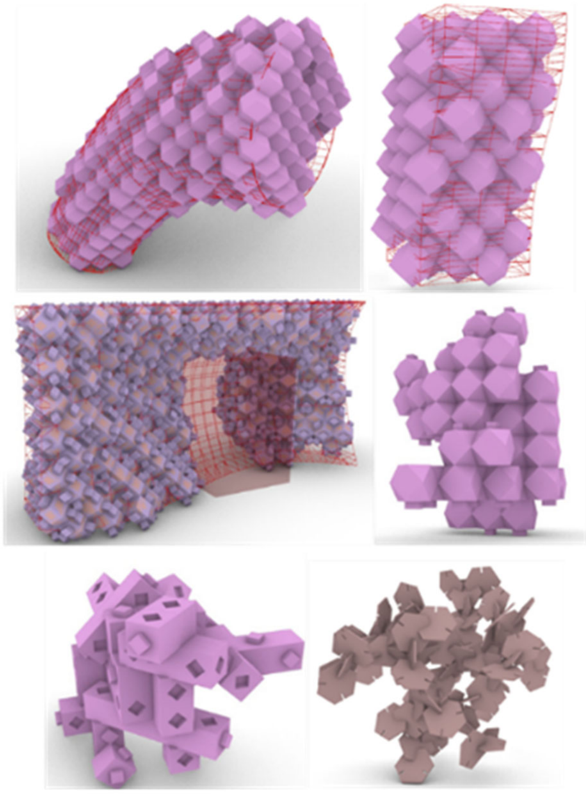


Figure 7: WASP Top-Down & Bottom-Up Validation, Credit by Erfan Zamani

4.2. BUILT STRUCTURES

In conjunction with literature proposed approaches, this paper parametrically recreate 6 built structures.

Table 2 Built Case Studies and methodologies, Credit by Erfan Zamani

Name	**Parametric Validation Method**	
1	(Traditional) Brick wall	Pattern and Modular Orientation
2	ArboSkin	Panelising
3	Serpentine Pavilion 2016	Pattern and Modular Orientation
4	British Museum Court Roof	Sub-division and Triangular Panels
5	80Hz Pavilion	Point's Network and Point Attraction
6	TLDC Tsumiki Pavilion	Modular Morphing

In 1999, Norman Foster designed a roof cover with a grid shell structure for Great Court (Figure 5) in National British Museum. Foster's technique approximates the degree of curvature network on a surface and applies triangular planers (9) & (13). Not only did architectural design and structural mechanism Foster consider, but he

also observed the fabrication process. For example, the average area of designed glass triangular panels is less than 0.7 square metres as larger sizes could not be manufactured (13). Although Foster used curvature, in this paper, we validate his approach in Grasshopper and curtail the algorithm by two times discretisation.
This paper recreates the brick wall as the simplest structural element. In this paper, the standard cubic brick has been used as the module. The form of the surface (wall) can be changed either parametrically or not parametrically. This algorithm is based on a planner curvature network, and the size of the bricks and the distance between them are parametrically changeable. This algorithm also can be applied to more complex geometries.

Figure 8: Built Discretization Case studies Revalidation, Credit by Erfan Zamani

The other examined case study is ArboSkin. First, the overall geometry is outlined with curves, and then it has discretised into smaller panels. In the case study, 80Hz Pavilion, a set of points in U and V dimensions are used to locate the panels and point attraction technique is used to define the angular adjustment. Tsumiki Pavilion had been designed by Kengo Kuma and this paper validate its structure in Grasshopper. For this case study a network of points is applied on the final geometry (Pyramid) and the designed modules have morphed into the points.

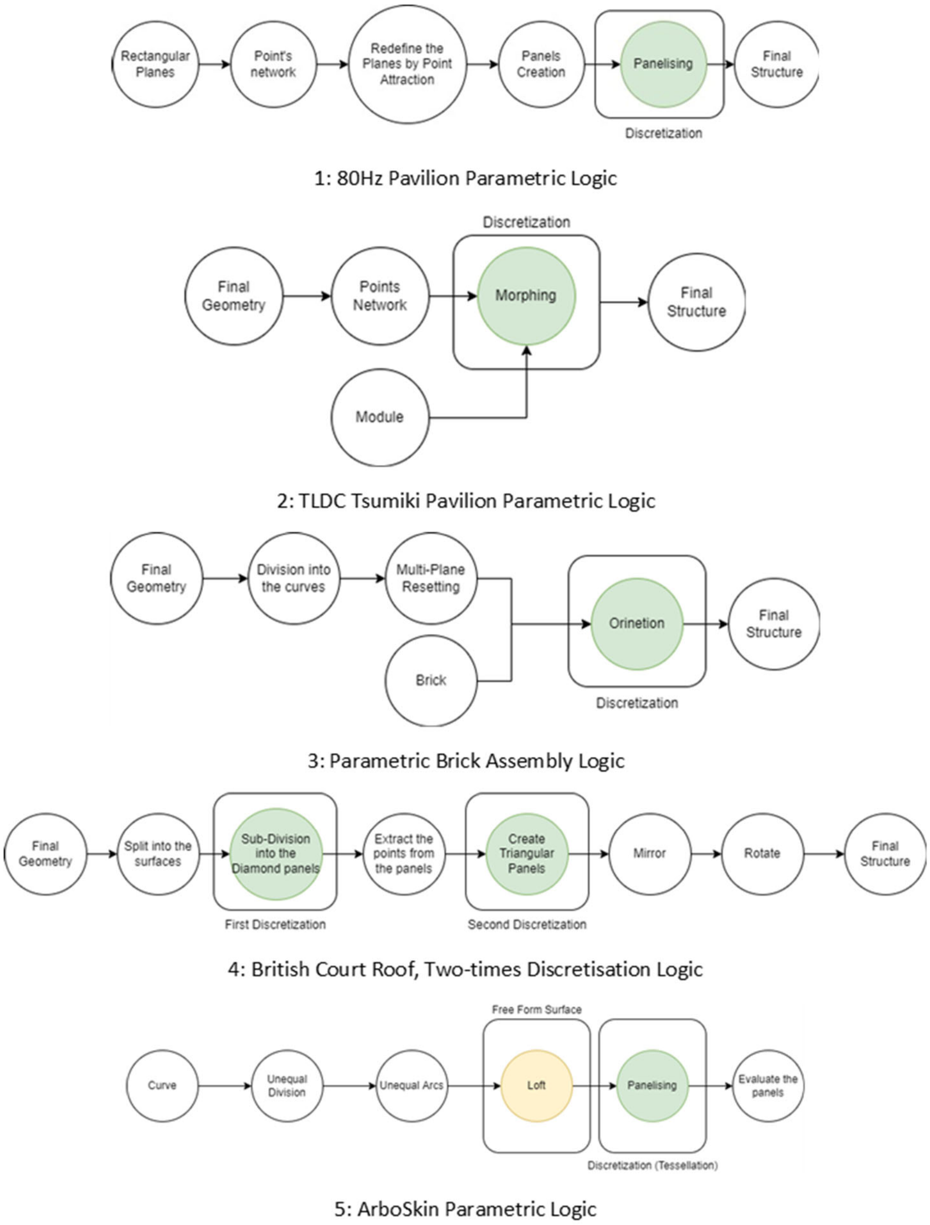


Figure 9 Parametric Logics of each built case study, Credit by Erfan Zamani

5. Classification

To classify the case studies, we consider the design's starting point and algorithmic logic of each. According to the case study validation and analysis, the parametric design starting point is either overall geometry or modular design or a combination of both. In addition, the parametric specifications and the potential of algorithmic development have been considered too.

Figure 1Table 3 Classification of Discretisation Approaches, Credit by Erfan Zamani

Approach	Design Starting Point	Parametric Specifications
Top-Down	Overall Geometry	The modules are constrained inside the geometry.
Bottom-Up	Modules	The modules follow the algorithmic rules to aggregate and form a geometry.
Hybrid	Overall Geometry & Modules	The modules parallelly follow the algorithmic rules and geometries (either surface or solid mesh). The closest match is the aggregation that is formed inside or extraneous of the larger geometry.

In the Top-Down approach, the resulted shape is being designed first, and then a parametric tool would come to create the nearest match. Hudson in (6) named this method "post-rationalisation". Hudson describes that the "Final Geometry" may be designed either in or out of the parametric tools and framework. This parametric re-creation can link the discretisation algorithms with fabrication and assembly machinery.

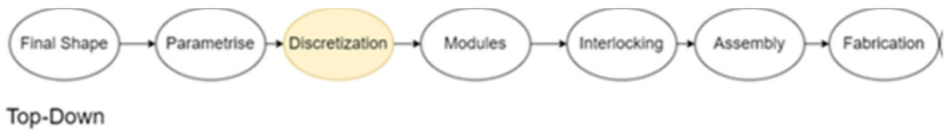


Figure 10 Top-Down Logic, Credit by Erfan Zamani

In the Bottom-Up approach, the module's design is the start point so that the discretised elements are defined first, and then rule-based algorithms form the overall structure. Hudson named this method "Pre-rationalisation" (6). As a result, a parametric rule-based setting will be achieved that can be adjusted according to the required application, dimensions, and fabrication possibilities.

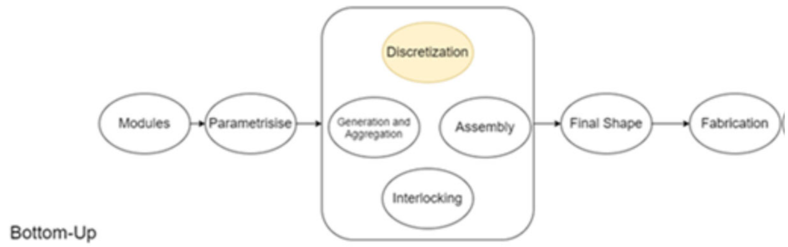


Figure 11 Bottom-Up Logic, Credit by Erfan Zamani

There is another approach, eliciting from the combination of mentioned approaches above. This Hybrid approach can include a top-down approach for overall geometry (large scale) in parallel with the bottom-up approach for modules (small scale). However, hybrid, like other parametric methodologies, creates a revisable system in which the different parameters and sub-parameters will be changed by changing the parameters on any scale (large or small).

The discretised hybrid digital models act in two stages: first, creating the outline of the final structure and second, making the modules. In the first stage, the outline can be parametric or not parametric border sketches of the resulted shape, but there are more options to create a map for modules to follow. For example, it may be a closed curve or a parametric pattern. Indeed, in this approach, the outline acts like a bag filled with several fruits(modules) or a string that connects several beads.

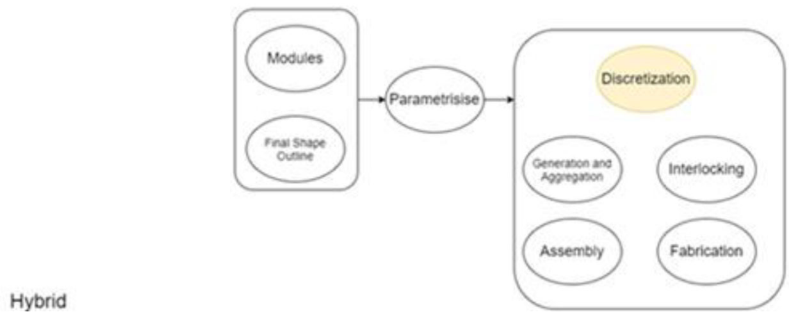


Figure 12 Hybrid Logic, Credit by Erfan Zamani

6. Discussion

The research presented is original in the sense that, addresses a classification for logical parametric discretisation. The research is also significant in the sense that it establishes the legitimacy, constraints and pragmatic aspects of discretisation and provides the toolset and a comprehensive foundation to be expanded in terms of fabrication and assembly.

On the one hand, this paper provides a systematic classification across discretisation approaches and, on the other hand, highlights the parametric design methodology as an efficient tool for innovative and intelligent construction.

Each category of proposed parametric logic can be developed with different interlocking options. This possibility brings new potentialities to offer innovative assembly methods. The design and assembly are the parts of a circular and dynamic process in which pre-programmed, and computer-controlled machines collaborate with digital models, parallelly with implementation.

Furthermore, this research is expandable to design structures specifically ideal for robotic assembly. The proposed logical classification can validate the assembly system by examining the joints and structural stability under the scale.

References

BAHARLOU, EHSAN and MEGNES., 2013. Generative Agent-Based Design Computation. http://papers.cumincad.org/cgi-bin/works/paper/ecaade2013_081

BEJARANO, A., & HOFFMANN, C., 2019. A generalized framework for designing topological interlocking configurations. International Journal of Architectural Computing, 17, 53–73. https://doi.org/10.1177/1478077119827187

BRANKO KOLAREVIC, & MALKAWI, A., 2005. Performative architecture: beyond instrumentality. Spon Press.

GU, N., WATANABE, S., ERHAN, H., & HAEUSLER, M., 2014. DESIGNING WITH DISCRETE GEOMETRY (pp. 513–522). https://doi.org/10.1111/j.1531-314x.2006.00068

HENRIKSSON, V., & HULT, M., 2015. Rationalizing freeform architecture - Surface discretization and multi-objective optimization.

HUDSON, R., 2010, Strategies for parametric design in architecture. (p. 274).

7. JENETT, B., CELLUCCI, D., GREGG, C., & CHEUNG, K., 2016. Meso-Scale Digital Materials: Modular, Reconfigurable, Lattice-Based Structures. V002T01A018. https://doi.org/10.1115/MSEC2016-8767

KANEL-BELOV, A., DYSKIN, A., ESTRIN, Y., PASTERNAK, E., & IVANOV-POGODAEV, I., 2010. Interlocking of Convex Polyhedra: towards a Geometric Theory of Fragmented Solids. Moscow Mathematical Journal, 10, 337–342. https://doi.org/10.17323/1609-4514-2010-10-2-337-342

KATRIN, J., PENN, A., & SHEPHERD, P., 2014. Designing with Discrete Geometry. http://papers.cumincad.org/cgi-bin/works/paper/caadria2014_177

KOLAREVIC, B., 2004. Architecture in the digital age: design and manufacturing (pp. 280–304).

LEDER, S., 2020. Voxelcrete - Distributed voxelized adaptive formwork. http://papers.cumincad.org/cgi-bin/works/paper/ecaade2020_172

LIU, Y., POTTMANN, H., WALLNER, J., YANG, Y.-L., & WANG, W., 2006. Geometric modeling with conical meshes and developable surfaces. ACM Transactions on Graphics, 25, 681–689. https://doi.org/10.1145/1141911.1141941

MALEK, SAMAR RULA., 2012. The Effect of Geometry and Topology on the Mechanics of Grid Shells (p. 131).

MANAHL, M., STAVRIC, M., & WILTSCHE, A., 2012. Ornamental Discretisation of Free-form Surfaces. International Journal of Architectural Computing, 10(4), 595–612. https://doi.org/10.1260/1478-0771.10.4.595

PFEIFFER, A., LESELLIER, F., & TOURNIER, M., 2020. Topological Interlocking Assemblies Experiment (C. Gengnagel, O. Baverel, J. Burry, Ramsgaard Thomsen, Mette, & S. Weinzierl, Eds.; pp. 336–349). Springer International Publishing. https://doi.org/10.1007/978-3-030-29829-6_27

POTTMANN, H., BRELL-COKCAN, S., & WALLNER, J., 2007. Discrete Surfaces for Architectural Design. Curves and Surface Design: Avignon 2006, 213–234.

POTTMANN, H., & WALLNER, J., 2008. The focal geometry of circular and conical meshes. Advances in Computational Mathematics, 29, 249–268. https://doi.org/10.1007/s10444-007-9045-4

RETSIN, G., 2019. Toward Discrete Architecture: Automation takes Command.

ROSSI, A., & TESSMANN, O., 2017. Integrating design and fabrication with discrete modular units.

ROSSI, A., & TESSMANN, O., 2017a. Aggregated Structures: Approximating Topology Optimized Material Distribution with Discrete Building Blocks (p. 10).

ROSSI, A., & TESSMANN, O., 2017B. Collaborative Assembly of Digital Materials.

STAVIC, M., WILTSCHE, A., & FREIßLING, C., 2011. GEOMETRIC AND AESTHETIC DISCRETIZATION OF FREE FORM SURFACES.

TESSMANN, O., 2012. Topological Interlocking Assemblies.

TESSMANN, O., & ROSSI, A., 2019. Geometry as Interface: Parametric and Combinatorial Topological Interlocking Assemblies. Journal of Applied Mechanics, 86, 111002. https://doi.org/10.1115/1.4044606

WANG, W., & LIU, Y., 2009. A Note on Planar Hexagonal Meshes (Emiris, Ioannis Z, F. Sottile, & T. Theobald, Eds.; Vol. 151, pp. 221–233). Springer New York. https://doi.org/10.1007/978-1-4419-0999-2_9

GLYMPH, J., SHELDEN, D., CECCATO, C., MUSSEL, J., & SCHOBER, H., 2004. A parametric strategy for free-form glass structures using quadrilateral planar facets. Automation in Construction, 13(2), 187–202. https://doi.org/10.1016/j.autcon.2003.09.008

DRUDE, J. P., ROSSI, A., & BECKER, M., 2020. Project DisCo: Choreographing Discrete Building Blocks in Virtual Reality. In C. Gengnagel, O. Baverel, J. Burry, M. Ramsgaard Thomsen, & S. Weinzierl (Eds.), Impact: Design with All Senses (pp. 288–299). Springer International Publishing. https://doi.org/10.1007/978-3-030-29829-6_23

TIBBITS, S., 2011. A Model for Intelligence of Large-scale Self-assembly. 8.

KLEMMT, C., PANTIC, I., GHEORGHE, A., & SEBESTYEN, A.,2019. Discretized Fabrication of Geometries Generated with Cellular Growth Simulations. 11.

KAIJIMA, S., MICHALATOS, P., TAYLOR, A., & LONDON.,2007. Discretization of Continuous Surfaces as a Design Concern.

FARMER, M., 2016. The Farmer Review of the UK Construction Labour Model Modernise or Die Time to decide the industry's future.

SRINIVASAN V, AKLEMAN E, MANDAL E., 2005. Remeshing schemes for semi-regular tiling's. in ieee compute. soc; 2005. p. 44–50. Available from: http://ieeexplore.ieee.org/document/1563209/

PINKALL, U. BOBENKO, A.,1996. Discrete isothermic surfaces. Journal für die reine und angewandte Mathematik (Crelles Journal), 1996(475), pp.187–208. doi:10.1515/crll.1996.475.187.

PASTERNAK, E., DYSKIN, A.V., ESTRIN, Y., KHOR, H.C. AND KANEL-BELOV, A.J., 2003. Fracture Resistant Structures Based on Topological Interlocking with Non-planar Contacts. Advanced Engineering Materials, 5(3), pp.116–119. doi:10.1002/adem.200390016.

ARCHITECTURAL TECHNOLOGY, IT, AND DESIGN OF CITIES

DR N. BARRETT AND DR J. HARTY
KEA Granplantagen 1, 3550 Slangerup
Email address: nielsbarrett@gmail.com
KEA Prinsesse Charlottes Gade 38, 2200 Copenhagen
Email address: jmh@kea.dk

Abstract. To date, the construction industry and environmental planners are continuing to empty the built environment of all other functions, other than a single main function like industry or housing. This is contrary to the known fact that the most attractive environments are those with a mixture of functions (Gehl, 2006). We are essentially building suburbs instead of cities. The size of buildings tends to mirror the size of the investment, which is growing, because it is now quite rare that the user is the investor. The user most often acts as a tenant or buyer of some square meters in the investor`s building design, that is made to support the investor in the best possible way. This is also the case in housing where many uniformed buildings bear witness of the huge scale of the investor initiative. Thus, the users do not have much of a say and their individuality is depressed by a single dominant investor (Barrett and Kruse, 2016). This is how the desired number of square meters is produced the easiest and in the most economical way, but it provides rather poor environments for people to live in. How can we again make it attractive for the users themselves to invest in their own small urban buildings? How can it become just as easy and relatively as cheap, to get one's own tailored building as it is becoming a tenant, submitting to a monument of a profit-investment?
This paper will investigate how architectural technology can change that development and ensure diverse functional and architectural environments in a more cost-efficient way by the help of IT and advanced robotic technologies. To do so, we must investigate what advanced techniques are already being used by other industries and discuss how they can be imposed on "construction" or the manufacture of buildings. It must also look at the planning of city areas, which needs to adjust to new architectural technologies and vice versa.

Keywords. Size of buildings**,** Suburbs, Investors, Industrialisation, IT, Ordinary fabric, AT.

1. How size of buildings is equivalents to the size of the investment.

It is quite a logical phenomenon that the size of the investment in a building tends to be equivalent to the desired size of it. Square-meter prices tend to be almost the same within the same areas due to the standards coming from building regulations and the habits of investors within the industry itself. It has always been like that, and it is hard to see how it could change (Barrett, 2019). If the size of the buildings in the urban fabric of our cities is too big, the logical thing to do is to secure smaller investments. Back in time, the main fabric of the cities in Europe consisted of single-family houses because their size followed the size of the investment the future user could afford. Buildings were made for the specific use of specific households. The resulting urban fabric was very varied in comparison with what we can experience today. Within a relatively few meters of a street another building appeared, and no two buildings were the same in size, the arrangement of their windows and doors, or their architectural features, even if they followed the same common standards and habits.

This was very entertaining and attractive for the citizens who took the whole thing as something quite natural. It was quite natural that the user bought a plot of land and had the required building erected on it in a way that respected the common standards. In Denmark, it could look like what we see in the images below:

*Figure 1:*Rows of old buildings in Copenhagen and Svendborg

What changed this practice? In Copenhagen, it began to change into what we see today when a big fire in 1728 destroyed one third of the city and left many hundreds of families homeless. People with money saw an opportunity to invest and earn more money and the resulting buildings became tenement buildings of a relatively decent size with only one staircase and apartments to each side of it. Like the single-family houses, these buildings were also designed and erected by master craftsmen – the equivalent to today's architectural technologists who are educated in how to put a building together, where today it is left to contractors to manage the erection. Until the beginning of the twentieth century architectural technology was embedded in construction handicrafts that developed during a millennium (Barrett, 2016).

A second fire in 1795 destroyed another third of the city of Copenhagen and, when the Duke of Wellington in 1807 commanded English troops to surround the city and begin the first terror bombardment of a big city in the history of war, meaning the last part of the town became destroyed by fire. In these three incidents a lot of people lost their homes, and each time 'innovative' people took new steps to expand the size of buildings and investments in new tenement structures. In most western countries the influx of people from the countryside to the industries of the bigger cities caused similar ideas and developments. From the middle of the nineteenth century most citizens in bigger cities had to live in buildings made by investors and not on their own initiative. Still, most of the structures were made by master craftsmen except those meant to house wealthy families (Barrett, 2011). They were now designed by architects in order to appear more stylish.

When the size of structures to house ordinary people in relatively cheap apartments grew to amounts that would attract the profession of architects, they took over the design task and they have kept it ever since. The result of that appears like this:

Figure 2: Tenement buildings in Copenhagen from 1920 and 2005

2. What the building structures tell and their degree of attraction

The small old buildings in figure 1. speak about homes of families who have had their own say in how they wanted to dress and show themselves to be a bit different from the others but also that they participated in the shaping of the public sphere. These characteristics are fully in line with the idea of democracy despite the paradox that they are erected in the period of royal monarchy (Barrett, 2019). The tenement buildings in figure 2. both tell about huge investments made on the initiative of economic powers high over the head of the people who were meant to live in them. People must accept the dress and appearance chosen by somebody else; they are patronised, uniformed, and anonymised like under a Stalinist dictatorship. It is also in conflict with the basic constitutional law of Denmark which in its paragraph 72 states that the home is inviolable and in paragraph 73 states that the property right is inviolable as well. Thus, the latter right violates the homes of tenants, who cannot decide the colour of their own front door and several other details within their homes. In fact – the home is not theirs and that is a disgrace in a democracy. Unfortunately, this is not appreciated by the people or their political leaders.

Another problem with the huge building structures is that they do not make real urban environments or develop the cities (Barrett and Kruse, 2016). They make suburbs and waste areas that attract nobody, except the people who live there. As soon as they get the possibility of a home less bad, they go for it. This has led to a new kind of settlement where people decide themselves, namely the so-called villa areas where people have a single-family house on their own lot of land with a garden and private parking as they had earlier inside the cities. This might be much better for the owners and the families, but the created environment is also a wasted area for those who do not live in it. It is, seen from a town planning point of view, just another kind of suburb that occupies huge areas lacking any attraction to the rest of society. Suburbs surround the old town centres but do not create nice landscapes or townscapes.

Therefore, we should stop making suburbs and again begin to make townscapes where all kinds of people can live in their own single family town houses with attached gardens and private parking (Barrett, 2019). Is that possible? Yes, if we want it! But how can it be done and funded?

3. Single family town houses – what is possible?

At the time being, there are a few examples of areas where newer tenement town houses look like single-family town houses, but there are only very few examples of real single-family townhouses. Below we find an example from Copenhagen, in the first image, and a Dutch example in the second. Both examples were built under the guidance of Dutch architects (Abrahamse et al, 2006).

Figure 3: Sluseholmen in Copenhagen and houses at Borneo Island in Amsterdam

As mentioned, the inferior villa areas at an urban level, is that the environment is not good for anybody else other than those who live there, and therefore they are missing out on something important. They miss-out on both the services that can be given by the town centre and the well-appreciated pleasure of the open landscapes around built environments. Back in time, the gentry, who could get most of what they wanted, had a decent country house and a nice private house in the city close to the palace of the monarch. They made the whims most people desire, come true. They were masters in their own home and their 'home was their castle'. It is obvious, that people who want to raise a family, want enough space for adults and children both inside and outside their homes and that everything they need in daily life is close by. If we accept it as being their own house, with enough space inside and some outdoor space for a small garden and for carparking, we might arrive at something like what can be seen below:

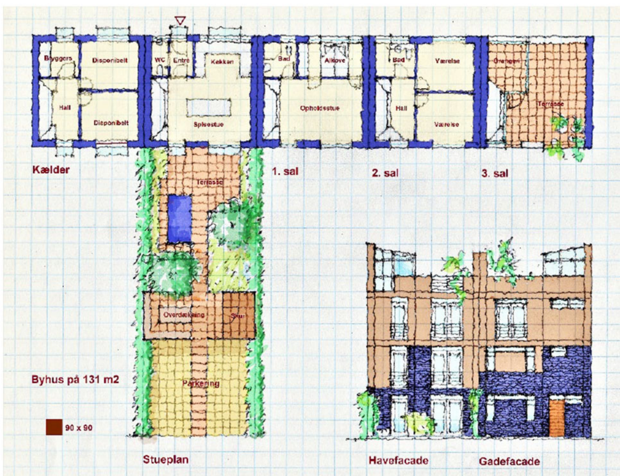


Figure 4: A small townhouse of 131 m2 for a family of parents and 2 children

This small townhouse is fully industrialised and comes as two fully finished modules per level, including a basement and a roof terrace with its own orangery. The next image will show a bigger building for the same number of people and with a lift big enough for disabled. These images are taken from a book in Danish "Opgør Med Byggekulturen" (Conflict in Building Culture), (Barrett, 2019).

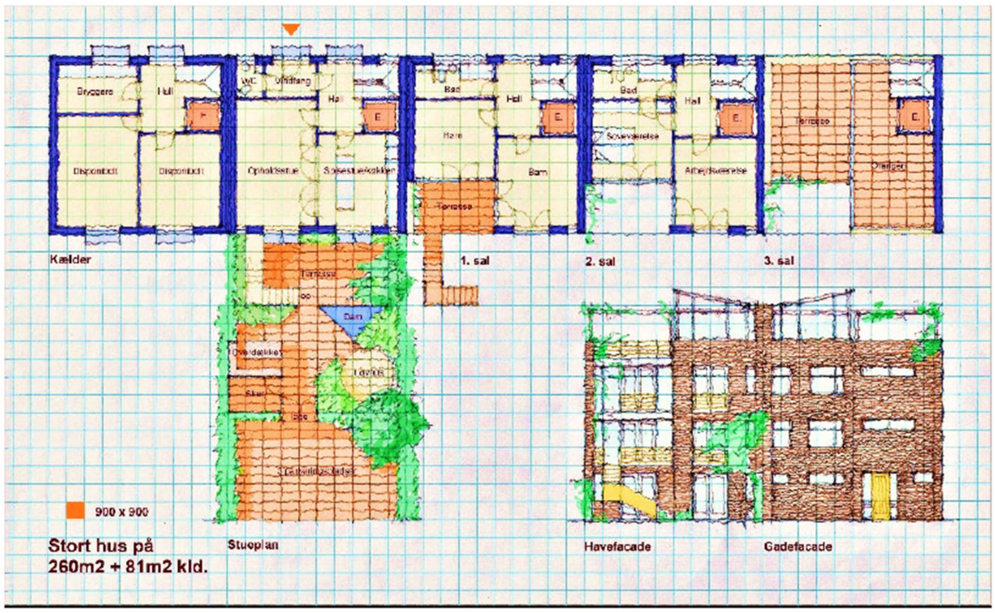


Figure 5: Townhouse of 260 m2 plus basement and roof terraces.

With an appreciative gesture to the British mews, a block of such houses with integrated small industrialised smaller business buildings could look like this:

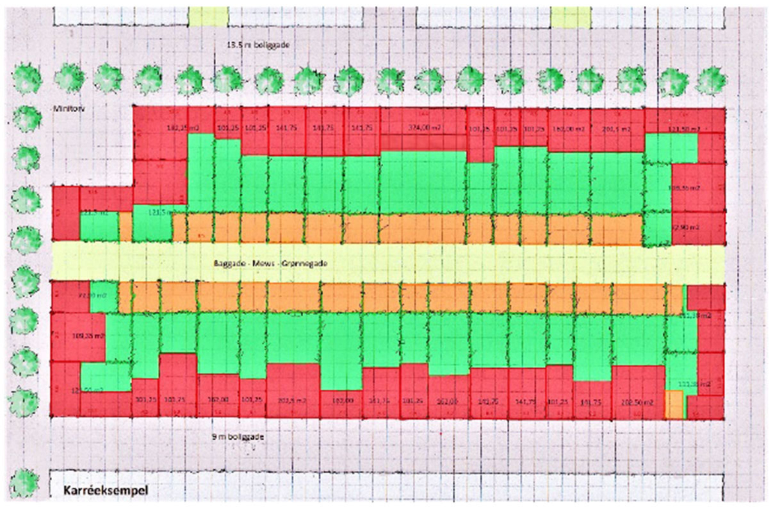


Figure 6: Example of a block of industrialised buildings with individual appearance.

A cross section in this block could look as shown in the next image:

Figure 7: Cross section in the block showing the left end.

To meet the requirements of the investors, who are now the individual householders themselves – investors who want to express their individuality like people have always wanted to, the building system or more correctly the manufacturing system should be very flexible and allow a variety of different plan solutions, sizes, appearances, and colours so that no two buildings are the very same. This means that the standard parts are relatively hidden, allowing for a diversity of desires for each aspect of a house design to be met. As an example, the same plan solution desired by several neighbours, (which would be an extremely rare situation), will automatically look different, when the individual wishes regarding appearance, are met by the manufacturers:

Figure 8: The narrowest facades of 4,5 meter – towards street and garden.

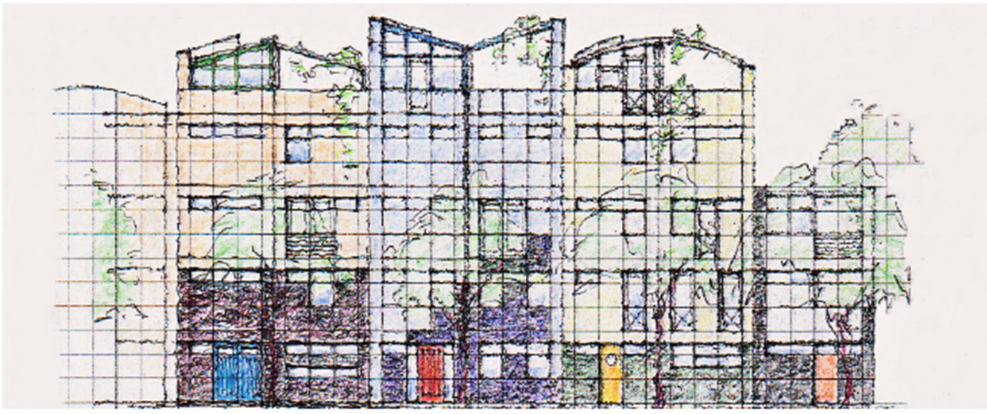


Figure 9: Three larger houses sharing plan solution plus the smallest one.

4. How such buildings can be produced and bought?

Therefore, it is necessary to quit the traditional design and construction methods in order to reach a decent, modest square-meter price and to secure buyers decent and easy access, in order to achieve their individual building. This is what a real industrial producing company can do by developing a smart and advanced flexible production system using the principle of readymade portable modules. In an article presented at the 7th ICAT conference, it was described how a system of two main materials could be utilised by the producer (Barrett, 2016). Steel and fibre concrete were proposed – steel for the framework and fibre concrete in different colours as fire protection and cladding inside and outside.

4.1. ROLES OF MANUFACTURING COMPANIES AND SOCIETY

A company specialising in the utilisation of these two main materials for the main structure of the buildings described above will need professionals to develop the manufacturing system and to meet and give the necessary service to its single-family customers.
Additionally, it is necessary that the customers can obtain the required plot of land from someone, independent of the house manufacturers, for example, the local municipality, that will make a local plan for the actual block of land parcels. The local plan might state how to utilise the land and what limits to stay within in the use of the land. This could be a maximum hight of buildings of four levels plus basement, a minimum of 1/3 of the land arranged as garden and a zone for parking of 5,4 meter along the back street. This can secure pricing and utilisation of the land, under democratic control and avoid speculation of investors and developers (Barrett, 2019).

To achieve this the manufacturing company needs a good sales and service organisation and, in our scenario, where its key players see themselves as professionals who give their service to families while desiring to make them quite satisfied with their home and garden. At the same time, the professionals aim to secure a high professional standard on behalf of the company and society.

Which profession could do this? What kind of education leads not only to the right professional qualifications but also to the wishes or desires to offer this service, which is also a service to the whole manufacturing system and organisation in the company? We, the authors, who are educated architects but have dealt with the education of architectural technologists are in no doubt.

The architectural technologist is the best equipped professional both technically and mentally. He or she is the true successor of the old master-builders and is able to take those responsibilities that were earlier embedded in the handicrafts. It is not yet a widely understood reality, that their training in dealing with the architectural technicalities is especially needed in the drawing office because the old handicrafts are no longer in use there. But this need has given their profession (it's still growing) recognition in society. The mindset of the architect has always been to make something outstanding, but the ordinary fabric of single-family townhouses needs a kind of "master builder" who is able to realise the beauty in houses obeying certain common rules. No other profession, other than that of architectural technology, is close to the appropriate background (Barrett, 2011).

4.2. SUGGESTION OF A MAIN STRUCTURE

In the article "A truly industrialised house building system" in the ICAT conference 2018, the following technical details were shown for houses assembled of fully ready modules on locations around the market area of a house producing company (Barrett, 2018).

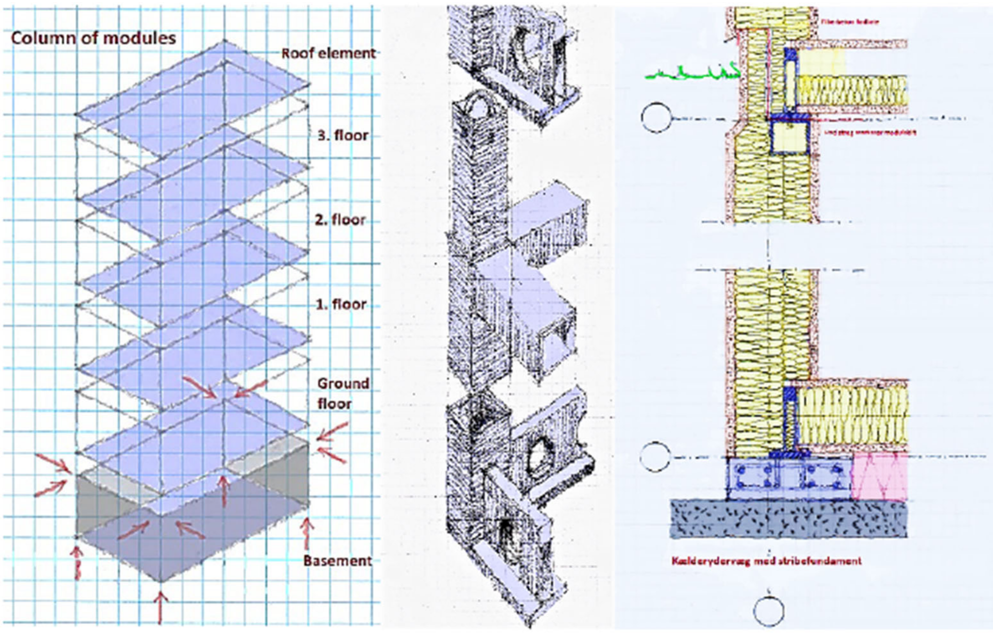


Figure 10: Columns of modules, load bearing parts, and standard construction.

As to how the manufacturing process could take place in the factory, this article described how the loadbearing frame of columns and beams could be welded together in modular units. The description included how 30 mm thick fibre-concrete plates could be produced and how secondary frames of thin-plate steel profiles could be embedded in the wet fibre-concrete to create a rigid connection between the two elements. Furthermore, it was mentioned that most of the activities in the factory could be done by robots governed by computer numerical control systems (CNC) obeying developed BIM systems. Manpower in these processes would be primarily needed for quality and control.

The architectural technologist, who engages with the customers and realises their wishes and hopes, will be using BIM systems designed to stay inside the limits of the house structure system and will do all the necessary design work. First, they will send a 3D model digitally to the customer and after approvement, send technically ready data for production 3D model to the manufacturing department. To dig a bit deeper into this, we have the following information to give.

4.3. EXISTING TECHNOLOGY IN CONSTRUCTION AND MANUFACTURING

Increasingly, both digitalisation and automation, is impacting buildings and how we make them, with far reaching effects. As this disruptive technology emerges, it affords new improved methods too. A disruptive technology means that new methods and procedures will replace existing systems with redundancy and job losses. But it also reveals new opportunities and prospects for those willing to embrace and deploy such possibilities.

It is important to acknowledge these opportunities and deploy them to our benefit, and this fits nicely into our paper here, where architectural technologists are best suited to oblige (Harty 2012). Buildings are now authored through modelling, and the data created can be checked, corroborated, and be analysed, simulated while its performance can be mapped before a sod of earth is turned. This is important. It brings certainty and better practices, which makes improvements while removing poor work, fragmentation, and errors. It improves the whole process, and the professional best suited to delivering it is the architectural technologist.

Because technologists are educated in project driven semesters with group-work to the forefront, they become the glue that joins the other stakeholders in the procurement process. They also possess the skills necessary to deliver such a payload. They develop competences to evaluate and explore innovative solutions, and this is borne out in how many are registered SME's before, during and after their education. Their arsenal also includes the ability to cost work, understand the programme, and produce acceptable solutions to both the homeowner and society in general.

Being better informed, and in full control of budget, process, and the timeline, improves margins and reduces mistakes, while bringing better practices on board. This then means changing the perceived traditional methods while overhauling procedures, in a revolutionary manner. So, in a collaborative environment where many stakeholders are involved, there must be better coordination at start-up with clearer rules of engagement and a no-blame culture. Construction is a fragmented industry, which is slow to improve, especially in production, precisely because there are no incentives to do so. Double work and sloppy work usually result in reworking and double payments, all because the payment structures in force, reflect the tiny profit margins that prevail at large.

John Tobin, in his article: "Measuring BIM's Disruption: Understanding Value Networks of BIM/VDC (Virtual Design & Construction)" stated:
"BIM is a disruptive technology, in contrast to CAD, and brings a different 'value network' to the AEC industry… where BIM sows information in a model environment, while VDC largely harvests that information for downstream uses including commissioning, facility management and construction logistics" (Tobin, 2013).

He refers to CAD being a progressive feature of traditional methods, but that it was merely Computer Aided *Drafting*, whereas VDC, harvests data for several new features, not fully understood by the profession at that time. David Shepherd, author of the BIM Management Handbook, in an article entitled "Ahead of the Game" (Malleson, 2016) stated:
"Where a disruptive technology emerges – and BIM is a disruptive technology – its effects on the mainstream is not always clear. What we might be seeing is the early stages of disruption, and in those early stages it's very difficult to know what the effects will be. We don't have the breadth of vision to see where, and for whom, the benefits of BIM will emerge" (Malleson 2016).

The Internet of Things (IoT) describes a network of physical objects that have sensors, software, and other technologies embedded in them to connect and exchange data with each other. It has become widespread, due to the number and prevalence of digital devices, namely mobile phones, hand-held devices, and the coverage of internet penetration across the globe. Cisco Systems estimate that the ratio of people to things grew from 0.08 in 2003 to 1.84 in 2010. This was predicted to grow to 6.58 by 2020 (Evans, 2011).
It gives rise to Smart Homes, Smart Cities, and a plethora of new interconnected networks, which can predict, track, be proactive, or prescriptive and optimise operations. This also means that it can be a big technology disrupter, as it makes analogue methods redundant. Buildings become proactive rather than just reactive.
Increasingly, we are seeing digital hand-held devices making an impact on building sites. The use of QR codes allows relevant data to be accessed just-in-time, where and when it is needed. The ability to check up-to-date information, means that errors can be identifies immediately and assigned to be corrected by the person finding it, all the way through to the person in a position to correct it. The single point of reference means that the red lining or issue noted can be cleared and assigned a new stature as being fixed, all in the cloud, meaning the speed and efficiency of such methods become quickly adopted because they are seen to work. Bringing this into a factory makes the process better.
Both augmented reality and mixed reality are slowly making their way into construction. Already products can be transposed into settings, such as mapping services on to structure, checking clashes and reporting project status. IKEA too is moving its assembly manuals to an augmented reality app, which locates the flat pack in the room and step by step shows how to assemble the chest of drawers or whatever, paying particular attention to difficult or not obvious details (Morby, 2018). This

allows procedures to be shown where needed, removing poor work and empowering new methods.

Construction smart hard-hats (with a visor), on to which project information can be displayed (via a dashboard) or augmented virtual modelling can be placed into their position in real time are now available (Lorek 2018). On a lessor level, hand-held devices can perform the same tasks and either by using QR codes or barcodes can retrieve relevant information to relevant tasks at the source of the problem (BSI-Group, 2017).

Technologists are implementing these developments in design and on-site using common data environments, allowing them to coordinate and minimise mistakes and reworking. They are taking the new technologies into the workplace and as first responders are becoming masters of these skills and competences.

Using Levels of Development (LOD's), this is akin to going from LOD-300 to LOD-400 to LOD-500 and/or even LOD-350 in between (BIM-FORUM 2017). LOD-300 is the level of development that broadly defines the designers' requirements. 350, is the contractors' take on the designer's requirements. 400, then, is what materials and techniques are ordered to be built, while 500 is the "as-built" completed project. Arguably, there should be no changes through these stages, but this is clearly not the case, as can be seen most glaringly in a project like Grenfell Towers in London (Moore-Bick, 2019), where the project went through too many iterations from the architect's intentions to the completed refurbishment, resulting in disaster. New replacement windows were 150mm too short in width to fit the openings, to meet new energy requirements. These gaps were not properly filled out, allowing the fire unabated access to the interiors (Barratt, 2018).

Smart contracts will be one of the most fundamental and disruptive innovations (Kinnaird, Geipel, 2017). There are no middlemen, and it is effectively executed once where pre-defined conditions are met. They lead to faster settlements and are very accurate. Risks are lessened and costs are reduced because there is no reliance on third parties, especially with legal costs and dispute resolutions. As the Big-Data aspect increases not only will the construction branch improve, but also society in general, will appreciate the scalability and maturity of the technology.

Where these developments affect single family town houses (with attached gardens and private parking), is that is inclusive in the design phase. This means that all stakeholders are involved and can have a proactive influence in framing their home and can both see and measure the impact of those design decisions.

With families of components, a language is built, where differences can be made but within the scope of choices offered. No two houses will be the same, but the cost of those differences is minimised, making them feasible. Notably, it will reduce the differences in LOD's 300 to 500, with the accruing benefits.

4.4. EXISTING TECHNOLOGIES USED IN HOUSE MANUFACTURING

While BIM and new technologies cause disruption in the construction industry due to its organisational structure, it is not the case within industrialised production industries. In them the very same routines of the very same people characterise what is going on. Contrary to the always changing conditions from building site to building site the very same physical environment characterises these industries, and each

company always try to find better and smarter ways for their production (Kristensen, 2011).
It is easy to realise that the 3D modelling tool, taken into use within the one and same house-producing-factory that possesses a developed house structure system, can be utilised to be presented to customers as well as to act as the CNC part in a BIM manufacturing process. The 3D model itself should direct most of the manufacturing process, which has only few people involved as inspectors and controllers. Instead of people lead by people, robots and automatization of machinery will be guided by the advanced 3D model.
In the first place the manufacturing company will have to invest a lot in buildings, machinery, and IT, but after a while everything will go smooth as we know from other industries of a certain level of high tech. Thus, the square-meter new house will end at a much lower cost than now. This is the lesson from all the other industries.
As described, in the present state of the construction industry, an increasing number of components are made in processes like that, but they are assembled and adjusted to each other on site and the whole organisation is basically the same as it has been for centuries. BIM will perhaps slowly reorganise something in the future. Right now, we are stuck in a traditional culture with traditional thinking while trying to find smarter ways to do the same thing, instead of doing something different, new and smart (Kielland, 1920).
In the future, most square meters needed in society can be made in a fully industrialised way, but all houses with special functions like for example churches and swimming baths might still need a more construction like production process. Square meters for living and similar common uses can easily be fully industrialised.

5. Conclusion

To conclude and create an overview of all the above given argumentation and references several statements can be mentioned:

1. Any house or building is in size and appearance a visualisation of an investment, the investor, and its designer (Barrett, 2016; Barrett 2019).
2. Investments in buildings meant to cause income from numerous tenants or buyers create unpleasant environments, tending to be out of human scale (Barrett and Kruse, 2016).
3. The common ongoing construction practice with the involvement of clients, consultants, lawyers, real-estate agents, solicitors, banks, mortgage credit-institutes, and numerous contractors and subcontractors make the square-meter prise of a building for ordinary use unnecessary high and often out of reach for ordinary incomes (Kristensen, 2015; Barrett 2019).
4. The common construction practice is outdated and behind the state of all other main industries due to lack of adjustment to modern industrialisation methods for both organisation and execution of major parts (Kristensen, 2015).
5. By smarter use of existing technologies and ways of manufacturing and marketing, square-meter prices of ordinary buildings can be significantly lower than at present and secure better access for ordinary people with ordinary incomes (Barrett, 2019; Kristensen, 2015).

6. Single-family townhouses and small business buildings can create a nice entertaining urban and green environment for daily life of inhabitants and attractive urban activities for the benefit of all (Abrahamse et all; Barrett 2019).
7. Modern IT and robots together can do the majority of all the former hard-work when utilised in manufacturing instead of in construction on site. Work on site can be reduced to crane-work, excavation, and soil adjustment (Barrett, 2019).

Figure 11: A city environment made by industrialised single-family townhouses.

References

ABRAHAMSE, J, ET ALL, 2006. Eastern Habour District Amsterdam – Urbanism and Architecture. Rotterdam: NAi Publishers.

BAKER, E., 1999. *The Top 10 construction achievements of the 20th century.* Wadhurst, England: KHL International

BARRATT, L., 21 June 2018-last update, Grenfell council was warned about gaps in windows by resident of flat where fire began [Homepage of Inside Housing], [Online]. Available: https://www.insidehousing.co.uk/news/news/grenfell-council-was-warned-about-gaps-in-windows-by-resident-of-flat-where-fire-began-56882 [13 June 2019].

BARRETT, N., 2019. *Opgør med Byggekulturen – Hvad der skal til for at alle kan bo godt og rart – i deres by*. Aarhus: Forlaget Hovedland.

BARRETT, N., 2018. A truly industrialised house building system. *In:* T. KOUIDER and G. Alexander, ed. *Architectural Technology at the interfaces,* Ulster University June 2018, 127 – 140.

BARRETT, N., AND KRUSE, J, 2016. How Buildings Visualise Client and Architect. *In:* A. G. GARRIGOS and T. KOUIDER, ed. *Healthy Buildings: Innovation, Design & Technology*. University of Alicante May 2016, 139-158.

BARRETT, N., 2014. The Outstanding and the Ordinary. *In:* T. KOUIDER, ed. *Architectural Technology, Towards Innovative Professional Practice,* Aberdeen November 2014, the Robert Gordon University, Aberdeen, 128 – 150.

BARROW, L., 2004. Elitism, It and the modern architect opportunity or dilemma. *Automation in Construction,* **13**(2), pp. 131-145.

BIM-FORUM, 2017. LEVEL OF DEVELOPMENT SPECIFICATION GUIDE. November. Dallas: IKERD.

BROOKFIELD, E., EMMITT, S., HILL, R. and SCAYSBROOK, S., 2004. The architectural technologist's role in linking lean design with lean construction, DTU - BYG, ed. In: *IGLC 12 Annual Conference on Lean Construction*, 2004 2004, DTU Data, pp. 375-387.

BSI-GROUP, 25th July 2017-last update, BSI Kitemark™ for BIM Design and Construction with BAM Ireland [Homepage of BAM Ireland], [Online]. Available: https://youtu.be/hzjLLDwwU_w [12th March 2020].

EVANS, D., 2011. The Internet of Things How the Next Evolution of the Internet Is Changing Everything. USA: Cisco Internet Business Solutions Group (IBSG).

FRAMPTON, K., 1980. *Modern Architecture: a Critical History*. London: Thames and Hudson.

FRIEDMANN, D., 1995. *Historical building construction: design, materials and Technology.* New York: W.W. Norton.
GIDEON, S., 1967. The Schism between Architecture and technology. In: S. GIDEON, ed, *Space, Time and Architecture.* 5 edn. Cambridge, Massachusetts: Harvard University Press, pp. 211-217.
GOLDSCHMIDT, G., 1994. On visual design thinking: the vise kids of architecture. *Design Studies,* **15**(2), pp. 158-174.
GRAFE, C., 1960. Architecture is a social art. *In:* HUNCH: *The Berlage Institute report,* (6), pp. 222-224.
GEHL, J., 2006. *Life between Buildings,* Copenhagen: Arkitektens Forlag
GEHL, J. and GEMSØE, L., 2001. *New City Spaces*. Copenhagen: Arkitektens Forlag
HARTY, J. and LAING, R., 2008. The Impact of Coded Digital Design of Architectural Process and Management, *Visualisation, Procedings of 2008 International Conference* 2008.
JAMES, J., 2001. CPD update. *Architectural Technology,* (35), pp. 10-11.
KIELLAND, T., 1920. Til Hvad? For hvem? Af hvad? og Hvorledes? *Skønvirke,* **6**(2), pp. 17-22.
KIM, Y.J., GRABOWECKY, M., PALLER, K.A., MUTHU, K. and SUZUKI, S., 2007. Attention induces synchronization-based response gain in steady-state visual evoked potentials. *Nature Neuroscience,* **10**, pp. 117-125.
KINNAIRD, C. and GEIPEL, M., 2017. Blockchain Technology How the Inventions Behind Bitcoin are Enabling a Network of Trust for the Built Environment. London: Arups.
KRISTENSEN, E. K., 2011. *Systemic Barriers to a Transformation of the Building Industry from a Buyer Controlled to a Seller Driven Industry.* PhD thesis, Robert Gordon University, Aberdeen, UK.
KRISTENSEN, E. K., 2015. *Byggeriets industrialisering: Mere byggeri for mindre.* Aarhus: Forlaget Hovedland
LAWSON, B., 2006. *How Designers Think - The Design Process Demystified.* 4 edn. Oxford: Architectural Press, Elsevier Ltd.
LESAGE, D., 1966. The task of the architect (a remix). *In:* HUNCH: *The Berlage Institute report,* (6), pp. 305-306.
LLEWELLYN DAVIES, R., 1957. Deeper knowledge: better design. *Architects' Journal,* **125**, pp. 3247.
LOREK, S., 30th January 2018-last update, Mixed Reality In Construction Gets Real with Trimble's HoloLens Hard Hat [Homepage of Constructible], [Online]. Available: https://constructible.trimble.com/construction-industry/mixed-reality-in-construction-gets-real-with-trimble-hololens-hard-hat-video [12th March 2020].
MALLESON, A., 2016. Ahead of the Game. RIBA Journal, 123(01), pp. 46-47.
MOLLERUP, J., BARRETT, N., BARSLEV, M., BENGTSSON, L., HØWISCH, J., SELCK, P. and SØNDERLUND, M., 1991. *Husbygnings Materialer.* 5 edn. Copenhagen: Nyt Nordisk Forlag Arnold Busck.
MOORE-BICK, S.M., 11 June 2019-last update, Grenfell Tower Inquiry [Homepage of GOV-UK], [Online]. Available: https://www.grenfelltowerinquiry.org.uk/ [11 June 2019].
MORBY, A., 23rd March 2018-last update, IKEA assembly made easier through augmented-reality app [Homepage of Dezeen], [Online]. Available: https://www.dezeen.com/2018/03/23/ikea-assembly-made-easier-through-augmented-reality-app/ [12th March 2020].
NADIM, W. and GOULDING, J.S., 2009. Offsite production in the UK: the construction industry and academia. *Architectural Engineering and Design Management,* **5**(3), pp. 136-152.
PAGE, W.D., 1961. Preassembled Roof Structures. *In:* M. C. COON, ed. *Preassembled Building Components*, Washington, USA, Publication 911 the National Research Council, Washington, 113-121.
PHILLIMORE, A.J., 1989. Flexible specialisation, work organisation and skills: approaching the 'second industrial divide'. *New Technology, Work and Employment,* **4**(Autumn 89), pp. 79-91.
PRATS, M., LIM, S., JOWERS, I., GARNER, S.W. and CHASE, S., 2009. Transforming shape in design: observations from studies of sketching. *Design Studies,* **30**(5), pp. 503-520.
TOBIN, J., 4th April 2013-last update, Measuring BIM's Disruption: Understanding Value Networks of BIM/VDC [Homepage of AECBytes], [Online]. Available: http://www.aecbytes.com/feature/2013/BIMdisruption.html [29 April 2020].
WEBER, M., 1947. *The Theory of Economic and Social Organisations.* 1 edn. New York: Free Press.
WHITE, B. and MORGAN, B., 2005. *RIBA Constructive Change: a strategic industry study into the future of the Architects' profession.* London: RIBA.

AN EMBODIED CARBON IMPLICATIONS OF HOME GROWN CROSS LAMINATED TIMBER, THE SCOTTISH CASE

KYLE HENDERSON, HUDA SALMAN
Scott Sutherland School of Architecture and Built Environment
Email address: k.b.henderson@rgu.ac.uk
Email address: h.salman@rgu.ac.uk

Abstract. Cross-Laminated Timber (CLT) is a carbon-efficient form of construction, but no UK manufacturers exist, therefore, it remains a product imported from mainland Europe, doing so significantly increases the associated carbon emissions. This paper presents an 'embodied carbon over life-cycle comparative analysis between Austrian CLT manufacturers and a hypothetical CLT supply chain in Scotland using Scottish homegrown timber.
The analysis uses an existing seven-story CLT construction project in Scotland as the unit of analysis, to test the following hypothesis: The amount of embodied carbon emissions would differ should a hypothetical Scottish Manufacturer also have supplied this construction. The predominant variables include the timber species, European grown Spruce, and homegrown Sitka Spruce, the different qualities, and the distances between forest, manufacture, and site. Calculations will be performed by analysing the embodied carbon within every stage of the building life cycle with a focus on the sequestered carbon in the timber products. The results will provide an approximate figure which can quantify the embodied carbon emission difference between imported CLT and homegrown CLT.
The study concludes that a Scottish CLT manufacturer would achieve lower carbon emissions exclusive of sequestered carbon. If including sequestered carbon, both manufacturers produce a net loss in carbon emissions, however, Austrian timber would sequester more carbon dioxide than Scottish timber.

Keywords. Cross laminated, timber, embodied carbon, supply chain, Scotland.

1. Introduction

There is a global climate emergency, and the construction industry is responsible for 49% of carbon emissions exasperating it (LETI 2019). A global housing shortage has coincided with record-high levels of atmospheric (greenhouse) gases (GHG) trapping heat and significantly increasing the global temperature. Greenhouse gases make up 0.03% of the Earth's atmosphere yet contribute vastly towards trapping Earth's radiant heat, warming the planet (Buis 2019). The majority of global greenhouse gases (94%) are carbon dioxide (CO2). An increasing population presents an increasing demand for housing construction as well as a decrease in global carbon emissions. There is presently an increasing movement towards reducing energy from the operation of buildings, but there is also a large inherent amount of carbon associated with the extraction, production, and construction of building materials. It is now possible to construct architecture using less carbon-intensive building materials, mass timber products like Cross Laminated Timber (CLT) being prime examples, materials that can sequester and store carbon from the atmosphere and reduce the carbon footprint of construction.
There is vast and tangible evidence that CLT can compete fairly with the structural

properties of concrete and steel. Moreover, CLT provides numerous additional benefits throughout use, including healthy indoor living environments and speed of assembly. In the isolation of costs and business plans, there is an inherent reduction in carbon emissions achievable by building from mass timber over concrete and steel. Carbon emissions in Scotland account for 74.2% of the greenhouse gas emissions (Scottish Government 2020). Scotland is a country abundant in timber and trees, yet the majority of our construction timber is imported. Can Scotland further reduce carbon emissions by using homegrown timber in large construction projects as mass timber systems? Such innovation would contribute to the Scottish economy through local manufacturing and processing industries to benefit the country and the environment. With recent timber losses from natural disasters, there is an expectation that CLT importation into the UK is going to become more difficult and more expensive, therefore there is a motive and there is an opportunity for a homegrown mass timber supply chain. It is assumed that should a Scottish CLT manufacturer exist then there would be a vast carbon emission reduction, especially given shorter transportation distances.

2. Study Aim & Objectives

This paper aims to explore CLT as a suitably sustainable and well performing construction method for medium-high rise buildings in Scotland.

The study objectives are:

1. to review CLT as a suitably sustainable and well performing construction method for medium-high rise buildings. Research into CLT as it regards architecture in pattern and cultural movement.

To achieve this objective, a desk-based literature review will take place of existing documentation. The proposal will investigate the arguments advocating for designing with mass timber products with performance information somewhat comparative to concrete and steel.

2. To review current practices of CLT manufacture, production, distribution, and importation from mainland Europe with analysis of associated embodied carbon.

A desk-based literature review of existing methods of manufacture as well as published documentation surrounding the Environmental Performance of the production of CLT facilities will be conducted.

3. to test whether using homegrown (Scottish) CLT would produce tangible lifecycle emission savings compared to EU imported CLT.

Comparative calculation between Scottish timber and EU timber for a Scotland-based construction project would be worthwhile and would produce new and definitive insight into this area. An example construction project of a medium-high rise CLT housing project based in Scotland, will provide volumetric quantities of CLT and timber. Volumetric figures could be used to quantify the entire embodied carbon over life cycle emissions and to gauge the quantity of sequestered carbon stored in the CLT. Furthermore, it is necessary for the building to be placed at a literal site to analyse embodied carbon over the life cycle associated with travel to and from the forest, manufacturing facility, and construction site.

Comparisons would be drawn between the embodied carbon over the life cycle from building the structure from CLT from Scottish timber than with CLT imported from mainland Europe. It will be necessary for the model to define the use of CLT as per the definitions (alluded to in the literature review) of pure CLT, Pure Timber, or Hybrid CLT. The outcome of the calculation should be compatible with national life cycle assessment standards as far as possible. Comparisons would be drawn between the embodied carbon over the life cycle from building the structure from CLT from Scottish timber than with CLT imported from mainland Europe. It will be necessary for the model to define the use of CLT as per the definitions (alluded to in the literature review) of pure CLT, Pure Timber, or Hybrid CLT. The outcome of the calculation should be compatible with national life cycle assessment standards as far as possible.

3. LITERATURE REVIEW

Buildings produce approximately 35-45% of all global GHG emissions (World GBC 2018). Approximately 28% from Building Operations and 11% from Building Materials & Construction. The domestic construction industry alone in the UK is responsible for approximately 49% of GHG emissions in the UK (LETI 2019, Architecture 2030). Total GHG emissions from the construction sector equal 72% from Building Operations, this is
referred to as Operational (Energy). The remaining 28% is from Building Materials and Construction, this is referred to as Embodied (Carbon).

3.1. THE CASE FOR BUILDING IN TIMBER

"There is a global climate emergency, the evidence is undeniable, and the science is coherent" (Scottish Government 2019). A worldwide shortage of readily available houses is to be continually felt whilst there is migration to urban areas. Increased urban area demand should logically be met by the construction of medium to high rise housing and supporting infrastructure. The current drawbacks to this solution are that an increase in construction leads to an increase in atmospheric carbon emission levels. The carbon content within the current most common superstructure materials of concrete and steel continues to increase atmospheric carbon levels. For example, the extraction and utilisation of cement for concrete accounts for around 8% of global CO_2 emissions (Waugh & Thistleton 2018). The widespread use of concrete does not appear to be sustainable nor able to reduce carbon emissions to an acceptable level in the immediate future. As such, an ever-increasing number of Built Environment Professionals are advocating that building in timber could be our best and most readily available solution to climate change (Hairstans 2019; Build-in-Wood 2020; Smedley 2019).

Timber grows and can be grown, therefore can be classed as renewable and sustainable, and can be a mainstream structural material available for implementation in the built environment (Ramage 2017). Timber as a primary superstructural material produces fewer carbon emissions than concrete or steel. Trees absorb and store (sequester) atmospheric carbon through growth, ceasing once fully grown, therefore creating an abundance of fully-grown natural construction material. Cutting and re-planting would maintain the carbon cycle and produce a renewable stock of timber.

The cut timber can be utilised in construction, storing the sequestered carbon within the timber construction throughout the building's life cycle. Furthermore, should panellised mass timber such as CLT, be re-used or recycled after the building's life cycle, the sequestered carbon will remain stored and thus will achieve significant carbon emission reductions. Timber construction tends to absorb more CO2 than is emitted in producing timber construction products. Simply put, mainstreaming timber construction can reduce the greenhouse gas content that is causing the global warming effect (Build in Wood 2020). Building in timber would reduce atmospheric carbon content by approximately 40 tonnes of CO2 per home (Waugh & Thistleton 2018).

A form of timber construction perceived most suitable for medium-high rise construction is 'mass timber', a phrase that describes 'large slab' engineered timber construction components (Hairstans 2020). Recent innovations in mass timber have produced an unforeseen opportunity to compete with steel and concrete for the superstructure (Waugh & Thistleton 2018). There are a variety of mass timber products currently available, and CLT is perceived as the most competitive mass timber product in terms of performance for medium-high rise construction compared to concrete and steel, based upon results from extensive testing as well as practical implementation.

CLT was established in the 1960s and has been successfully used as the superstructure for multiple medium and high-rise construction projects (Waugh &Thistleton 2018). Timber boards of varying grades are glued adjacent to one another, each rotated at a full right angle from the adjacent board. This process is called cross lamination and it produces high-strength timber panels with many associated positive performance attributes (Laguarda 2015; Waugh &Thistleton 2018). CLT originated in Austria and it has been very prolific in the European market ever since its introduction (Lehmann 2012). CLT production increased by 315,000m3 between 1996 and 2016 (Crespell & Gagnon 2010). As of 2013, an analysis of Edinburgh Napier University showed that an estimated percentage of 74% of total CLT imported was from Austria.

CLT construction has been increasing in the United Kingdom, the legislative structure allows for a versatile and diverse range of CLT applications as superstructure and can be categorised as: Pure CLT (CLT only), Pure Timber (CLT Combined with other timber structural elements) and Hybrid (CLT combined with non-timber elements such as steel or concrete) (Waugh & Thistleton 2018).

As of 2020, The United Kingdom has approximately 500 completed construction projects which utilise CLT in the superstructure (Waugh 2021). All of these projects imported CLT from out of the UK, with none of the projects utilising CLT manufactured in the UK.

3.2. CLT PERFORMANCE

It is important to define how well CLT performs comparative with other structural types. 'Performance Characteristics' are attributed to CLT to measure this. The following performance characteristics of CLT are highlighted by Laguardia Mallo & Espinoza (2015) study and others:

3.2.1 Environmental Performance and Sustainability:

CLT sequesters carbon over time (Lehmann 2012). CLT panels are suitable for reuse for a reduced carbon footprint and increased lifespan. However, increased CLT production would decrease fossil fuel emissions through the manufacturing process (FPInnovations 2013). CLT buildings embodied carbon emissions are less than half in comparison to concrete or steel (Hammond and Jones 2008). This results in net loss in Global Warming Potential (GWP) comparative to concrete or steel (John et al 2009). CLT buildings require less energy to operate (Chen 2012), and they have smaller environmental impacts and can thus produce 18% less emissions from non-renewable energy compared to reinforced concrete buildings (Robertson et al. 2012).

3.2.2 Installation Simplicity and Cost Effectiveness:

CLT construction can be easier to construct than timber frame through fewer but larger components (Waugh, Thistleton 2018). Construction per storey can take no more than 4 days, a whole 17 days less than with concrete (WoodWorks 2013). Construction time with CLT can be reduced by up to 30%, making vast economic reductions in on-site labour (Silva et al. 2013).

3.2.3 Structural Performance:

Hybrid CLT and concrete construction could produce designs as high as 150m (Van de Kuilen et al. 2011). All CLT elements have an inherent structure that is stable and resistant to two directions of force (Popovski et al. 2010). The cross laminating of panels enables good performance as shear panels and load bearing plates (Steiger and Gülzow 2010), in addition CLT provides a competitive and viable competitor to steel and concrete for medium and high-rise construction (Fountain 2012).

3.2.4 Design Flexibility:

200mm thick CLT panels can produce spans of 7.5m not too dissimilar to spans achieved by concrete (Malczyk 2011). Wall structures utilized as deep beams and columns can produce long uninterrupted spans (Silva et al. 2013). Techniques known as “cassette” and “folded” can achieve spans as large as 19m (Fountain 2012).

3.2.5 Fire Performance:

Airtight seal between elements prevents the spread of smoke and fire, thereby limiting fire damage to specific areas (Frangi et al. 2009). CLT panels under testing could withstand 180m of fire before collapsing (AWC 2012). Internalised metal plates contribute to good performance in fire. (FPInnovations 2013).

3.2.6 Seismic Performance:

CLT structures withstand no lasting deformation from earthquake simulations (Popovski and Karacabeyli 2012). CLT construction offers strength and ductability which improves seismic performance of panels (Winter et al. 2010). CLT fastening systems aid dissipation of seismic energy (Hristovski et al. 2012).

3.2.7 Thermal Performance:

CLT construction creates opportunity of airtight construction. Reduced air leakage therefore producing improved thermal performance (Skogstad et al. 2011). CLT offers a substantial quantity of thermal inertia from being a large mass, improving the building’s thermal performance (Cambiaso and Pietrasanta 2014).

It is apparent through the summary of the performance characteristics of CLT that the product offers many construction benefits in addition to the significant carbon emission savings to be had. There does not appear to be a significant performance flaw which advocates for the specification of concrete or steel over CLT in buildings under 150m tall. CLT use in building of over 150m tall becomes more complicated and requires deeper research and detailed scrutiny at this time.

3.3. THE PERCEPTION OF CLT

Given the well-established performance characteristics of CLT it is necessary to understand the awareness, willingness, and perception of CLT in the construction sector and in the UK market. The results of Laguaradia's (2015) study upon the US architecture community discovered that awareness of CLT was low in the U.S firms, it is expected that similar results would have been experienced at the time in the UK. Whilst this study was taken six years ago and awareness of CLT should by now have improved, it is the case that a lack of knowledge of CLT was perceived as a threat to the industry by 38% of industry professionals who undertook a survey in 2020. (CSIC 2020). Therefore, it is paramount that CLT be publicised and taught, with information upon its use in construction advised to be open source and accessible to all. Results from a webinar poll (CSIC 2020) concluded that CLT is perceived as the most suitable of all mass timber systems in a UK / Scottish context. The primary market for mass timber was divided: Health/Education (30%) Commercial/Office (26%) 1-4 storey housing (26%) and 5-9 storey housing (13%). Of industry professionals who are aware of CLT, there is a perception that CLT is applicable across multiple sectors.

The emergence of mass timber and CLT resembles the patterns of the architectural movement and innovation associated with steel in the 19th and 20th century. It can therefore be perceived that we are in the midst of a new architectural movement and a paradigm shift towards mass timber perpetuated by innovation and climate emergency.

The adoption of mass timber may be hindered by multiple factors. A perpetual love affair of the architectural steel movement, or perhaps association of timber being a historical and therefore a superseded or redundant construction material, and many in the industry hold firm to the erroneous perception of timber being a flammable and combustible material. Furthermore, some in the industry with conflicting interests will rally against the use of CLT in the spirit of economic competition and may spread deceptive information to curry perception in favour of alternative construction products. Equally, there may be bias on the side of CLT advocates with conflicting interests, though it cannot be denied that the offering from CLT of fewer carbon emissions questions the validity of a perpetual endorsement of steel and concrete. Mass timber should be perceived as a new form of construction material distinct from timber frame, and one with the potential to spark widespread industrial change and opportunity for architectural space, quality and ultimately, a much lower carbon footprint. In the contemporary age we refer to concrete and steel as 'traditional' methods of construction. Traditional, to mean 'existing in, long-standing'. Concrete and steel were a product of the 20th century, and it could be argued that timber frame which predates steel, is the traditional method of construction. Albeit timber frame is different to mass timber construction, but it can be perceived as a challenge to the contemporary ideal of traditional construction.

Based upon a recent survey by Construction Scotland Innovation centre (2020) from UK Architects and Engineers, Figure 1. Precision manufacture was identified as the top motivational driver. Offsite manufactured products such as CLT allow for increased precision of manufacture and design, enabling airtight and correct detailing. Mass timber products being inherently machined and manufactured offsite enable repetitive changes based upon constraints, a noticeable advantage from a highly engineered mass timber product. The sustainability and the life cycle benefits including recycling, ease of maintenance and re-use after life and carbon sequestration differential compared with alternative structural materials were deemed approximately as important by designers. The eco-conscious architect and specifiers with a long, whole life product view would have appreciated the sustainability of mass timber products. 49% of specifiers felt that faster construction was a motivational driver, a figure which was deemed the most important driver by Building Contractors. Fast construction benefits architects by product of simplified construction detailing, requiring fewer design consultations.

Key motivational drivers for investors, specifiers and contractors:

Investors	Specifiers (architect, engineer)	Building contractors
Reduced on site labour (59)	1. Precision manufacture (59)	1. Reduced on site labour (71)
Carbon sequestration (58)	2. Parametric design flexibility (57)	2. Speed of construction (70)
Sustainability (56)	3. Life cycle benefits (57)	3. Ease of construction (63)
Speed of construction (54)	4. Sustainability (56)	4. Reduced wastage (55)
Life cycle benefits (53)	5. Speed of construction (49)	5. Reduced H&S risks (53)

Figure 1.0. Motivational Drivers for Built Environment Professionals. (Construction Scotland Innovation Centre 2020)

In another section of the survey (2020), the primary threats to CLT implementation in the UK were identified as follows: Building Regulations (50%), Lack of Knowledge (38%), Traditional Construction Materials (38%) and Perception of poor performance (25%). Regulations which may erroneously prohibit CLT, or which may incite upside to more carbon intensive building materials. A lack of comprehension regarding CLT was deemed to be a threat to it as an industry. This is perceived to stem from a lack of education from obtaining an architectural qualification, coupled with a dis-interest or an inability to readily accept and access information about CLT sufficient to overhaul an architecture practice understanding of construction.

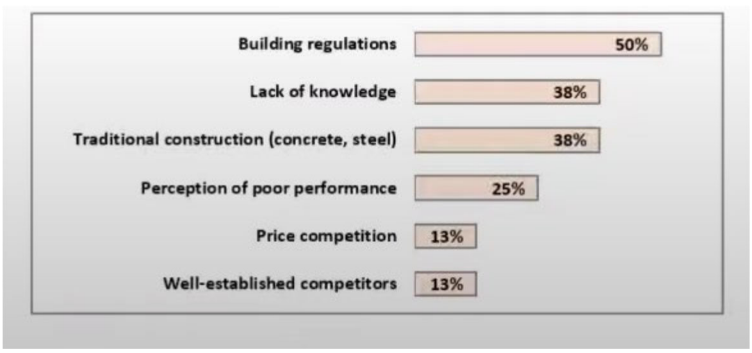


Figure 2.0. Primary Threats to Mass Timber in the UK (CSIC 2020)

CLT requires implementation from the Initial Design Stage, it would be understandable to suggest that some find it more efficient use of their time to utilise structural forms more known, such as concrete and steel, which also gained 38% of the survey votes (CSIC 2020). A perception of poor performance received a quarter of the votes. There will remain voices within the industry that lobby against mass timber products for they provide direct competition to traditional forms of construction.

3.4. THE PROCESS OF CLT PRODUCTION FROM TREE TO SITE

As already alluded to, mature softwood trees cease to absorb atmospheric carbon. The embodied carbon calculations begin in the felling of trees from sustainable and managed forests. Trees are replaced and re-planted. An expectation of minimal carbon emissions is to come from the use of tools in order to fell trees. For CLT this normally takes place in mainland Europe, not in UK forests. Felled trees must be transported to a CLT manufacturing base.

CLT is one of many examples of off-site manufacture (OSM). OSM it is the manufacture and pre-assembly of construction components, elements, or modules in a factory before installation into their final location (Abosaod et al, 2010; BuildOffsite 2013). manufacturing construction products in a factory support efficiency and design quality precision and control. A direct benefit of OSM techniques can result in fewer days spent upon the construction site. OSM can be considered to be a “Modern Method of Construction (MMC),” A UK Government phrase for house building innovations (Hairstans 2014).

The vehicles used in transportation of the trees would emit carbon and add to the embodied carbon calculation. Manufacturing machinery requires energy to convert felled lumber into cross-laminated panels. Approximately 40% of the timber is lost through machining sawdust, capable of use in biomass and animal bedding. Further energy is required for heat to kiln dry CLT. Logistics, which concerns the organisation of transportation tools, routes, and sequence is of increased significance to the carbon emissions control for the product and construction stage**.** Efficient planning of prefabricated construction components will aid in the reduction within the logistics stage (Dong et al 2018).

Once dried, energy is required to cut and plane CLT into usable construction components, and subsequent sawdust can be added to the existing stock for transportation and use. Once prepared off site, panels need transportation to the construction site. CLT requires significantly less deliveries to site than a concrete frame would require (Waugh & Thistleton 2018). Common practice dictates that panels are transported from mainland European manufacturing facilities to United Kingdom construction sites. Construction and

building assembly may require vehicular assistance requiring fuel and energy, a final contributor to the total sum of embodied carbon emissions for a single construction. In absence of any major fluctuations in vehicle efficiency it is an undisputable fact that CLT transportation from a UK manufacturing facility to a UK construction site would emit less carbon. Timber would therefore be transported from either UK or mainland European forests, and conclusively it can be said that timber from a UK forest would travel a smaller distance and thus emit less carbon. The largest carbon emission reduction stands to be made through reduced transportation distances of CLT panels from manufacturing base to the construction site, though carbon associated with sequestered biogenic carbon also provides large potential savings.

3.5. MEASURING & REDUCING EMBODIED CARBON

3.5.1 Reducing Operational Energy

Operational Energy is the largest carbon emission contributor in the Built Environment. Current UK construction recommendations for reducing Operational Energy are firstly for buildings to be 100% electric with no fossil fuels such as gas involved in heating. As the grid becomes carbon free, building operations will also become carbon free. The Electricity grid is increasing in carbon-free energy generation, renewable energy (such as wind & solar energy.) Furthermore, we can increase the energy efficiency of buildings and reduce the Operational Energy demand, therefore requiring less electricity from the grid.

3.5.2 Reducing Embodied Carbon

Whilst reducing operational energy from Buildings should be a priority, it is important to not neglect the embodied carbon emissions. There is a large inherent amount of carbon associated from material extraction through to the construction of buildings. Constructing architecture using less carbon intensive building materials like CLT which remove carbon from the atmosphere can therefore reduce the embodied carbon of a construction.

The following Diagram, Figure 3, is from a European Standard which defines each stage of the construction cycle using a letter and a number e.g. A1. Operational Energy accounts only for stages B6 & B7, every other stage is classed as Embodied Energy. European Standard 15978:2011 is utilized in a professional statement by the United Kingdom Royal Institute of Chartered Surveyors (RICS). All members of RICS must abide by this European Standard and thus it is mandatory to use these terms in the United Kingdom (RICS 2017). Therefore, any professional calculation in the United Kingdom of the Operational Energy or Embodied Carbon must adhere to EN15978:2011. This RICS Statement upon Embodied Carbon Calculation is the most accepted methodology.

Embodied Carbon measurements can be termed differently based upon the amount of EN 15978:2011 stages included within the calculation.

- Stages A1-A3 (Cradle to Gate)
- Stages A1-A4 (Cradle to Site)
- Stages A1-A5 Embodied Carbon to Practical Completion (Cradle to Practical Completion)
- Stages A1-A5 & B1-B5 & C1-C4 Embodied Carbon over Life Cycle, (Cradle to Grave)
- Stages A, B, C & D reported separately = Whole Life Carbon (WLC)

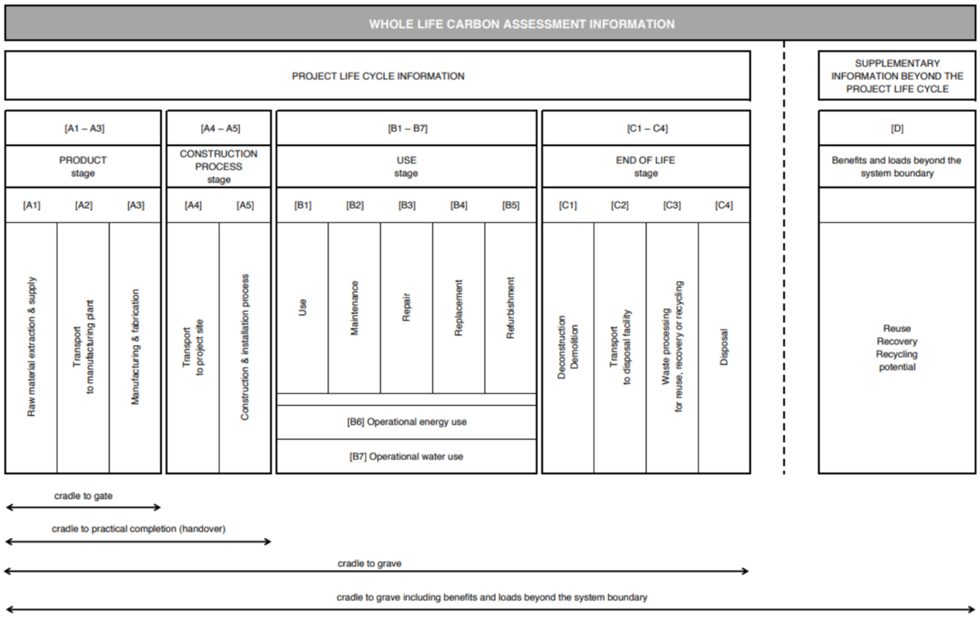


Figure. 3.0 EN 15978 introduces a modular approach to a built asset's life cycle, breaking it down into different stages. (RICS 2017). Life cycle stages from BS EN 15978: [B6-B7] = Operational Energy.

3.5.3 Sequestered Carbon

None of these Embodied Carbon Measurements consider the value of sequestered atmospheric carbon stored in timber as biogenic carbon. The largest carbon saving achievable in mass timber is in biogenic carbon and therefore it's place in the embodied carbon calculation would have a large impact upon its use in construction. "The carbon sequestered in timber or other bio-based materials (biogenic carbon) being repurposed should be considered in module [D], where applicable." sequestered carbon should though only be considered a benefit in the scope of whole life carbon assessment when the timber is sustainably sourced – certified by FSC, PEFC or equivalent. This is to ensure that any trees felled are being substituted with a minimum of the same number of trees planted and therefore not contributing to deforestation and not compromising the overall carbon absorbing capacity of woodlands (RICS 2017). Therefore, Carbon sequestration figure should be reported separately but can be included in the total product stage figures [A1–A3] provided the specified conditions are met.

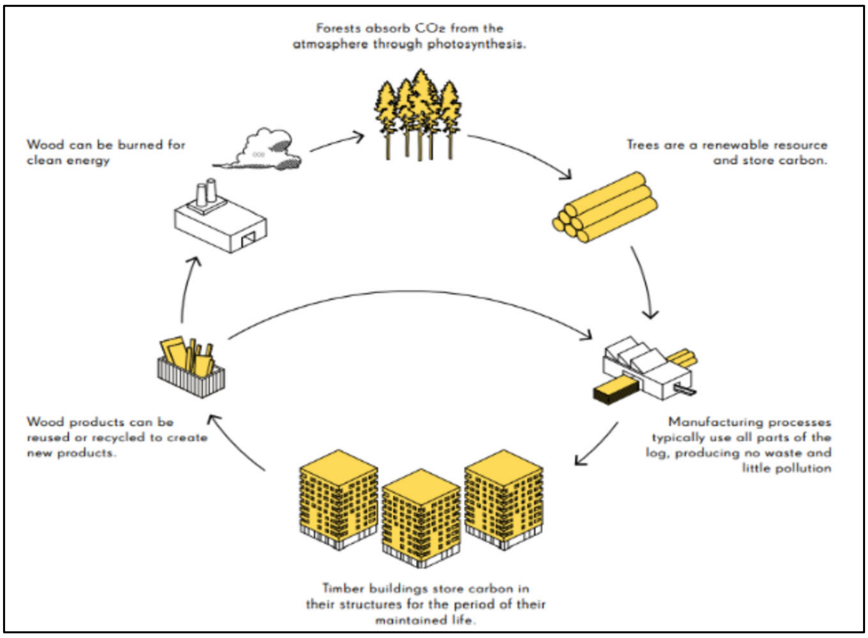


Figure 4.0. Cross Laminated Timber Life Cycle (Waugh; Thistleton 2018).

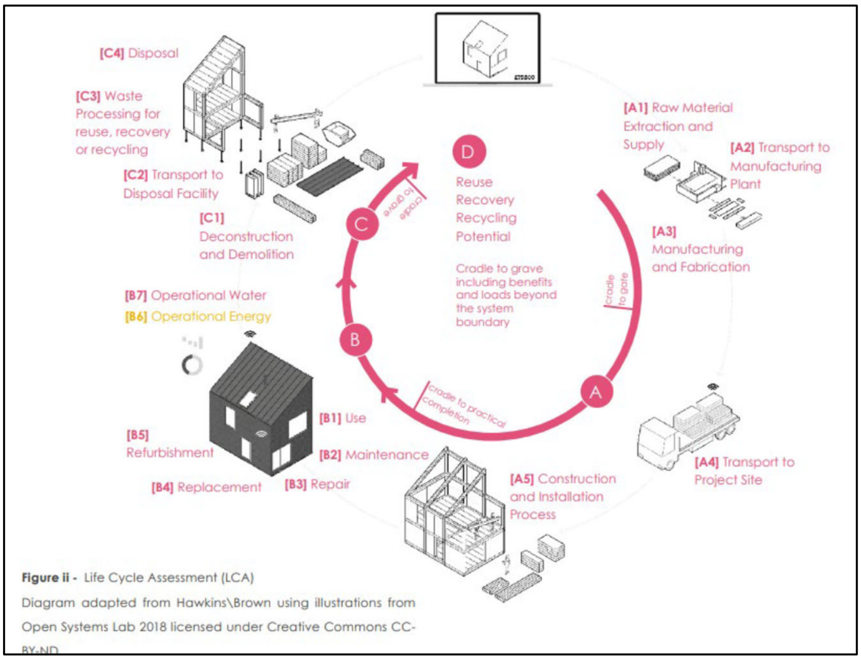


Figure 5.0. Circular Life Cycle (LETI 2018).

3.5.4 Alternative carbon measurement standards

The Measurement of embodied carbon through LCA or WLC is being widely considered across Europe, leading to many alternative developments to the existing assessment methods.

France have implemented requirements for new buildings and renovation through voluntary carbon-related labels. In 2020 the French Government implemented a carbon footprint calculation method which favours the use of wood and biogenic products more than the standard Life Cycle Analysis, described as Dynamic Life Cycle Assessment. Furthermore, they are due to release an energy and carbon regulation for new buildings with LCA based carbon thresholds in 2021. The Nordic Council of Ministers are initiating a plan for harmonization of building regulations concerning climate emissions (Nordic co-operation 2020). Finland is preparing new legislation to promote low-carbon building. The target is that life-cycle-based carbon footprint regulations are applicable by 2025. The Carbon Handprint concept in Finland aims to approach the carbon footprint from a positive standpoint, the climate benefit offered by a service or a product which people can use to reduce their own climate load. This encourages people to strive for a carbon handprint which is greater than their carbon footprint. Construction projects should strive to produce better than bad for the climate. Häkkinen (2021) concluded that the definition of a carbon handprint is equal to Stage [D] Benefits beyond the system boundary. Both terms should be used interchangeably dependent upon the context.

3.6. CLT IN THE UK & SCOTLAND

The pursuit of low carbon construction materials has produced a rise in timber usage in the UK built environment, yet the majority of timber used in these construction projects has been imported. UK Timber stock grown in, and ultimately used in the UK should be more sustainable long term and hopefully prove to be economically beneficial. If timber from Scottish resources is effectively produced through silvicultural practices, the resultant economic and environmental cost due to transportation would be much less comparative with current imported timber (Hairstans and Sanna). CLT panels produced from UK sourced Sitka Spruce have shown encouraging performance for strength and stiffness (Hairstans 2014). CLT can be manufactured with UK Sitka spruce, resulting in a structural performance similar to products manufactured and imported from central Europe (Hairstans 2014). Scotland Construction Innovation Centre are actively promoting the advantages of CLT with particular focus upon the economic potential CLT could be homegrown and mainstreamed in Scotland (MacDonald 2020). Prior research and innovation have tested and approved the potential for UK grown timber for successful CLT performance. It can be understood that there would be reduced embodied carbon from CLT transport should the product be mass manufactured in Scotland.

The most pioneering approach to a UK CLT facility comes from the financial institution Legal & General, they have established a subsidiary company and invested in a 51,000m2 offsite manufacturing facility for CLT and module assembly, based in Leeds (Wilson 2017). They are yet to produce any mass timber products for construction. In Scotland, the construction firm CCG has invested over £4m for a Lanarkshire based ‘massive’ timber production plant at 11,300m2 with a view to producing Cross Laminated Timber (Ridley-Ellis 2015). The Construction Scotland

Innovation Centre's 3,250m2 factory in Hamilton currently contains the only CLT vacuum press in the UK. It is expected that a hydraulic press would be preferred for a mainstream CLT manufacturer. Innovate UK have provided them with funding to produce a viable business model for the use of Scottish Timber in Construction (CSIC 2020). Timber strength classes are categorized in a range from C16 to C24. The most common class for CLT is C24, but it is expected that if/when production facility(ies) start operating in the UK, C16 strength class is likely to be used as it is the most common strength class available in the UK." Furthermore, recent European experience in CLT production forecast that £15-50 million would be required alongside a lead-in time of 3+ years before a UK CLT Production plant would be able to be fully operational (Wilson 2020). Large upfront costs to establish a CLT manufacturing base become an obstacle of progress towards a homegrown supply chain.

Existing research has provided irrefutable evidence that CLT is a competitive structural material which offers a sustainable new future for medium to high rise construction. CLT demonstrates beneficial performance qualities in addition to lower carbon emissions and sequestration. Transport carbon emissions would be reduced from using homegrown CLT, and there is sufficient research to conclude that UK grown timber would be suitable as CLT. In amidst a housing crisis and a timber import crisis, there is opportunity, albeit one with large upfront costs. UK CLT manufacture is seen as necessary and is viable, though there remains to be seen an embodied carbon comparison between import and homegrown to fully quantify what environmental advantages could be achieved from a homegrown CLT supply chain.

4. MATERIALS AND METHODS

The methodology of this study uses a case study approach to test The calculation method bears closely with RICS framework (2017) for embodied carbon testing.

4.1. CASE STUDY

Ellerslie Crescent is Scotland's tallest CLT construction project. For details https://mastarchitects.co.uk/our-projects/ellerslie-crescent-yoker/ . The CLT was imported from Austria. The design aimed for maximum efficiency of the CLT as structural material. Three 7-storey blocks of accommodation, 42 flats in total, arranged around a stair core. The superstructure is 100% CLT including the lift shaft and the common areas. This construction project saw noticeable advantages in construction time, reduced material waste, inherent air tightness, excellent acoustic, and thermal properties and as an exemplar project of CLT in Scotland (MAST 2019), more details in table 1 & 2.

TABLE 1. Case Study Details

Client:	CCG (Scotland) Ltd / Sanctuary Homes	Timber Engineer:	Smith and Wallwork	Completion Date: January 2018
contract:	Design and Build	Structural Engineer:	Scott Bennet Associates	Project value: £4.5m
Main Contractor:	CCG (Scotland)	CLT Installer:	Eurban	
Architect:	MAST Architects	CLT Manufacturer:	Stora Enso	

TABLE 2. Case Study Quoted Values

CLT Volume: 1240 m3 (Stora Enso; CCG 2019).
Timber Volume: 1170 m3 - 94.3% timber and 5.7% glue (MAST 2019).
(Stated) Embodied CO2: 936,000 kg (CCG; MAST 2019).
(Stated) Sequestered Carbon: 757,000 kg (Stora Enso; CCG 2019).

According to MAST Architects, 936,000 kg of embodied CO2 is calculated, however, the EN:15978.2011 stages are not included in the calculation. Therefore, this figure of 936,000 kg CO2 embodied carbon (in 1240 m3 of CLT) without further detail to the formula or stages would be a hinderance to consider the stated value as accurate.

4.2. LIFE CYCLE STAGES

The life cycle stages as established in EN 15978, is shown in Figure 3.2, depicts a graphical representation of the life cycle stages.

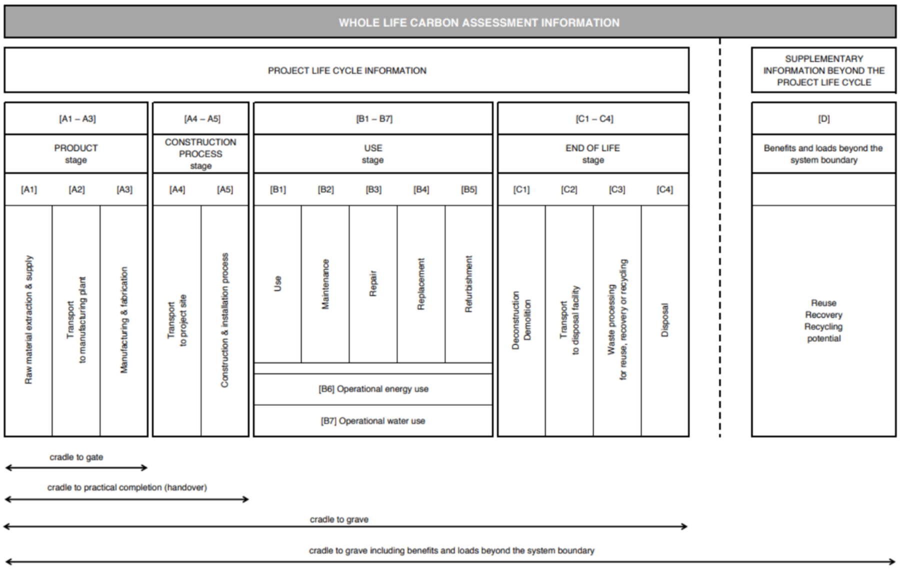


Figure 6.0. Embodied Carbon Over Life Cycle (RICS 2017).

The embodied carbon within the CLT superstructure can be obtained from the following methodology. The structure is in accordance with EN 15978. The intent is to produce a Life Cycle Assessment of the Embodied Carbon over Life Cycle, [A, B1-B5, C] based upon typical end of life scenarios. Furthermore, sequestered carbon will be emphasised for its significant carbon emission reduction which should not be neglected, for doing so would be to disregard all applicable embodied carbon information. The values used for the methodologies have been sourced using information readily available online by the Ellerslie Crescent Design Team, as well as any other applicable and readily available online sources.

The CLT used for Ellerslie Crescent is manufactured in Austria by Stora Enso. Stora Enso released an environmental product declaration (EPD) on the 11th of May 2020 for its CLT products. This EPD is in accordance with International Standard (ISO) 14025 and EN 15804 and based off of the International EPD System's core product category rules for the assessment. The EPD has been independently verified by an external party. This study utilises the values stated within this EPD for Austrian CLT. This study also assumes some Scottish homegrown CLT would be equal or similar to values stated in this EPD. The EPD covers stages A, B1-B5, C & D covering the biogenic carbon sequestered in the product.

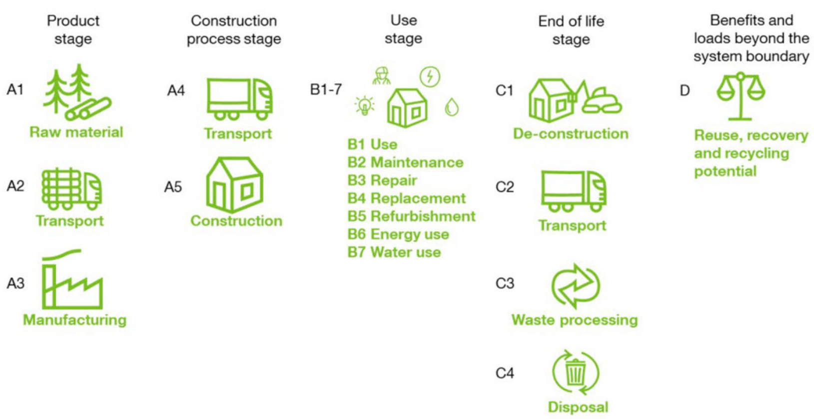


Figure 7.0. Embodied Carbon Over Life Cycle (Stora Enso 2020).

For this study, the data in this EPD is used by default, except in cases where more accurate information has been obtained.
[A] Product and Construction Stage
[A1] Extraction of Timber:

Stage A1 should regard the carbon emissions related to felling the Spruce trees and through extracting the glue for the CLT. The average GWP for Stage A1 is provided by the Stora Enso 2020 EPD for Austrian CLT. It is to be assumed that Scottish Timber extraction for CLT manufacture would have a similar carbon emission output.

[A2] Transport (From Forest to Manufacture)

Stage A2 concerns the carbon emissions associated with the transport of the timber from forest to factory and the glue from source to factory. Transport could be calculated should I be able to identify PEFC sustainable forests, the quantity of timber / deliveries and the fuel efficiency of the transports. The average GWP for Stage A2 is provided by the Stora Enso 2020 EPD for Austrian CLT. It is to be assumed that Scottish Timber and glue transportation from source to manufacture would have a similar carbon emission output.

[A3] Manufacture:
As per Stora Enso EPD 2017, The GWP is provided for stages A1-A3. The processes in stage A3 comprise:
Kiln Dried Sawn Timber > Strength Grading > Trimming > Finger Jointing > Planing > Edge Bonding > Surface Bonding > Laying > Pressing > Finishing > Machining > Surface Treatments. The average GWP for Stage A3 is provided by the Stora Enso 2020 EPD for Austrian CLT. It is to be assumed that Scottish Timber CLT manufacture will have a similar carbon emission output. A logical assumption would imply Austrian Manufacturers would be more energy efficient than a start-up Scottish Manufacturer, however there is no current way to quantify to what extent this may be.

[A4] Transportation to Site:
I will utilise a transportation method utilised within 100 CLT Projects UK (2018).
https://www.distancecalculator.net to calculate distance.
Number of deliveries x distance between manufacturer to site
d = Number of Deliveries (25 deliveries).
Z = Distance from Forest to manufacture I will determine: Number of deliveries x distance forest to site
Fuel Consumption = 0.44 L/km
(Department of the Environment, Food and Rural Affairs (DEFRA) 2007 qtd in 100 UK CLT Projects).
Carbon impact of fuel = 2.63kg CO_2 /L (DEFRA 2007).
d x (0.44(Z) x 2.63))

[A5] Construction: TBC
Ellerslie Crescent took 16 weeks to assemble (Stora Enso, 2018). The carbon emissions associated with the construction of Ellerslie Crescent should be equal for both Scottish and Austrian sourced CLT.
[B1-B5] Use Phase: Use, Maintenance, Repair, Refurbishment & Replacement
According to the same Stora Enso 2020 EPD; “Use stage: B1–B7: There are no environmental impacts expected in the use phase, and at least no harmful substances are released to air, water or ground during the use of the product”. Therefore, as per the Stora Enso EPD of 2020 there is expected to be no emissions from these stages during the buildings use and occupation for sections B1 – B5 = 0.

Operational energy [B6-B7]
Operational Energy is not applicable for determining the embodied energy over life cycle. A Whole Life Carbon Assessment would include the Operational Energy.
[C1-C4] End of Life

The end-of-life scenarios varies in carbon emissions depending upon which occurs. Re-use, Recycling, Landfill, and Incineration. It is hoped that CLT structures are Re-used or recycled, retaining the biogenic carbon, and minimising resource usage. The four End of Life scenarios for this model (Stora Enso 2020) are as follows with details about what would occur for each stage:

Reused: CLT is reused in built form. C1: demolition of the building, C2: transportation to be sorted; 50 km, C3: preparation for reuse, C4: product for reuse, D: reuse of product, substituting virgin material.

Recycled: CLT chipping for recycling. C1: demolition of the building, C2: transportation to be sorted, 50 km, C3: preparation for recycling, C4: chipped for recycling, D: recovery of wood chips, substituting virgin material.

Incinerated: CLT incineration for energy recovery C1: demolition of the building, C2: transportation to be sorted, 50 km, C3: preparation, chipped for incineration, C4: chips to incineration (75% efficiency), D: substitution of natural gas in heat production.

Landfill: CLT is landfilled. C1: demolition of the building, C2: transportation to the sorting 50 km, C3: preparing for landfilling, C4: arrives and placed at landfill.

[D] Re-Use Recovery Recycling

[D] Sequestered Carbon

The carbon sequestered in timber or other bio-based materials (biogenic carbon) being repurposed should be considered in module [D], where applicable.

BS EN 16449 provides an equation for calculating the amount of carbon dioxide sequestered by a growing tree, carbon dioxide which is stored as biogenic carbon in wood products until the end of their life. Oven-dry timber contains approximately 50% carbon. Although this is only a measure of carbon in the timber, it can be translated into the equivalent amount of atmospheric CO2 using a calculation based on the atomic weights of carbon (12) and CO2 (44) (Forestry Scotland 2015). The biogenic carbon stored (sequestered) in timber elements must be calculated based on the formula provided in EN 16449:

The formula is:

$$P_{co2} = \frac{44}{12} \times cf \times \frac{P_{\omega} \times V_{\omega}}{1 + \frac{\omega}{100}} \quad (1)$$

Where:

PCO2 is the biogenic carbon (kg) oxidised as CO2 at the end of the timber component's service life, cf is the carbon fraction of the woody biomass when oven dry, ω is the moisture content of the product, ρ is the density (kg/m3) of woody biomass at that moisture content and V is the solid wood volume (m3) at that moisture content. In this study this formula is used to test one CLT Project.

5. FINDINGS

The exemplar building is intended to represent the superstructure of a potential new build medium-high rise residential but should not be taken as representative for all of the current building stock or all new buildings.

The main variables within the calculation occur within Stage [A] Product and Construction Stage. The two main variables, alongside logically assumed hypothetical variables are:

• Carbon sequestration

• Transport from manufacture to construction site

• (Potential variable) Density differences, harder timber to work is more energy intensive?

• (Potential variable) Energy inefficiency of a more inexperienced Scottish supply chain?

Considering only the Embodied Carbon to Practical Completion inclusive of sequestered carbon, Scottish CLT = -518 kg CO_2/m_3, Austria CLT = -588kg CO_2/m_3.
[A1] Scottish trees may require marginally more energy load to fell due to being more difficult to work. Otherwise, values are close to identical.
[A2] Transport between forest and manufacture is deemed to be similar across both methods. Scottish forest to the CCG manufacturing site should be similar in carbon emissions to the carbon emissions of an Austrian forest to the Austrian Stora Enso manufacturing site.
[A3] Stora Enso's EPD from 2020 has provided average values. Scottish timber is harder to work than Austrian Timber. Scottish timber has a lower density than Austrian Timber by approximately 70kg/m_3. It therefore may require greater energy load, though this dissertation has no way to quantity this statement. The density would the main variable.
Scottish timber, due to density, is harder to work and that means more energy required to machine, therefore, density = greater energy load.
Machine energy load should be similar across both models, for the same quantity of timber is required to be machined. A marginal variable is the estimated more efficient machines of Stora Enso against the newly created machines within the hypothetical Scottish manufacturer.
[A4] The transport from CCG manufacturing to Ellerslie Crescent is 1% of the emissions from Stora Enso Wood products Austria to Ellerslie Crescent. 25 deliveries would take place from either country.
[A5] The construction would produce similar-to-identical carbon emissions. Drilling holes into the Scottish timber may require marginally more energy.
[D] According to the EN 16449 biogenic carbon calculation, European timber absorbs more carbon than Scottish Sitka Spruce due to the higher density. Ellerslie Crescent constructed with Austrian CLT over Scottish CLT would store an additional 107 kg CO2/m3.

TABLE 3 Summary of calculation totals. Red highlights extreme highs, green highlights extreme lows. Demonstrates clear carbon emission reductions from re-use and from recycle.

Region of CLT Origin	Cradle to Grave / Embodied Carbon over Life Cycle (kg CO_2 / m^3)	[D] Benefits & loads beyond System Boundary. (kg CO_2 / m^3)	Whole Life Embodied Carbon (kg CO_2 / m^3)	End of Life Scenarios
Scottish	139.55	-706.20	-652	Re-Use
	145.20	-713.20	-654	Recycling
	934.55	-365.03	569	Incineration
	1153	-3.92	1149	Landfill
Austrian	175.60	-820.20	-637	Re-Use
	181.25	-827.20	-639	Recycling
	970.60970	-365.03	605	Incineration
	1185.60	-3.92	1185.68	Landfill

With estimated tolerances created using the difference in density, the four values are as follows:

TABLE 4 Scottish Homegrown CLT Manufacture estimated to produce 15-20kg CO2 per m3 less than Austrian CLT.

6. Scottish Timber: Cradle – Practical Completion	7. 136.97 kg CO_2 / m^3
8. Austrian Timber: Cradle – Practical Completion	9. 173.0 kg CO_2 / m^3

WITH Sequestration:

TABLE 5 Denser Austrian CLT sequesters more carbon and produces lower embodied energy when considered.

Scottish Timber: Cradle – Practical Completion	-518 kg CO_2 / m^3
Austrian Timber: Cradle – Practical Completion	-588.9 kg CO_2 / m^3

TABLE 6 Scottish Homegrown CLT Manufacture estimated to produce 15-20kg CO2 per m3 less than Austrian

Scottish Timber: Embodied Carbon over Life Cycle (re-use)	139 kg CO_2 / m^3
Austrian Timber: Embodied Carbon over Life Cycle (re-use)	175 kg CO_2 / m^3

TOTAL:

TABLE 7. Total Emissions from the structure of Ellerslie Crescent, sees a difference of 44700kg CO2.

Scottish Timber: Embodied Carbon over Life Cycle (re-use)	173048 kg CO_2
Austrian Timber: Embodied Carbon over Life Cycle (re-use)	217748 kg CO_2

Scottish CLT would produce equivalent to 21 average UK home's annual energy emissions, or the annual carbon footprint of 40 cars.

Austrian CLT would produce equivalent to 26.4 average UK home's annual energy emissions, or the annual carbon footprint of 47 cars.

A difference equivalent to annual emissions from 5.4 average UK home's or 7 cars.

6. Conclusion and Recommendations

The results of this embodied carbon calculation shall be used with care as the uncertainties on these results are high or as there is limited scope within available values, therefore the calculation has some degree of tolerance through multiple possible variables. The paper aimed to assess the carbon emission savings over the life cycle from a hypothetical Scottish CLT supply chain for a Scottish construction project, the likes of which could be used to demonstrate an environmental advantage to the establishment of a Scottish CLT supply chain. Specifically, an existing medium-high rise residential construction project was utilised to obtain accurate data regarding the Embodied Carbon over the Life Cycle. For this purpose, an Embodied Carbon Calculation was utilised as per the RICS 2017 Statement upon Embodied Carbon. The results displayed carbon emission savings of 7% based on the current RICS measurement strategies from a Scottish CLT supply chain. The results also found that CLT from Austria would store 15% more CO2 than Scottish CLT. Inclusive of sequestered CO2, this investigation would conclude that the use of Austrian timber offers more upside.

This study advocates that both Scottish and Austrian CLT produce net negative atmospheric carbon emissions, which is ultimately a good thing for the planet. CLT should be championed and encouraged as specified structural materials in the built environment.

5.1 RECOMMENDATIONS AND FURTHER RESEARCH

- This paper attempted to quantify the carbon emission savings achievable from using a Scottish CLT supply chain taken in isolation from economic variables. Further studies should explore the possible business case and economic standpoint of a potential Scottish CLT manufacturer.
- A business case could work in tandem with an environmental case to propose the extent of possible benefits that a Scottish CLT manufacturing base could provide to Scotland and the UK market.
- Further research could explore possible ways for Scottish Timber to absorb more carbon should we wish to further reduce the atmospheric carbon content from Scottish sources. Given the results of this study, it would be useful to explore ways in which Scottish timber may be able to absorb as much carbon as Austrian trees do.
- There is expected to be more demand for medium-high rise housing in urban areas of England than in Scotland, but it would be logical to assume that Scottish timber would be more commonly used and more widely available.

- There are two scopes for discussion: UK CLT manufacturing enhancement and the more regional Scottish CLT. There will be more demand for urban CLT development in England whilst Scotland maintains the forestry suitable for CLT. This paper focuses on Scotland, and it applies to the whole UK for CLT implementation, such as from the L&G Offsite Manufacturing base in Leeds.
- This paper concludes that architects and recent graduates should embrace CLT as a new pattern of architecture that can contribute significant characteristics aesthetically and spatially in addition to the carbon savings. Offsite construction provides the opportunity for precision engineering and efficient designs. Mass timber should be perceived as an opportunity and therefore be an exciting driver for future change.
- Further research into this area should investigate whether there is a significant amount of additional energy required to work Scottish timber into CLT relative to the energy load required of Austrian CLT, quantifying the amount of difference this would cause. Such investigation would aid with the increased accuracy of an embodied carbon comparison.

References

ABOSAOD, H., UNDERWOOD, J., ISIKDAG, U. AND BARONY, S. (2010) A classification system for representation of off-site manufacturing concepts through virtual prototyping, 9th International Detail Design in Architecture Conference

A.B. ROBERTSON, F.C. LAM, R.J. COLE. (2012). A comparative cradle-to-gate life cycle assessment of mid- rise office building construction alternatives: laminated timber or reinforced Concrete Buildings, 2 (3) (2012), pp. 245-270

ADAS Dundee (2021) INNOVATION IN TIMBER CONSTRUCTION - Lecture by Andrew Waugh from Waugh Thistleton [online video] Available at: https://www.youtube.com/watch?v=qrjHXBJpdEA

Architecture 2030, WHY THE BUILDING SECTOR? Architecture 2030, [Accessed 20.04.21] https://architecture2030.org/buildings_problem_why/

AWC, 2012 AWC Preliminary CLT Fire Resistance Testing Report American Wood Council (2012) Retrieved ttp://www.awc.org/Code-Officials/2012-IBC-Challenges/Preliminary-CLT-Fire-Test-Report-FINAL-July2012.pdf.

BSI, 2016. BS EN 350 Durability of wood and wood-based products. Testing and classification of the durability to biological agents of wood and wood-based materials . Online: BSI.

BUILD IN WOOD 2020 Why building in wood is the future - Project: Build-in-Wood . 2020. Directed by Build in Wood H2020. -: Build in Wood H2020.

BUIS, A., 2019. The atmosphere: Getting a handle on carbon dioxide . [online] USA: NASA. Available from: https://climate.nasa.gov/news/2915/the-atmosphere-getting-a-handle-on-carbon-dioxide/ [Accessed 11/02 2021]

Construction Scotland Innovation Centre (2020) i-Con webinar: Mass Timber Alliance. [online video] Available at: https://www.youtube.com/watch?v=FXg6BUG-geM

Construction Scotland Innovation Centre Building a Sustainable Future: Timber Innovation [Interviews] . 2020. Directed by F. MacDonald, R. Hairstans and A. Chalmers. Online: Youtube.

CSIC, 2020. Scottish timber initiative plants seed of sustainability for UK construction. [online] Online: Available from: https://www.cs-ic.org/news/2020/november/23-november/scottish-timber-initiative-plants- seed-of-sustainability-for-uk-construction/ [Accessed 04.20 2021]

CRAWFORD, D., HAIRSTANS, R. & SMITH, R. E. (2013). Feasibility of cross-laminated timber production from UK Sitka Spruce. ISBN 1 85790 181 9

CAMBIASO AND PIETRASANTA, 2014 F. Cambiaso, M. Pietrasanta Innovative timber construction: sustainability and high-performance building skin IACSIT Int. J. Eng. Technol., 6 (1) (2014), pp. 47-54

CCG, 2019. Ellerslie road, Glasgow. Online: CCG Glasgow. Available from: http://c-c-g.co.uk/project/ellerslie- road-glasgow/ [Accessed 04.20 2021]

CHEN, 2012 Y.J. Chen Comparison of Environmental Performance of a Five-storey Building Built with Cross- laminated Timber and Concrete (Thesis) Department of Wood Science (2012)

CHEN, C., PIEROBON, F. & GANGULY, I., 2019. Life Cycle Assessment (LCA) of Cross-Laminated Timber (CLT) Produced in Western Washington: The Role of Logistics and Wood Species Mix. Sustainability, 11(5), p.1278. Available at: http://dx.doi.org/10.3390/su11051278.

Construction (2013) WoodWorks Presentation. Retrieved 2014 from: http://www.woodworks.org/wp- content/uploads/2013-14-Q4-Introducing-CLT.pd

CUNNINGHAM, R., 2019. The Global Climate Emergency - Scotland's Response: Climate Change Secretary Roseanna Cunningham's statement. Edinburgh: The Scottish Government.

C.V. SILVA, J.M. BRANCO, P.B. LOURENÇO. (2013). A Project Contribution to the Development of Sustainable Multi-storey Timber Buildings Report Department of Civil Engineering. University of Minho, Guimarães, Portugal.

DAVIES, I. (2016). Sustainable construction timber: sourcing and specifying local timber. Forestry Commission Research Report Forestry Commission, Edinburgh. i-vi + 1-54 pp.

Dong et al., 2018 C. Dong, R. Boute, A. McKinnon, M. Verelst Investigating synchromodality from a supply chain perspective Transport. Res. Part D: Transport Environ., 61 (2018), pp. 42-57, 10.1016/j.trd. 2021.04.20

Ellerslie road [online] Online: Stora Enso. Available from: https://references.buildingsolutions.storaenso.com/en/projects/flats/uk/yoker-clyde [Accessed 04.20 2021]

EN 16449, 2014. Wood and wood-based products - Calculation of the biogenic carbon content of wood and conversion to carbon dioxide.

Fowler, 2014 FPInnovations CLT Handbook FPInnovations, Montreal, Canada (2013)

Frangi et al., 2009 A. Frangi, M. Fontana, E. Hugi, R. Joebstl Experimental analysis of cross-laminated timber panels in fire Fire Saf. J., 44 (2009), pp. 1078-1087

GARDINER, J., 2020. How is the CLT industry responding to the combustibles ban?. [online] Online: Building.co.uk. Available from: https://www.building.co.uk/focus/how-is-the-clt-industry-responding-to- the-combustibles-ban/5097651.article [Accessed 04.20 2021]

HÄKKINEN, T., 2020. Definition and methods for the carbon handprint of buildings. Danish Housing and Planning Authority.

Hairstans, R. (2014). Building offsite: an introduction. Edinburgh, Scotland: UK Commission for Employment and Skills (UKCES)

HAIRSTANS, R. and SANNA, F., 2017. A Scottish perspective on timber offsite construction. 1st ed. Online: Routledge.

Hairstans, R. (2019). Off-site and industrialised timber construction. (2nd). BMTRADA

Harvard GSD (2020) Mass Timber and the Scandinavian Effect [online video] Available at: https://www.youtube.com/watch?v=w2STKPvELD0

H. Fountain Wood that Reaches New Heights The New York Times (2012) Retrieved 2014 from: http://www.nytimes.com/2012/06/05/science/lofty-ambitions-for-cross-laminated-timber- panels.html?pagewanted=all&_r=0

Hristovski et al., 2012 V. Hristovski, B. Dujic, M. Stojmanovska, V. Mircevska Full-scale shaking- table tests of XLam panel systems and numerical verification: specimen 1 J. Struct. Eng., 139 (11) (2012), pp. 2010-2018

IBC, 2012 IECC, 2012 Jaksch et al., 2012 John et al., 2009 S. John, B. Nebel, N. Perez, A.H. Buchanan Environmental Impacts of Multi-storey Buildings Using Different Construction Materials Report Department of Civil and Natural Resources Engineering. University of Canterbury, Christchurch, New Zealand (2009)

Krug, D. and Miles, J. (2013) Offsite Construction; Sustainability Characteristics, BuildOffsite, www.buildoffsite.com

LEHMANN STEFFEN, 2012. "Sustainable Construction for Urban Infill Development Using Engineered Massive Wood Panel Systems," Sustainability, MDPI, Open Access Journal, vol. 4(10), pages 1-36, [Accessed 20.04.2021.]

MALIK, C., Construction cycle and waste. [online] Available from: https://ciaranmalik.org/portfolio/construction-cycle-and-waste/ [Accessed 20.04 2021]

Passivhaus: the route to zero carbon? London: Passivhaus Trust (2019)

LAGUARDA MALLO, M.F. and ESPINOZA, O., 2015. Awareness, perceptions and willingness to adopt Cross-Laminated Timber by the architecture community in the United States, Journal of Cleaner Production, Volume 94, pp. 198-199-210

LETI., 2018. LETI Embodied Carbon Primer.

LETI., 2019. LETI Climate Emergency Design Guide.

MAST, 2019. Ellerslie crescent, yoker. [online] Online: MAST Architects. Available from: https://mastarchitects.co.uk/our-projects/ellerslie-crescent-yoker/ [Accessed 04.20 2021]

MALCZYK, R., (2011) Cross-laminated timber in British Columbia Presentation. CLT Symposium. February 8–9 (2011)

H. SKOGSTAD, L. GULLBREKKEN, K. NORE (2011). Air leakages through cross laminated timber (CLT) constructions 9th Nordic Symposium on Building Physics (2011) Retrieved 2014 from: http://www.treteknisk.com/fullstory.aspx?m=1585&amid=14888

Michael Green, The Case for Tall Wood Buildings, Blurb, 2018

MONAHAN, J. and POWELL, J.C., 2011. An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework. Energy and Buildings, 43(1), pp. 179-188

Nordic co-operation, 2020. Declaration from the Nordic Ministerial meeting concerning buildings and construction on the 29th of May 2018, Stockholm. Available at: https://www.norden.org/en/declaration/declaration-nordic-ministerial-meeting-concerning-buildings-and- construction-29th-may [Accessed 4 20 2021].

POPOVSKI AND KARACABEYLI, (2012) M. Popovski, E. Karacabeyli Seismic behaviour of cross-laminated timber structures World, 15 (2012), p. 19

Popovski et al., 2010 M. Popovski, J. Schneider, M. Schweinsteiger Lateral load resistance of cross-laminated wood panels World Conference on Timber Engineering (2010), pp. 20-24

PLOWAS, W., 2019. COCIS Research into Mass Timber Systems – Cross Laminated Timber. Online: Centre for Offsite Construction + Innovative Structures.

RAMAGE, M.H. et al., 2017. The wood from the trees: The use of timber in construction. Renewable and Sustainable Energy Reviews, 68, pp. 333-359

RICS, 2017. Whole life carbon assessment for the built environment. (1st Edition). London: Royal Institute of Chartered Surveyors (RICS).

RIDLEY-ELLIS, D., 2020. What's known about home grown? [online] Online: Centre for Wood Science and Technology. Available from: https://blogs.napier.ac.uk/cwst/clt-production-uk/ [Accessed 04.20 2021]

SMEDLEY, T., 2019. Could wooden buildings be a solution to climate change? [online] BBC Future. Available from: https://www.bbc.com/future/article/20190717-climate-change-wooden-architecture-concrete-global-warming [Accessed 14/12 2020]

R. Steiger, Gülzow, R. A. Validity of bending tests on strip-shaped specimens to derive bending strength and stiffness properties of cross-laminated solid timber (X-lam) The Future of Quality Control for Wood and Wood Products (2010), pp. 4-7

R. Steiger, Gulzow, R. A. Gsell, D. Non-destructive evaluation of elastic material properties of cross-laminated timber Conference COST E53. 29–30 October 2008, Delft, The Netherlands (2008), pp. 171-182 Retrieved 2013 from: http://www.coste53.net/downloads/Delft/Presentations/COSTE53-Conference_Delft_Steiger_Guelzow_Gsell.pdf

Scottish Government., 2020. Greenhouse gas emissions 2018: estimates. (Estimates of greenhouse gas emissions in Scotland for the years 1990 to 2018.). Scotland: gov.scot.

Scottish Government., 2019. Global climate emergency Scotland's response climate change. [online] Online: gov.scot. Available from: https://www.gov.scot/publications/global-climate-emergency-scotlands- response-climate-change-secretary-roseanna-cunninghams-statement/#:~:text=Publication%20%2D%20Speech%2FstatementThe%20Global%20Climate%20Emergency%20%2D%20Scotland's%20Response%3A%20Climate,Change%20Secretary%20Roseanna%20Cunningham's%20statement&text=There%20is%20a%20global%20climate,The%20science%20is%20clear. [Accessed 04.20 2021]

STORA ENSO., 2020. Environmental Product Declaration CLT (Cross Laminated Timber). Online: The International EPD System.

STORA ENSO, 2019. Ellerslie road. [online] Online: Stora Enso. Available from: https://references.buildingsolutions.storaenso.com/en/projects/flats/uk/yoker-clyde [Accessed 04.20 2021]

Sutherland, N. qtd. in Riverside Sunderland: University Design Challenge (2021): RSUC VIDEO CALL 7 #RSUDC21 Desirable Homes & Communities [online video] Available at: https://www.youtube.com/channel/UClE63Emi7rx4M5dIngVy0ZA

S. Pei, M. Popovski, J.W. van de Lindt Seismic design of a multi-story cross laminated timber building based on component level testing World, 15 (2012), p. 19

Van de Kuilen et al., 2011 J.W.G. Van de Kuilen, A. Ceccotti, Z. Xia, M. HeVery tall wooden buildings with cross laminated timber Various, Cross-laminated timber, Design and Performance, Exova BM TRADA, 2017

WAUGH, A. and THISTLETON, A., 2018. 100 UK Projects CLT 1st ed. Canada: Waugh Thistleton Architects. https://www.cs-ic.org/news/2020/november/23-november/scottish-timber-initiative-plants-seed-of- sustainability-for-uk-construction/ STORA ENSO EPD 2020

WILSON, P., 2017. The Modern Timber House in the UK: New Paradigms and Technologies. 1st ed. Arcamedia Ltd.

WILSON, P., 2020. The butterfly effect on Scottish-grown timber. [online] Timber Design Initiatives. Available from: https://www.build-back-rural.com/post/the-butterfly-effect-on-scottish-grown-timber [Accessed 14/12 2020]

Winter et al., 2010 W. Winter, K. Tavoussi Tafreshi, A. Fadai, T. Pixner Development of wood based sustainable construction methods for high-rise buildings under lateral loading High Rise Towers Tall Build. (2010), pp. 1-8

WoodWorks, 2013 WoodWorks Introducing Cross-laminated Timber. New Opportunities for Timber Wold GBC., 2018. Global Alliance for Buildings and Construction 2018 Global Status Report. Available Online. [Accessed 20/04/2021]

THE EFFECT OF COVID-19 LOCKDOWN ON DESIGN STUDIO LEARNING AND ARCHITECTURE STUDENTS' PERFORMANCE

Josh Mitchell, Tahar Kouider
Robert Gordon University, Aberdeen UK
Email Address: j.mitchell11@rgu.ac.uk
Email Address: t.kouider@rgu.ac.uk

Abstract. The first UK lockdown halted all facets of life and quickly became the greatest challenge the education system has ever faced. In order to continue teaching curriculums remote learning was promptly adopted as the emergency method as a substitute learning environment to continue teaching curriculums. Discussions surrounding the effectiveness of remote teaching emerged after the initial year of the lockdown with many studies worldwide surveying universities and student performance across all courses. Study findings claimed no change in performance however the lack of specific research and different pedagogies in architecture compared to typical lecture-based learning subjects suggests otherwise. This paper explores the adaptability of architecture in remote learning, in comparison to face-to-face, and its effect on students' academic performance.

This study targeted British architecture-based students and their experience with remote learning surrounding the UK lockdowns and subsequent hybrid learning methods. The nuanced differences between architecture-based pedagogies were explored through an extensive literature review of fundamental, modern and current pedagogies. In a remote learning environment, the said pedagogies were affected, and design studio did not translate well to the remote teaching style.

When surveyed, over ¾ of respondents established links between their performance and the lack of traditional face-to-face learning. There was a prevailing negative view of exclusively remote learning and a preference towards a hybrid approach. Despite this, many recognised the benefit of remote learning however only in scenarios such as lectures. Research concluded that the likely external factors, economic and digital poverty, appeared ineffectual according to respondents. Findings suggest potential damage to academic performance within architecture disciplines and in wider applied learning disciplines. Future predictions surrounding higher education see technologically based pedagogies taking precedent as the benefits surrounding hybrid learning have been discovered with its flexibility and accessibility to students and educators

Keywords: Architecture, Design Studio, Pedagogy, Remote Learning

1. Introduction

University teaching methods have used the person-to-person lecture and discipline practice formats since the earliest evidence of academic institutions. Universities have since evolved learning methods and pedagogies to integrate technology and online learning for a blended method. The blended method offers material to students on and off campus to provide support in a flexible and adaptable format (Kaushik. M, 2016). Emergency remote learning, a result of Remote learning, as we know it, was introduced in the 1980's but didn't become widespread in universities until the 2000's (The History of Online Schooling, n.d.). However, the UK COVID lockdown in 2020 forced an immediate mass migration to emergency remote teaching with a select few disciplines teaching in-person. The hasty transition to online learning methods saw an intensified workload for teachers as they transferred their current curriculum to an online delivery method and become adept in the necessary software's and services (Allen, Rowan and Singh, 2020).

Design courses, such as architecture, are heavily dependent upon collaboration between peers and their teachers in a design studio, mimicking professional practice (Emam, Taha and ElSayad, 2019). COVID-19 has compelled isolation of remote learning which has reduced the effectiveness of the collaborative pedagogy, implicating the opportunity to develop these skills have been missed. Waite (2021) surveyed architecture students revealing a significant portion of students were feeling lonely and found working in isolation challenging, thus suggesting that the performance and output of the students had not reached full potential productivity nor quality.

Debates have sparked concerning student performance under COVID-19 circumstances and in an online learning environment. Emergency remote learning and its effectiveness in design disciplines such as architecture, is open to discussion concerning its adaptability from traditional face-to-face to an online setting. Some academics hypothesize that the impact on student performance to be negligible (Watson, 2020). However, opposing research concerning students and teachers received a mixed reception to online learning and its adaptation to design-based courses (Ibrahim, Attia, Bataineh and Ali, 2021).

1.1 RATIONALE

The implications COVID-19 has had on education is a current and under- examined crisis with sparse research conducted on specific design disciplines in education, such as architecture. Education at all levels, had been replaced with emergency remote learning to prevent education halting all together as the COVID-19 crisis saw no clear end. In this short time, educators had to transfer their curriculum to a suitable online delivery method that was as effective as traditional blended learning (Allen, Rowan and Singh, 2020). Design subjects have suffered with students expressing their difficulty to learn in the new remote learning environment, absence of studio, collaboration, and socialising (Waite, 2021).

Research conducted by El Said (2021) regarding grade difference between face-to-face and remote learning semesters suggests there was no significant grade change in higher education. However, there are limitations on the macro-scale of only one university being the basis and the micro-scale with all disciplines being measured on tests and quizzes, a less applicable format for design subjects such as architecture. Disciplines that rely heavily on coursework and projects may provide differing results due to their different learning environment. Opposing El Said’s conclusion is Watson’s (2021) survey of architecture students and their perceived challenge with online learning thus implying the possibility of students performing poorer academically.

The research conducted holds relevance to the current ongoing COVID-19 circumstances and the future of higher education online learning. The current effect on higher education through its dependence on remote/hybrid learning due to COVID-19 and in the future, as universities are predicted to integrate technology and digital learning into courses for flexible teaching methods and a more accessible learning strategy (Lederman, 2020).

1.2 AIM

This paper aims to investigate the effect of online/blended learning methods on higher education architecture students' academic performance and overall well-being. The absence of traditional design studio and in-person teaching will be scrutinised, and compared with online teaching methods, to ascertain the impact on students perceived performance and grades.

1.3 OBJECTIVES

- Critically review different student learning pedagogies and assess their capability in a remote teaching environment
- Identify the importance of design studios and collaborative student learning
- Examine the benefits and hindrances of remote learning, a result of COVID-19's university closures, on design students
- Review student perception of remote learning, its adaptability to online and the advantages or disadvantages it presents
- Establish the importance of design studio and student collaboration and its application to the online methods in relation to student learning and performance

2. Literature review

2.1. LEARNING PEDAGOGIES

Learning pedagogies is defined as "how we teach—the theory and practice of educating" (Persaud, 2021). Various or customised pedagogies are used by educators to adapt the curriculum to the best suited learning style for the student and subject/discipline. The intention of pedagogies is for development of cognitive and working skills whilst also teaching the student 'how' to learn according to their preferred method. Different pedagogical methods have been utilised by educators throughout the history of education and have been adapted to be tailor-made to the individuals and subjects. Pedagogical learning aims for the student to attain a full understanding of the subject matter or discipline beyond a superficial memorisation or shallow knowledge (Persaud, 2021).

In the modern age of higher education and its ever-reflective nature, an emerging student-centred approach is becoming the exemplar, with innovative and technology infused pedagogies reflecting this shift to create the "optimal learning environments with technology enriched spaces" (Giridharan, 2016). Kaushik (2016) expanded upon

Giridharan's observation of the technological trends further by addressing the requirement for modern pedagogies to integrate technology in order to create a better work environment and workflow for students. This would result in a more flexible, communicative, motivating, engaging and conscientious work environment. Modern pedagogies in design disciplines such as architecture have modernised and evolved to become better suited to the advancements in the industry towards a mostly digital work environment, with the widespread adoption of Computer-Aided-Design (CAD), Building Information Modelling (BIM) and 3D modelling software. These digital aids have revolutionised the construction industry and higher education pedagogy was adapted to integrate the new methods with traditional learning ahead of the curve.

Of the different pedagogical methods, some take priority over others or aren't the priority in a design studio environment. As such, some methods won't be included as they are deemed irrelevant by the author.
The relevant methods include Socratic - students learn through critical thinking, reason, and logic; Problem-Based Learning - students solving real world problems; Collaborative - peer-to-peer interaction and interpersonal management; Integrative - making connections between concepts and experiences and Reflective - reflecting upon lessons, projects, and assessments (Persaud, 2021).

Socratic learning in design studios can be found in the nature of a student logically interpreting a brief and critically thinking how to allocate time and resources to produce the necessary outlined project outcomes. Problem-based teaching sees projects and assessments relating to real world briefs and challenges that the student will encounter in their careers. Collaborative learning is seen throughout the entire design studio process with constant peer-review between student to student and student to educator; additionally correcting their peers/own work as a collective in the class. Integrative teaching sees students on trips to construction sites and existing structures, learning concepts whilst experiencing them in real time. Lastly, reflective learning concerns individual students evaluating past projects, assessments etc. and analysing what work/study methods are effective and where there is room for improvement.

2.2 ARCHITECTURE & PEDAGOGY

Architectural design courses are taught in a manner similar to real world practice with collaboration, realistic design problems and refining design through discussions and reviews. Education mimics the real-world design process as an integrative pedagogy with the initial conceptual stage, drafting and detailing of concept, CAD views and rendering of design and finalisation. "The design is then conveyed to those involved in the construction and development process, and construction begins" (Architectural Design Process and Phases | BluEntCAD, n.d.).
Soliman, A.M. (2017) conducted research detailing the necessary number of hours required from an architectural design course and broke down all fundamental segments of the learning methods for a comprehensive understanding of the design process. Design communication, design skills and design studio management

strategies are described as the main pillars that contribute to a holistic understanding of the design process.

Table 1. Appropriate teaching and learning strategies for the architectural design process in pedagogic design studios (Soliman, 2017)

Design Communication	Design Skills	Design Studio Management
Use of technology	Problem seeking	Group Discussions
Sketching	Analysis of Design	Interdisciplinary Teamwork
Physical Modelling	Developing Concept Designs	Realistic Design Problems
	Testing and Evaluating Design	
	Reflection	

Under usual circumstances all methods are possible, however, emergency remote learning complicates communication and impedes the conventional studio collaboration. This made it necessary for teachers to adapt the curriculum to an online method and a suitable delivery format.

Despite the sudden altered environment, multiple studies on remote learning demonstrate a positive impact on students. Gopal, Singh, and Aggarwal (2021) surveyed a high satisfaction rate from students and teachers in a remote learning environment with no links to performance being affected. A small survey of dental students and instructors, a course more dependent upon in-person learning, were satisfied with the transition to remote learning and their online curriculum. Instructors and students had even exhibited preference to remote learning for a better work-life balance (Rad, F. A. et al. 2021). Ceylan, S. et al. (2020) conducted an examination of architectural design studios during the COVID-19 outbreak which analysed student reception to online learning across varied course/programme stages. The survey when asking about remote learning saw an overall positive attitude from students, with a variation of third year and fourth-year students having a slightly less positive view, which the Authors linked it to the pressures of graduation. The criticism in the survey surrounded the lack of socialisation from physical studio and the absence of peer/instructor review that occurs naturally when working in studio. Concluding, Ceylan, S. et al believe that digital and remote learning is the next step for education and the COVID-19 pandemic merely accelerated the evolution in architectural design education.

2.3 THE IMPORTANCE OF DESIGN STUDIO

Design studio is the centre of collaboration and learning, a central pedagogy of the architectural design discipline. Peer-to-peer and student-to-educator exchanges in design studio as described by Dinham, S. M. (1987) are criticisms that lead to reflective, analytical, and constructive attitudes by students. Schon, D.A. (1987) developed a collaborative style coaching known as Schon's model that can be attributed to the design studio pedagogy. It is a model that "…has the strength of considering reflection in action (event/experience) with those that happen in hindsight (after the event)" (LibGuides: Reflective writing: Schön, n.d.). Fundamentally design studio refines architectural design through trial and error, experiencing failure and challenges to build student knowledge and train the complex method of problem seeking, analysis of design and reflection on past work.

As mentioned in section 2.2, evidence suggests that design studio can be adapted to a digital format, but it somewhat loses the collaborative and social aspect. Frambach, J. M. et al. (2014) discussed pre-COVID, how student communication in class was affected by cultural, contextual and personality factors. Group relations, uncertainty, hierarchal relations, and competition were all contributing factors that inhibited an ideal collaborative discussion between students and teachers. An anxiety to question or contribute to a lesson hinders the application of design studio, with collaboration being the core aspect. In a COVID-19 remote learning environment, the communication has been further affected by moving from in-person to digital communication such as video conferencing, e-mails, and messaging, changing person-to-person interactions majorly. With this transition comes challenges that affected students and teachers in an online environment; Adedoyin and Soykan (2020) examined these challenges. Challenges of technology, assessment and supervision, and digital competence were apparent in a remote setting that affected the learning environment. These challenges, affecting remote learning, were attributed to the lack of preparation for a crisis event like COVID-19. Connectivity problems that induced delay and disconnection leaving conversations stilted and one sided, added further complications. Progress and development of the best suited methods can be assumed as they have become tried and tested by educators over the 2 years since the widespread lockdowns in the world (Torre Arenas et al., 2020), and a consensus of the best suited methods had been deliberated upon.

Social presence within the online environment has been explored to analyse communication in the remote setting. "Social presence refers to the degree to which one perceives the presence of participants in the communication" (Wut, and Xu, 2021). The discipline explores how a person's psychological perception conveys their presence via different forms of media by their visual and verbal cues. Certain types of social communication can convey superior social presence such as video calls or telephone, rather than simple methods such as e-mail. Social presence is fundamental to how we build relationships whilst being an alternate method to physical contact (Zelkowitz, 2011).

Wut and Xu (2021) conducted a social presence study based upon a previous study regarding online classroom management by Li and Beverly (2008) but in the COVID-19 setting. The study investigated the challenges for student-to-student and student-to-instructor interactions through remote online methods. Findings conveyed the lack of natural communication distanced students from each other and their instructors, affecting motivation of both parties. The lack of challenging others' views, and the usual discourse found in face-to-face meant that the crucial cognitive and social development was absent in online classroom. Recommended solutions provided by

Wut and Xu include more pro-active online methods of teaching. Encouragement, incentives and break out rooms were found to be effective at facilitating interactions between the groups mentioned. Wut and Xu noted other factors that inhibited online communication which included teachers that weren't adept in online delivery software, larger class discussions failing to translate to online methods and the lack of engagement from students in online lessons. Given that communication has seen somewhat of a negative impact in the remote learning environment, it can be considered that the online design studio will have suffered also. Design studio historically has been dependent upon communication and collaboration, so one can speculate upon the effectiveness of studio in the remote setting. With the fundamental pedagogy, communication and collaboration hampered, performance may also be affected.
Studies from Asia Pacific (Allen, Rowan, Singh, 2020), Europe (Lischer, Safi, Dickson, 2021), Asia (Goppal, Singh, Aggarwal, 2021) and the US (Zalat, Hamed, Bolbol, 2021) all discussed the benefits and the obligation to move towards remote learning implementation. Whilst remote learning is not a new trend, the general consensus from these studies acknowledges the global shift, or rather integration, to remote learning in the future. This was suggested by the positive student and educator perception towards online learning and the 'crisis breeds focus' mentality that brought attention to remote learning application. Even in the unlikely scenario that remote learning is not integrated into future learning, it will be reserved as a solution for another similar crisis that may threaten to halt education.

2.4 EXTERNAL FACTORS IMPACTING STUDENT PERFORMANCE

The two major factors impacting students were digital poverty and economic poverty.
In the online environment, an emerging 'digital poverty' was revealed to affect students of all levels of education. In higher education within the UK "52 percent of students said their learning was impacted by slow or unreliable internet connection, with 8 percent 'severely' affected. According to the poll of 1,416 students, run for the OfS by Natives" ('Digital poverty' risks leaving students behind - Office for Students, 2020). Digital poverty includes students being unable to find suitable/quiet study spaces, be provided with the appropriate online course materials or lacked access to a computer/laptop/tablet for their work. This was simply another obstacle that students were faced with in the online learning environment. In an architecture setting, this is especially important for students to have a comfortable study space, with long hours at desks spent on projects, dissertations, and digital models. The extent at which digital poverty has affected students and their academic performance is difficult to quantify, so the impact of digital poverty on university students remains widely unknown.

Students also experienced economic poverty and issues regarding the facilities and resources readily available to them. Architectural design courses require computers with medium to high end graphical and RAM performance with large storage devices to smoothly run the required software and programs for digital projects and assignments. Whilst mainstream software packages such as AutoCAD, SketchUp and

REVIT offered free educational licenses, some rendering software or image editing packages had, at best, a discount that may not be an expense capable by a student in poverty (Russell, Thompson, and Jones, 2021).

The New Policy Institute (NPI) carried out a survey of student poverty in 2015, and their findings showed 1.3 million young people were in poverty, in full-time education and not living with their parents (Poverty Among Young People in the UK, 2015). In the context of COVID-19 the unemployment in people 16 and older increased from 3.8% at the beginning of 2019 to 4.2% in 2021, still higher than the last 3 to 4 years. The working student will have had many factors impacting their ability to pay for resources or time to allocate to studies fearing the loss of employment (Unemployment rate (aged 16 and over, seasonally adjusted) - ONS, 2021). Economic poverty poses the greatest external challenge to remote students with its cost to student time and the mental strain, linked to the diminished academic performance (Giusti et al., 2021).

Digital poverty merely implies that the effect on students may have impacted academic performance whereas economic poverty studies convey strong likelihoods of poorer academic performance when students suffer (Giusti et al., 2021). No conclusive evidence can be drawn to state an effect in academic performance without an in-depth study within the current remote learning time frame. But with the improvement of hybrid learning and steady return to classroom teaching, the gap of research may not appear worth further investigation. Despite this, the transition to the emerging trend of online learning is evident and, as discussed in section 2.1, poses the opportunity to address these challenges to students and provide future solutions.

2.5 FUTURE PROSPECTS OF REMOTE LEARNING

Student perception of remote learning has altered over time, as seen in studies conducted in the early weeks of the remote learning transition with students reporting ‘life becoming more difficult (Almendingen et al., 2021) comparatively with the improved results (October/November 2020) found in the Cranfield et al. (2021) study. As remote users became more adept to online learning and the most appropriate delivery methods were decided upon, a general improvement to remote learning could be found in conjunction with improved student reception. Whilst section 2.3 deliberated upon the difference in design courses and their remote learning, it can be assumed that with time they too have improved their methods. However, a report by The National Student Survey: Student experience during the pandemic (Office for Students, 2021) upsets this theory with data showing a slight decline in satisfaction agreement rates. With a huge range of over 332,000 core respondents in their annual survey of UK university students, the data is high quality and is hard to argue against. OfS acknowledged that the results could be short lived, and a circumstance of students weary of their situation. On the other hand, the results could be an indication of student reception to prolonged remote learning, a circumstance that has yet to impact students with only 2 years overall of exposure to remote learning and as such has yet to be studied.

The common advantage of remote learning noted by students is the 'convenience' or flexibility of time and location in accordance with their studying (Kemp and Grieve, 2014). Whilst this may suit some students, poverty-stricken students that cannot afford the necessary technology suffer academically as a result (Dhawan, 2020).

TABLE 2. Face-to-face or face-to-screen? Undergraduates' opinions and test performance in classroom vs. Online learning (Kemp and Grieve, 2020)

Advantages of Remote Learning	**Disadvantages of Remote Learning**
Convenience	Lacking in engagement
Wider contributions	Feedback (depending on form) is not immediate
More detailed online responses	Discussions lack flow due to delay/digital feedback
Less judgment in asking questions	Easier to review paper documents
More time to think	No need to read classmates' comments

No definitive conclusion can be drawn on remote learning applicability and the hierarchy of needs in terms of advantages and disadvantages. Though, the noted disadvantages specifically effect the pedagogy of design studios as mentioned in section 2.1. Lacking a clear advantage over traditional F2F, remote learning is unlikely to become the new norm, but it does have its place. Remote learning has been compared and studied under the guise of a replacement for teaching, though it presents solutions to challenges faced by F2F learning and as such should be treated as a supplement. A hybrid pedagogy of online and F2F, a holistic and balanced learning approach can be offered to students.

Despite any negativity, students have expressed their preference towards online learning with the most mentioned benefit being how 'flexible and convenient' it is for students (Miller, 2019). Students appear open to the prospect of online learning as a method with the caveat that they have some form of blended or F2F as mentioned by Wut and Xu (2021). Remote learning is suggested as not a 'one size fits all' solution, but to be combined with other learning strategies and methods as a supplement for a robust curriculum.

2.6 SUMATION OF LITERATURE

The literature reviewed conveys the lack of student collaboration and difficulty in communication is apparent. Of the reviewed student groups, generalised, dental, architecture and medical, only architecture and medical students have voiced moderately negative opinions towards remote learning. As mentioned in section 2.1 & 2.2 collaboration and communication are fundamental to architectural design and design studio pedagogies. The architecture discipline is an anomaly within the student groups and lacking relevant studies conducted within architecture courses, so no immediate trends can be formed.

The adaptability of remote learning to architecture in academia, as investigated in objective 4, is subject to criticism with a lack in relevant studies and weaknesses found in the absence of critical pedagogical methods. The gap in research presents an oversight in generalised studies that has overlooked nuanced disciplines with different methods of learning. Remote learning in architecture exhibits possibilities of an impact on students' academic performance that warrants further investigation.

3. Methodology

To verify the initial hypothesis within the literature review, a triangulation of data will be achieved through a mixed-methods approach. Open-ended survey questions regarding students' perception of remote learning in conjunction with a defined statistical survey from the same students coalesce in an insightful perspective from the respondents. Both sets of data will be used to confirm or deny the researchers hypotheses.

The survey consists of two main forms of questions, a 1 to 5 satisfaction scale/multi-choice questions and a subsequent open-ended question for students to explain their reason behind their answer. This will help identify motives and establish trends in the findings. From the initial literature investigation, the survey will focus upon meeting these objectives:

- Investigate student perception on remote learning as an alternative to traditional face-to-face
- Identify how the curriculum adapted to remote learning
- Examine external challenges, if any, students faced when working remotely
- Survey students' predictions for the future of remote learning
- Identify the preferred learning method according to course

Through these objectives, a comprehensive and discipline focused survey will be conducted to compare against the 'generalised surveys' previously mentioned. This aims to confirm or deny the initial hypothesis of overlooked subjects in generalised studies leading to sweeping claims that do not consider alternate learning pedagogies for disciplines such as architecture. The survey was conducted during the period between November and December.

4. Results, Analysis & Discussion

4.1 INTRODUCTION

This section examines the data collection results from the online survey, a combined method of qualitative and quantitative data. These outcomes are compared to and contrasted with previous findings from section 2 of the literature review and elaborated upon. Key findings are highlighted, and all results analysed and expanded upon in relation to the set objectives.

4.2 SURVEY RESPONDENTS' PROFILES

Survey respondents numbered 51 in total across 27 universities, with 26 respondents from architecture or design courses that completed the design studio section of the survey. The other respondents hailed from a variety of courses; these data sets are utilised comparatively to highlight differences in architecture subjects from other courses.

TABLE 3. Survey Profile, Universities (Author, 2021)

Which University do you attend?	Percentage of Respondents	Number of Respondents
Robert Gordon University (RGU)	25.4%	13
University of Leeds	7.8%	4
Brunel University London	5.8%	3
University of Portsmouth	5.8%	3
University of Aberdeen	3.9%	2
University of the Highlands and Islands (UHI)	3.9%	2
Liverpool John Moore's University	3.9%	2
Other	39.2%	20
Prefer Not to Say	3.9%	2

TABLE 4. Survey Profile, Course's/Programme's (Author, 2021)

Which Course/Programme are you enrolled in?	Percentage of Respondents	Number of Respondents
Architectural Technology	29.4%	15
Architecture	9.8%	5
Building Surveying	3.9%	2
Landscape Architecture with Urban Design	1.9%	1
Construction	1.9%	1
Interior Architecture	1.9%	1
Applied Design in Architecture	1.9%	1
Other	49%	25

Respondents make up a total of 26 different courses, 7 of which are architecture related and highlighted in table 4 with a spread in the course/programme stage, as shown in figure 1. This is a desired outcome to gather a varied perspective according to course stage.

A diverse range of student stages have experience in a remote setting. As expected, stages 3 and beyond having experienced most, if not all facets of learning typologies. Of the 26 students in architecture-based subjects, nearly all had experienced hybrid learning, in part with the gradual return to campuses at the time of the survey.

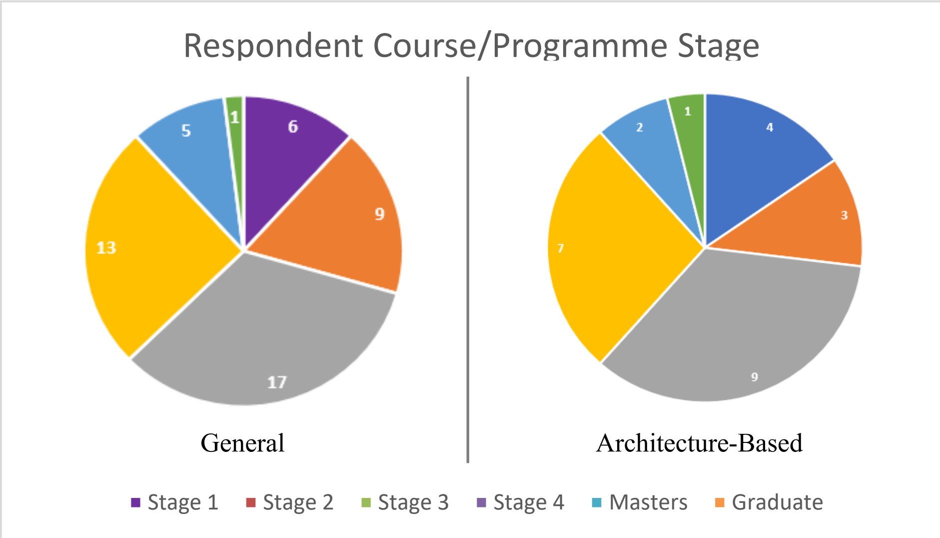


Figure 1. Course/Programme Stage (Author, 2021)

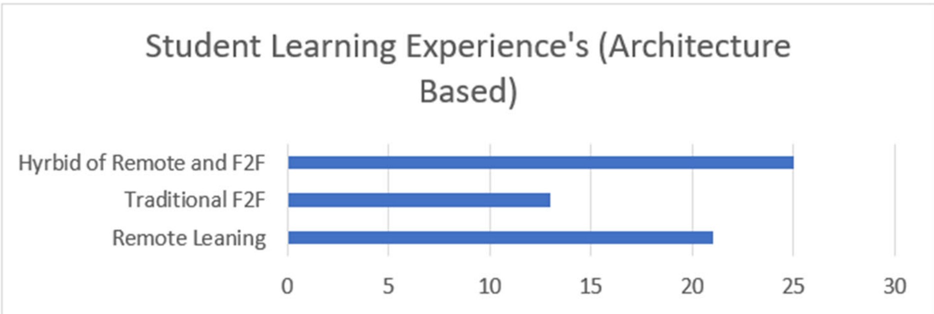


Figure 2. Experienced Learning Environments by architecture-based students (Author, 2021)

4.3 SURVEY FINDINGS

Qualitative findings were collected in the form of open-ended questions gathering student opinions and experiences with quantitative questions collected in the form of closed option answers to create distinct statistics.

When asked to compare the quality of remote learning from the beginning of lockdown to current remote teaching, students saw a definite increase in quality and stability in their online courses, as seen in figure 4. Whilst there was an increase, especially with students citing hybrid learning as a solution to remote learnings defects, some students believe that the remote learning experience to have plateaued

mentioning how "[it] still feels like the course is not totally catered to online". This may be a result of a select few courses neglecting remote learning with an optimistic outlook with no further lockdowns thus need for remote learning methods.
Satisfaction rates coincide with the generalised studies of student satisfaction surrounding remote learning and its improvements, much like the prevailing positive attitude reported by Ceylan, S. et al. (2020). Architecture-based respondents report a similar percentage for satisfaction with Scale 5 (S5) showing a 34.6% response, general S5 showing a 35.2%. In both cases, nearly all responses reported an increase in quality with only a small portion claiming no improvement, see figure 6.

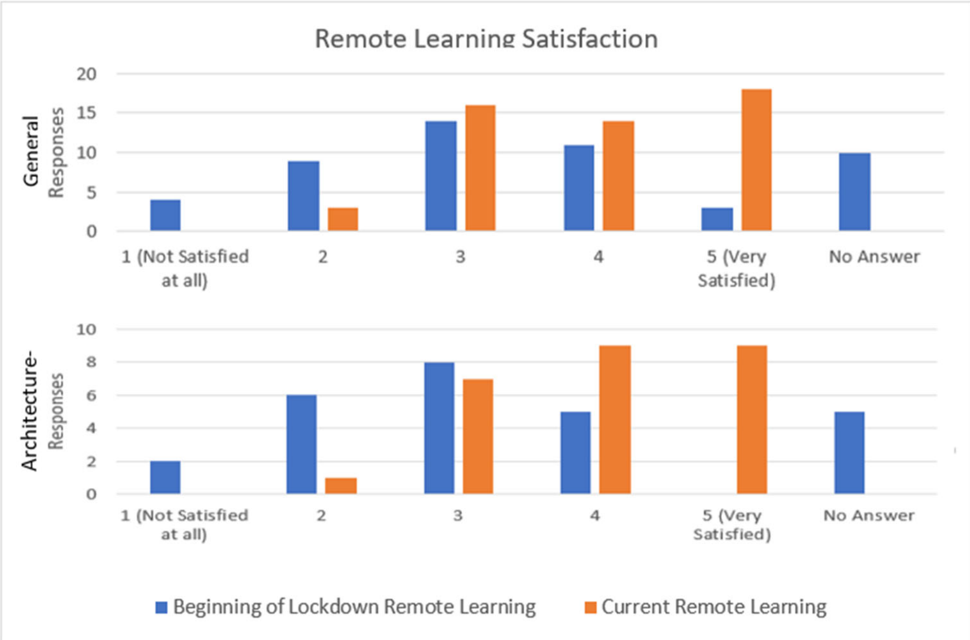


Figure 3. Compared Satisfaction Rates with Remote Learning (Author, 2021)

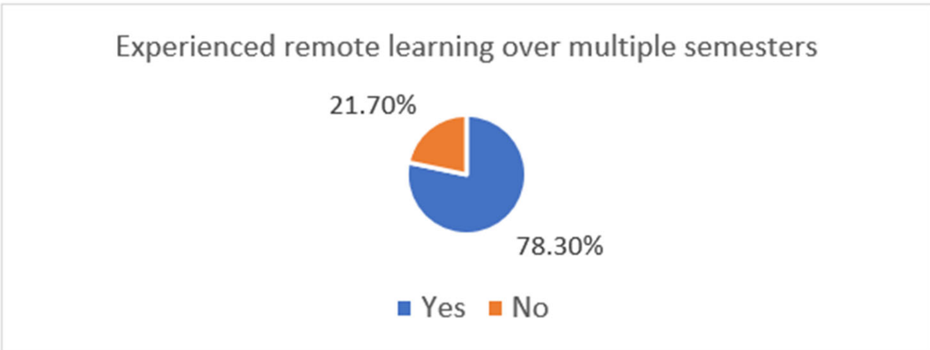


Figure 4. Student Perceived Remote Learning Improvement (Author, 2021)

To understand student opinion around remote learning, respondents were asked to list their perceived preferential attributes and disadvantages of remote learning. Of the 47 responses a commonality was drawn from the 3 most common answers of each.

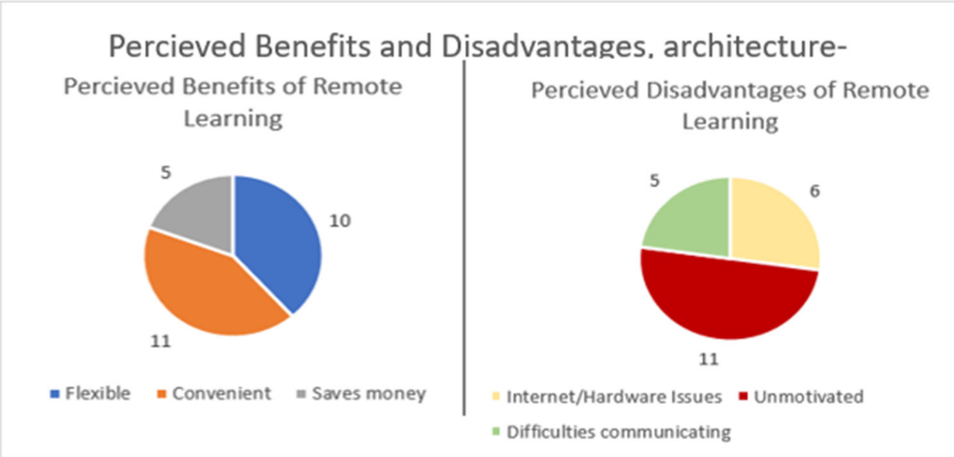


Figure 5. Perceived benefits and disadvantages of remote learning, architecture-based

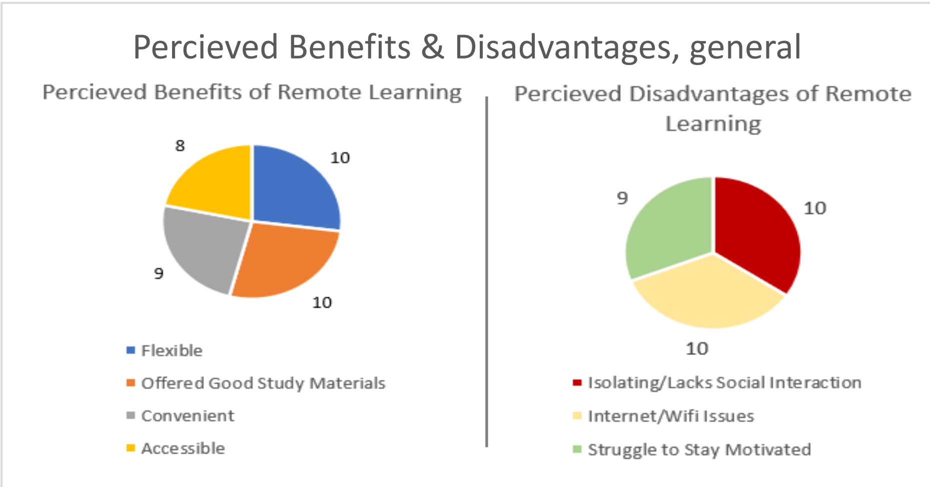


Figure 6. Perceived benefits and disadvantages of remote learning, general

Design studio is a core element for design-based subjects such as architecture. Respondents that utilised design studio were asked of their perceived effectiveness of design studio in a remote environment and more importantly if they believe it to have affected their academic performance.
All questions regarding design studio absence and its effect on academic performance saw over ¾ of the responses establishing a link between the two.
Each question subsequently asked the respondent to explain their rationale, in which another trend was discovered. Students mentioned various grievances, firstly with the refinement of work through seeing other students' output (34.6% of respondents) and

secondly, the feedback they had received felt inadequate in some way (30.7% of respondents).
Respondent X "In comparison to now with in-person studio I think it was affected... I could usually pick up on ideas other people would have that could improve my own work".
Respondent Y "…it has affected my outlook on the course. I value groupwork a lot more than I used to. Bouncing ideas back and forth can help with complex design problems".

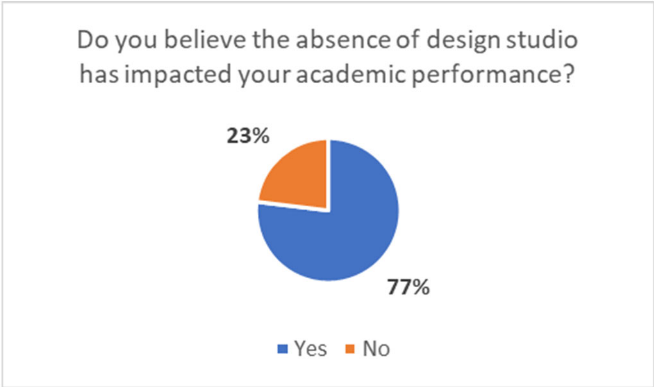


Figure 7. Design Studio Absence Chart (Author, 2021)

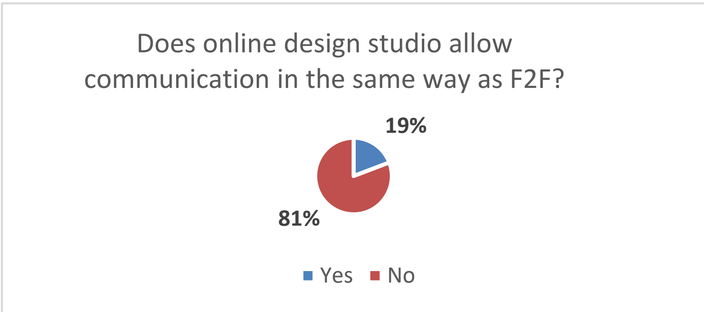


Figure 8. Online Design Studio Communication Chart (Author, 2021

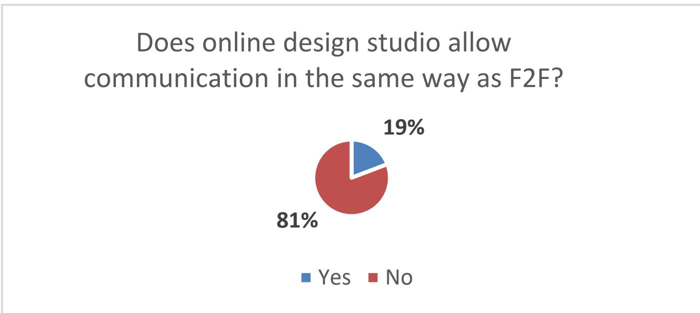


Figure 9. Student & Teacher Interaction Absence Chart (Author, 2021)

Respondent Z “Being present in the design studio you can get more feedback from tutors while in the online learning I only get a 10-minute feedback”.
Considering these are ‘perceived’ responses and not based on grading, it is hard to quantify. Despite this, the majority of respondents hold negative attitudes towards remote learning and deem it unsuitable or poorly adapted to the new online method.

External factors and their impact on students were evaluated to remove any additional challenges that may have been overlooked in generalised studies. Economic and digital poverty were highlighted in relation to the prevalent surge of reports concerning both factors, especially those conducted in a COVID-19 setting, particularly the OfS report (‘Digital poverty’ risks leaving students behind - Office for Students, 2020)

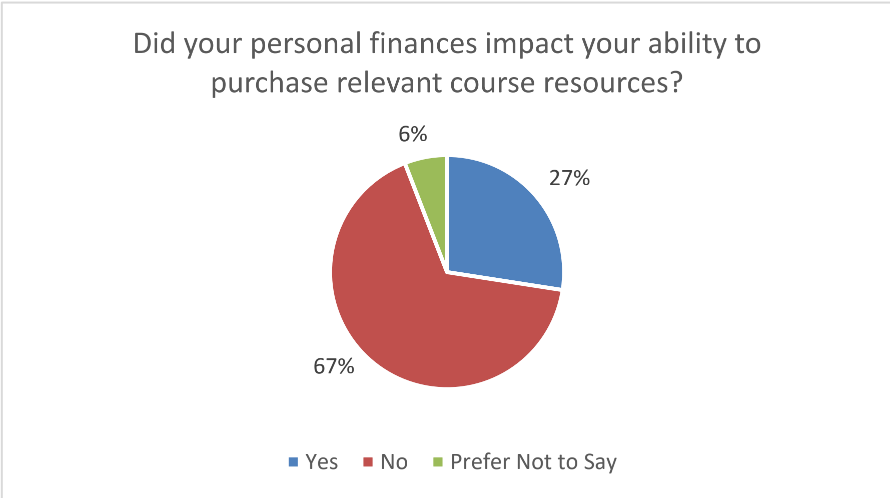


Figure 10. Personal finances impact (Author, 2021)

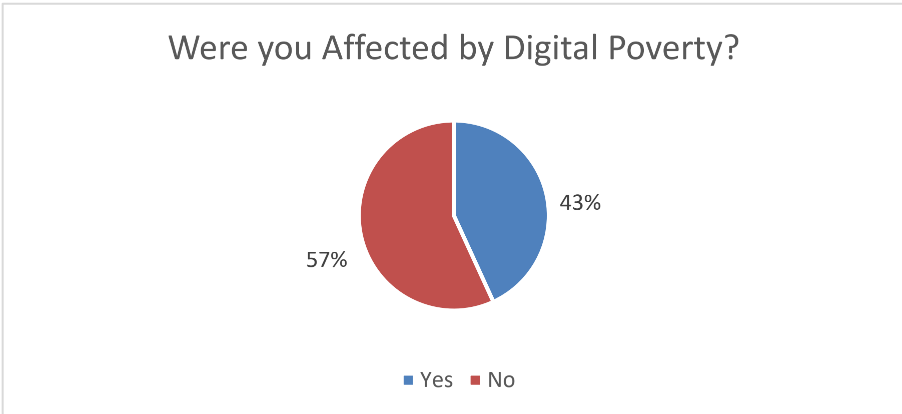


Figure 11. Digital Poverty General Chart (Author, 2021)

Findings from the survey present no significant differences or trends from economic poverty and only a slight increase in digital poverty by the architecture-based group. Within the survey, some of the same students posed digital poverty as a disadvantage of remote learning, however, did not declare digital poverty as an external factor. The reason for this discrepancy is unknown. Evidence suggests these issues transcend from course to course and affect all student stages and disciplines. All evidence considered doesn't dispute economic or digital poverty as challenges but it this case, no external factors had affected the survey respondents.

Lastly, respondents were asked to select their preferred method of learning to summarise overall feelings towards remote learning and traditional face-to-face learning.

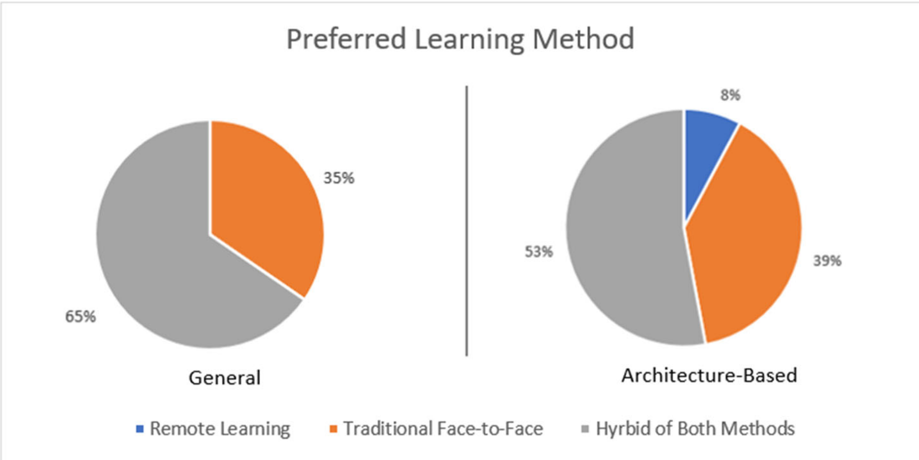


Figure 12. Preferred Learning Method (Author, 2021)

The collected responses confirm how students have responded to remote learning only, with the minority that prefer remote learning belonging to courses not reliant on applied learning such as communications and liberal arts. Many respondents, in both the general and architecture-based groups recognised the advantages of a mixed method approach with traditional face-to-face learning reserved for design studio, labs and tutorials and remote learning reserved for lectures and theory driven lessons. Responses to why they selected a hybrid approach adhere to the trend Wut and Xu (2021) observed in their own survey.

Respondent X: "Both has its positives and negatives. [A] combination of both gives you the social interactions as well alone time and convenience of [working from] your home"

Respondent Y: "I feel a hybrid [method] would be great as it would mean you wouldn't have to go into university every day which would save time and money. A hybrid method would also allow students to learn the skills needed to work from home, which will potentially create more job opportunities particularly to companies that are now advertising roles that are permanently remote"

Traditional face-to-face was still valued by both groups especially respondents from English universities, a link likely based on tuition paying students expecting access to university resources and facilities. Giridharan (2016) and Kaushik's (2016) response to university learning methods side with a hybrid method over purely traditional or remote. Their belief was that technologically rich and an advanced learning environment for students was required and, during 2016, observed a stagnation of the education system with no signs of growth. COVID-19 for better or worse has resuscitated growth and advancements within education and has forced technological integration, a result that will likely outlast the pandemic and become the 'new normal' cited by those studying COVID-19 learning methods.

4.4 KEY FINDINGS & TRENDS

- The majority of architecture-based students hold a negative opinion towards their experience with online design studio and believe it has impacted their academic performance
- Architecture-based students link the absence of in-person interactions and collaboration to their perceived poorer academic performance
- Student opinion valued hybrid learning far more than remote and with architecture course students exclusively preferring traditional face-to-face
- Differing opinions on the effectiveness of remote learning can be attributed to a course depending upon applied learning. This extends beyond architecture-based courses such as computer/digital design that also utilise applied learning
- Presumed external factors seem to pose no prominent challenge to general or architecture-based students

4.5 SUMATION OF SURVEY

The literature review implied heavily that there was no noticeable change nor impact to student grades in a remote learning environment had occurred. However, the lack of the focused studies specifically architecture-based aided by the prevalent communication flaws for remote design studio suggests otherwise. Primary data conveys a majority of architecture-based students viewed remote learning negatively and assumed the remote design studio resulted in their academic performance suffering. This confirms the initial hypothesis that generalised studies overlooked subjects that utilise varied learning methods which may result in sweeping and problematic claims. External factors, in this case economic poverty proved to be mostly absent within the study and digital poverty being far less prominent than the literature review would have suggested. A hypothesis within the literature review that was confirmed by the primary data was the advance to technologically enriched learning with over half of students preferring a hybrid learning method and foresaw the need for some form of remote learning in the future.

Research data suggests that not only architecture-based students have suffered in remote learning, but other disciplines that utilise applied learning have also been impacted. The method of applied learning can be seen in architecture-based, medicine and sport disciplines which poses a worrying neglect to focused studies. Remote learning excels when it concerns theoretical learning as a convenient and flexible option, which offers a multitude of resources to its users. It struggles to accommodate learning situations that are dependent on discussion and review, with stilted and delayed communications resulting in a poorer experience overall. Whilst the performance was not based on grades and thus lacks robustness, the major trends pose opportunities to investigate these disciplines and applied learning as a whole. Architecture and design studio present credible claims to academic performance suffering and may well have been affected.

5. Conclusions

5.1 CONCLUSION

This paper intended to investigate the potential effect remote learning has had on academic performance, specifically architecture-based subjects and those that utilise design studio.

From evaluation of literature and fundamental architecture learning pedagogies, it is apparent that there are pedagogies not suited to a remote teaching method. Comparing the findings and literature reveals communication and collaboration difficulties that hindered the typical learning in a remote setting. There is a clear possibility that remote learning adoption of architectural design pedagogies is incompatible, leading to possibly poorer learning potential, which is highly suggested by survey responses. Respondents aired grievances around their poor refinement of work and overall poorer outcomes than previous years. As such, design studio was identified as an integral part of architectural design and vital to developing student skills for real work scenarios. Additionally, findings acknowledge the importance of design studios, specifically in a traditional face-to-face format. Collaboration, peer review and communication were highlighted as crucial elements in design studio and the foundations of architectural design pedagogy. These learning pedagogies would act as preliminary professional practice scenarios with the design studio replicating real world architectural design.

The remote learning environment saw benefits and hindrances from respondents. The flexibility and convenience were valued highly, however, respondents conceded the lack of social interaction and Wi-Fi/connectivity issues were substantial challenges in their learning. Architecture-based students reflected this sentiment with the addition of communication as a challenge, an expected result for architectural design students, with regard to the fundamental pedagogies highlighted. Architectural design students' overtly negative opinion of remote learning cemented it as an auxiliary and only to be utilised in specific scenarios, a complete opposite of the surveyed theoretical courses in the primary data. Traditional face-to-face is valued highly by architecture-based students with the advantages outweighing remote learnings benefits with face-to-face being crucial for design studio or desk crits. Student perception in a general sense

enjoy remote learning to an extent but prefer the option of traditional face-to-face, a trend that explains hybrid methods being the most desired learning style. Architecture-based responses subverted this claim with those that selected hybrid option expressing that hybrid methods should only be used if design studio was face-to-face.
Generalised studies have overlooked the important nuances to learning in architecture and other applied learning courses. In all academic performance questions, over 75% of architecture-based respondents believe remote design studio to have affected their academic performance. This addresses communication and collaboration challenges in a remote setting. Remote learning has not failed to adapt design studio but is merely inadequate in its current state. It is unable to allow the regular discourse, collaboration, and peer-review traditional face-to-face offers. Future implementation of remote learning should consider the extent to which a course and its modules are taught remotely or face-to-face. A balance of methods adapting the curriculum, particularly in areas where students' express dissatisfaction with remote teaching, would see courses more adequately catering to the needs of students**.**

5.2 LIMITATIONS & FUTURE RECOMMENDATIONS

Evaluating academic performance based solely on students' opinion weakens claims with no valid statistical evidence. With a larger group of students examined and their grades observed and compared, this would present a credible and valid study to examine the issues recognised in this paper. As time progresses from the initial remote learning during lockdown, performing this study again may prove ineffective with the stabilisation of education and the learning methods returning to normal. However, the topic may still hold relevance in future research to improve this emergency learning method as a contingency plan or to aid international learners. Whilst this paper focused upon architecture and built environment students, this format of study may also be used for other applied learning subjects. This research method could collect and review student perception to fill gaps in research of specific courses and expand upon the needs of students in applied learning.

Acknowledgements

This paper is based on the BSc Architectural Technology dissertation "An Investigation into the Effect of the COVID-19 Lockdown on Design Studio learning and Architecture Students' Performances" supervised by Tahar Kouider.

References

ADEDOYIN, O. B. AND SOYKAN, E. (2020) 'Covid-19 pandemic and online learning: the challenges and opportunities', Interactive Learning Environments, 0(0), pp. 1–13. doi: 10.1080/10494820.2020.1813180.

ALLEN, J., ROWAN, L. AND SINGH, P. (2020) Teaching and teacher education in the time of COVID-19. Asia-Pacific Journal of Teacher Education, 48(3), pp.233-236.

ALMENDINGEN, K., MORSETH, M., GJØLSTAD, E., BREVIK, A. AND TØRRIS, C. (2021) Student's experiences with online teaching following COVID-19 lockdown: A mixed methods explorative study. PLOS ONE, 16(8), p.e0250378.

BLUENTCAD. (N.D.) Architectural Design Process and Phases | BluEntCAD. [online] Available at: <https://www.bluentcad.com/cad-resources/architectural-design-process/>

CEYLAN, S. ET AL. (2020) 'An evaluation of online architectural design studios during COVID-19 outbreak', Archnet-IJAR, 15(1), pp. 203–218. doi: 10.1108/ARCH-10-2020-0230.

CRANFIELD, D. ET AL. (2021) 'Higher education students' perceptions of online learning during COVID-19—a comparative study', Education Sciences, 11(8), pp. 1–17. doi: 10.3390/educsci11080403.

DHAWAN, S. (2020) 'Online Learning: A Panacea in the Time of COVID-19 Crisis', Journal of Educational Technology Systems, 49(1), pp. 5–22. doi: 10.1177/0047239520934018.

DINHAM, S. M. (1987) 'Ongoing Qualitative Study of Architecture Studio Teaching: Analyzing Teacher-Student Exchanges', Annual Meeting of the Association for the Study of Higher Education, pp. 21–24.

EL SAID, G. (2021) How Did the COVID-19 Pandemic Affect Higher Education Learning Experience? An Empirical Investigation of Learners' Academic Performance at a University in a Developing Country. Advances in Human-Computer Interaction, [online] 2021, pp.1-10. Available at: https://www.hindawi.com/journals/ahci/2021/6649524/

EMAM, M., TAHA, D. AND ELSAYAD, Z. (2019) Collaborative pedagogy in architectural design studio: A case study in applying collaborative design. Alexandria Engineering Journal, [online] 58(1), pp.163-170. Available at: https://www.sciencedirect.com/science/article/pii/S1110016818301704#:~:text=It%20is%20important%20when%20applying,atmosphere%20of%20achievement%20%5B23%5D.

FRAMBACH, J. M. ET AL. (2014) 'Quiet or questioning? Students' discussion behaviors in student-centered education across cultures', Studies in Higher Education, 39(6), pp. 1001–1021. doi: 10.1080/03075079.2012.754865.

GIRIDHARAN, B. (2016) Emerging Trends in Higher Education Pedagogy. [ebook] WOU Press, pp.23-30. Available at: https://static1.squarespace.com/static/55371ac3e4b08f12059e3112/t/586255f2be6594106ffbef5a/1482839565320/Emerging+Trends+in+Higher+Education++Pedagogy_draft+6.pdf

GIUSTI, L. ET AL. (2021) 'Predictors of academic performance during the covid-19 outbreak: impact of distance education on mental health, social cognition and memory abilities in an Italian university student sample', BMC Psychology, 9(1), pp. 1–17. doi: 10.1186/s40359-021-00649-9.

GOPAL, R., SINGH, V. AND AGGARWAL, A. (2021) 'Impact of online classes on the satisfaction and performance of students during the pandemic period of COVID 19', Education and Information Technologies, 26(6), pp. 6923–6947. doi: 10.1007/s10639-021-10523-1.

GOV.UK (2021) Remote education research. Research and analysis. [online] GOV.uk. Available at: https://www.gov.uk/government/publications/remote-education-research/remote-education-research#contents

IBRAHIM, A., ATTIA, A., BATAINEH, A. AND ALI, H. (2021) Evaluation of the online teaching of architectural design and basic design courses case study: College of Architecture at JUST, Jordan. Ain Shams Engineering Journal, [online]12(2), pp.2345-2353. Available at: https://www.sciencedirect.com/science/article/pii/S2090447920302471

JRF (2007) Experiences of poverty and educational disadvantage. [online] York: Joseph Rowntree Foundation. Available at: https://www.jrf.org.uk/sites/default/files/jrf/migrated/files/2123.pdf

KAUSHIK, M. (2016) Emerging Trends in Higher Education Pedagogy. [ebook] WOU Press, pp.55-71. Available at: https://static1.squarespace.com/static/55371ac3e4b08f12059e3112/t/586255f2be6594106ffbef5a/1482839565320/Emerging+Trends+in+Higher+Education++Pedagogy_draft+6.pdf

KEMP, N. AND GRIEVE, R. (2014) 'Face-to-face or face-to-screen? Undergraduates' opinions and test performance in classroom vs. Online learning', Frontiers in Psychology, 5(NOV), p. 1278. doi: 10.3389/FPSYG.2014.01278/BIBTEX.

LEDERMAN, D. (2020) The Shift to Remote Learning: The Human Element. Inside Higher Ed, [online] Available at: https://www.insidehighered.com/digital-learning/article/2020/03/25/how-shift-remote-learning-might-affect-students-instructors-and

LI, C. S., & BEVERLY, I. (2008) An overview of online education: Attractiveness, benefits, challenges, concerns and recommendations. College Student Journal, 42(2, Part A), 449–458.

LIBGUIDES.HULL.AC.UK. (N.D.) LibGuides: Reflective writing: Schön. [online] Available at: https://libguides.hull.ac.uk/reflectivewriting/schon

LISCHER, S., SAFI, N. AND DICKSON, C. (2021) 'Remote learning and students' mental health during the Covid-19 pandemic: A mixed-method enquiry', Prospects. doi: 10.1007/s11125-020-09530-w.

MILLER, K. (2019) The Benefits of Online Learning: 7 Advantages of Online Degrees. [online] Northeastern University Graduate Programs. Available at: https://www.northeastern.edu/graduate/blog/benefits-of-online-learning/

OFFICEFORSTUDENTS.ORG.UK. (2020) ‘Digital poverty’ risks leaving students behind - Office for Students. [online] Available at: https://www.officeforstudents.org.uk/news-blog-and-events/press-and-media/digital-poverty-risks-leaving-students-behind/

OFFICEFORSTUDENTS.ORG.UK. (2021) The National Student Survey: Student experience during the pandemic - Office for Students. [online] Available at: https://www.officeforstudents.org.uk/publications/the-national-student-survey-student-experience-during-the-pandemic/

ONLINESCHOOLS.ORG. (N.D.) The History of Online Schooling. [online] Available at: https://www.onlineschools.org/visual-academy/the-history-of-online-schooling/

PERSAUD, C. (2021) Pedagogy: What Educators Need to Know [Plus: 40+ Free Strategies to Implement in Your Classroom]. [Blog] Top Hat Blog, Available at: https://tophat.com/blog/pedagogy/

POVERTY AMONG YOUNG PEOPLE IN THE UK. (2015) [ebook] New Policy Institute. Available at: https://www.npi.org.uk/files/7114/2892/2456/Poverty_among_young_people_in_the_UK_FINAL.pdf

RAD, F. A. ET AL. (2021) ‘Rapid transition to distance learning due to COVID-19: Perceptions of postgraduate dental learners and instructors’, PLoS ONE, 16(2 February), pp. 1–22. doi: 10.1371/journal.pone.0246584.

RUSSELL, J., THOMPSON, M. AND JONES, A. (2021) Study Architecture Well. [ebook] London: RIBA, pp.23-31. Available at: https://www.architecture.com/-/media/GatherContent/Business-Benchmarking/Additional-Documents/RIBA-Study-Architecture-Wellpdf.pdf

SOLIMAN, A. M. (2017) ‘Appropriate teaching and learning strategies for the architectural design process in pedagogic design studios’, Frontiers of Architectural Research, 6(2), pp. 204–217. doi: 10.1016/j.foar.2017.03.002.

TORRE ARENAS, I., AHMED, M., LOWTHER, E., STYLIANOU, N., DALE, B. AND DUNFORD, D. (2020) Coronavirus: The world in lockdown in maps and charts. [online] BBC News. Available at: https://www.bbc.co.uk/news/world-52103747

WAITE, R. (2021) ‘Lost, lonely and stressed’: how Covid has hit architecture students. [online] The Architects’ Journal. Available at: https://www.architectsjournal.co.uk/news/lost-lonely-and-stressed-how-covid-has-hit-architecture-students

WATSON, J. (2020) “No significant difference” confirmed by a new study from AIR — Digital Learning Collaborative. [online] Digital Learning Collaborative. Available at: https://www.digitallearningcollab.com/blog/2020/11/5/no-significant-difference-confirmed-by-a-new-study-from-air

WUT, T. MING AND XU, J. (2021) ‘Person-to-person interactions in online classroom settings under the impact of COVID-19: a social presence theory perspective’, Asia Pacific Education Review, 22(3), pp. 371–383. doi: 10.1007/s12564-021-09673-1.

ZALAT, M. M., HAMED, M. S. AND BOLBOL, S. A. (2021) ‘The experiences, challenges, and acceptance of e-learning as a tool for teaching during the COVID-19 pandemic among university medical staff’, PLoS ONE, 16(3 March), pp. 1–12. doi: 10.1371/journal.pone.0248758.

ZELKOWITZ, M. (2011) Advances in computers. 1st ed. Amsterdam: Academic Press, pp.271-313.

DIGITAL CONSTRUCTION AND INFORMATION MANAGEMENT WORKFLOW

Part 1 – Information Management system and BS IN ISO 19650 Framework

WITYK, JAROSLAW; SALEEB, NOHA
Middlesex University, UK
Email address: jw1191@live.mdx.ac.uk
Email address: N.Saleeb@mdx.ac.uk

Abstract. The sudden increase in digitalisation in the construction industry necessitates a rapid transformation of traditional processes; therefore, the development of executable practical guidance is crucial. With the emergence and publication of a large number of Building Information Modelling (BIM) standards over the past few months, a large suite of international guidance documents complementing the ISO 19650 framework was developed to explain concepts and principles for digitisation, classification and organisation of information, and digital processes used in the construction industry. A comparison of these standards and guidance documents reveals repetitive ideas or the introduction of a degree of uncertainty. This paper evaluates the essential components, application, and ambiguity of the new ISO 19650 terminology for the UK BIM Framework.

Keywords: Construction, Digital, workflow, information.

1. Introduction

In recent years, international efforts aided defining Building Information Modelling (BIM) by publishing standards such as ISO 19650 series, and guidance documents for them based on dynamic, collaborative feedback from the industry. The ISO 19650 forms an integral part of the UK BIM framework, which defines business organisational and operational procedures used during the planning, delivery, operations, and decommissioning of built assets, leveraging disruptive technologies to improve social, economic, and environmental outcomes. Ideally, a framework would be built on shared knowledge and have a robust, modular structure built on consistent definable concepts that can be tracked, analysed, and measured.

This paper includes a critical review and relevance of ISO 19650 information management framework in defining project information needs across all business processes and project life cycle stages. It also examines the existing literature on the UK BIM Framework and its changes to comprehend the Framework's essential components and the interdependence of its project structure, with aim to reduce complexity which is hampering digital transformation (Succar and Kassem, 2015). This paper defines the terminology necessary to comprehend Information Requirements (IR) as a prerequisite for further study.

2. Information Management (IM) system

According to Alter (2013) it is a mistake to assume that people know what information they require, and that this information will aid them in making better decisions. Furthermore, Gorla et al. (2010) claim that managers' participation in the design of an information management system helps them evaluate its performance by comparing the output to what was expected. Stance asserted by Smith and Tardif (2009, pp. 173–174) was that Architecture Engineering and Construction (AEC) industry is unable to confirm whether the built assets perform as intended, and can't effectively improve methods, standards, technology, or processes until it transforms itself into learning industry. This viewpoint is based on the management philosophy of a 'learning organisation' which constantly evaluates and re-evaluates its workflow and related business processes to improve and refine them. When one business process is improved, it is likely that other, related business processes will also be improved. Understanding what information is needed, when and how it should be presented is critical to the success of a project's delivery (Senge,2006). Cavka et al. (2017) highlight the inconsistency in terminology and the method in which BIM policies, standards, guidelines, and protocols are used and developed. At the heart of the matter, a clear distinction between these documents is still lacking. Rodriguez-Trejo et al. (2017, p. 437) agree, claiming that the inconsistency stems from a lack of contractual or regulatory detailed requirement, and emphasise importance of analytical approaches to establishing the employer's information requirements to justify decisions that impact cost/operation of a building during early design stages.

2.1. THE BS EN ISO 19650 FRAMEWORK

ISO 19650 is a framework for the organisation, management, and digitization of asset-related information (British Standards Institution, 2018a). The relational concept shown in **Error! Reference source not found.** forms a context for this paper.

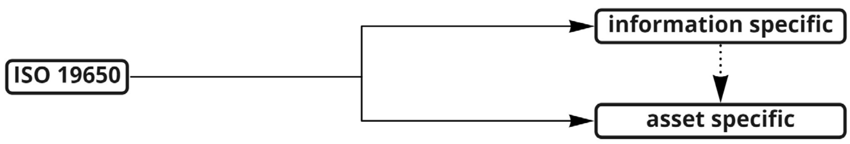


Figure 1. Characteristics of ISO 19650 Framework

The BS EN ISO 19650 sets of standards incorporated into the UK BIM Framework, aim to put international building information modelling (BIM) standards into practice in the UK. The framework incorporates existing British standards, publicly available specifications (PASs), transition guidance, and supplemental information such as Government Soft Landings. This promotes common standards and protocols that allow secure and resilient data sharing across organisations and sectors. In recent years, the AEC industry has relied on British Standard BS1192 and Publicly Available Specification (PAS) 1192 guidance, which has been largely replaced by BS EN ISO

19650 standards. The BS EN ISO 19650 suite is the result of large-scale teamwork, with the contribution of the involved parties depicted in **Error! Reference source not found.**.

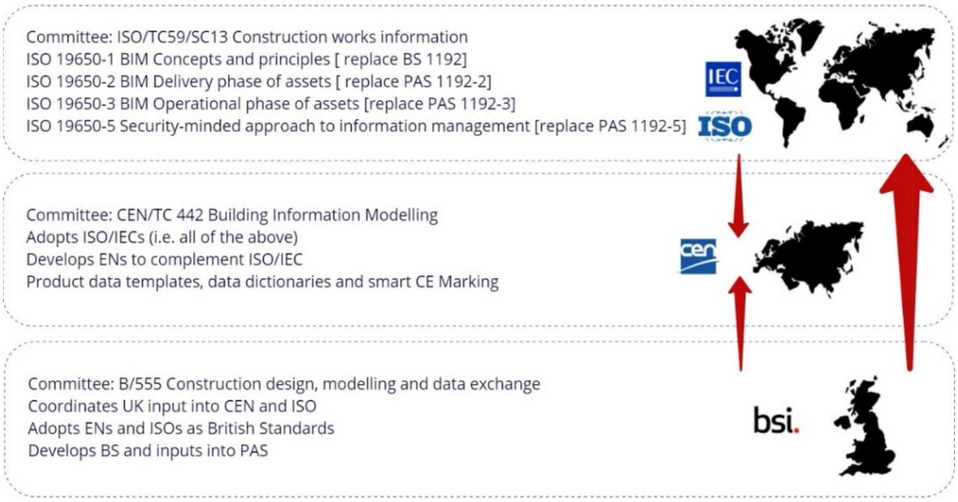


Figure 2. International BIM Standardisation (Kemp, 2020)

To avoid potential translation and meaning discrepancies, the international community decided that the UK and all international versions would remain in English only. Except for the National Annex, the BS EN ISO 19650 and ISO 19650 standards are identical. According to Winfield (2020), the application of the BS EN ISO 19650 Framework supports the 'appointing party' (client/employer) to receive all project-related information at key decision points, at reduced or better controlled project costs, time, and quality. The framework includes a detailed and coherent list of vital activities for allocation among the parties to ensure that parties clearly define the information and deliverables required by the appointing party, as well as the processes and tools that supply chain parties shall use. The ISO 19650 Framework's objective is to create a comprehensive information schema that encompasses all actors involved in the construction process. The schema is relevant in defining all project information needs across all business processes and project life cycle stages, however, according to ISO 29481-1:2016 what is usually delivered may not be what is specified. (British Standard Institution, 2017, p. 5). The observation may imply the need for expectation management or a more advanced information management system capable of anticipating possible outcomes and adjusting the process appropriately.

2.2 THE UK BIM FRAMEWORK'S ESSENTIAL COMPONENTS

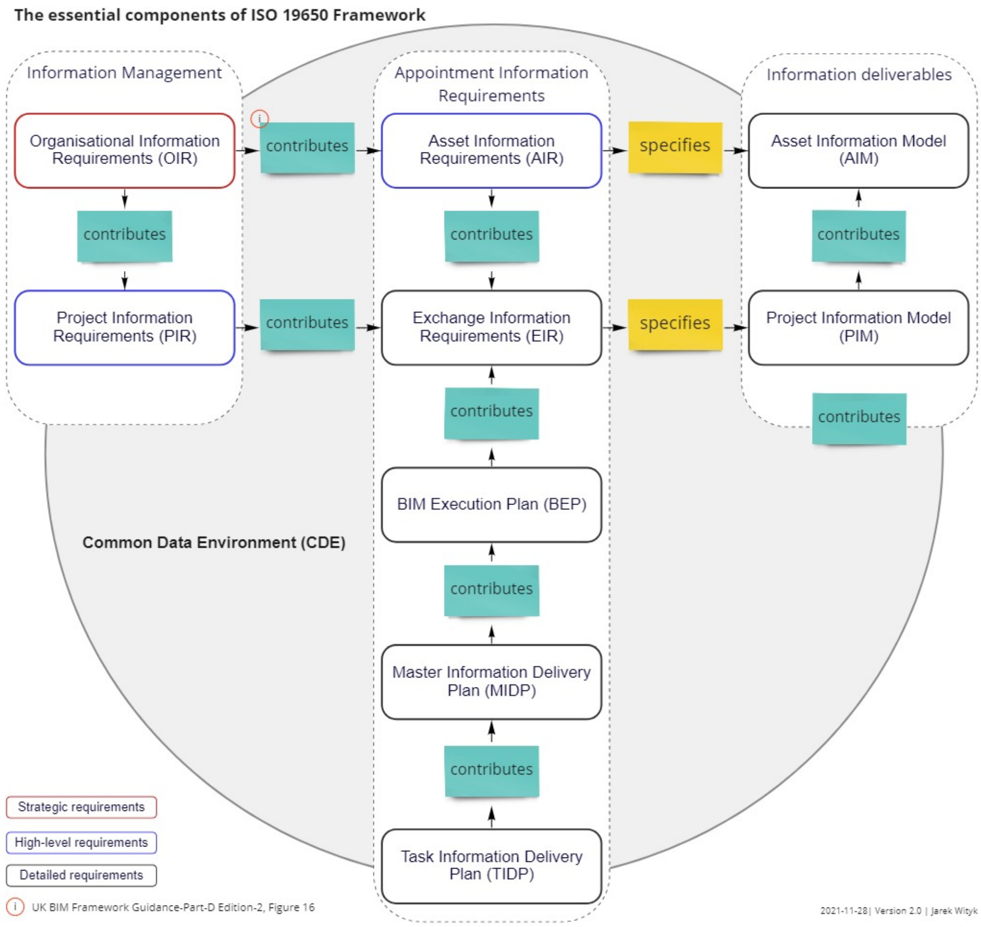


Figure 3. ISO 19650 Framework's essential components (Fec)

According to a report commissioned by the University of Cambridge's Centre for Digital Built Britain (CDBB) and produced by KPMG LLP (2021), the most used terms in academia and industry shown in **Error! Reference source not found.** are the EIR, AIR, OIR, BEP, plus Project Information Model (PIM), a three-dimensional model of a specific discipline or a federated multidisciplinary model, and the Common Data Environment (CDE) a primary driver for information exchange. The EIR, AIR, OIR, BEP, PIM, AIM, CDE, MIDP and TIDP are described as ISO 19650 Framework's essential components (Fec), term coined by the authors. The relationship of Fec is illustrated in **Error! Reference source not found.**.

The legal aspect of information exchange is supported by the UK BIM Framework Information Protocol. (JCT, 2019; NEC, 2020; RIBA, 2020; UK BIM Framework, 2021a, 2021b). As the AEC industry transitions from PAS 1192 to the BS EN 19650 Framework, the term Exchange Information Requirements (EIR) may cause some confusion, as the term introduced on the 16th of January 2019 by the publication of BS EN 19650 Part 1 and Part 2 replaces the PAS 1192 term: Employer's Information Requirements. Since both terms use the same acronym (EIR) the authors clarify the terms and delve into the details of information management workflow. While Employer's Information Requirements and Exchange Information Requirements are synonymous the authors recognise the significant impact on information management (IM). Employer is frequently translated in terms of employing people, which can be misleading on an international level. Thus, a term that would be easier to translate internationally without creating ambiguity was needed. The definitions illustrated in **Error! Reference source not found.**, imply that using the term Exchange instead of Employer in the EIR phrase has an advantage in cases where information is required to be exchanged between different parts of an organization (British Standards Institution, 2019).

Table 1 Definitions: employer, exchange and EIR

Definitions	
employer	the individual or organisation that employs others. (Cambridge English Dictionary, n.d.)
exchange	giving something to someone and receiving something in return. (Cambridge English Dictionary, n.d.)

Figure 4 illustrates the variations in the use of the acronym EIR. For example, on the right-hand side of the diagram, the use of Exchange Information Requirements (EIR) encompasses information exchanged between an asset management team and a direct labour team, or between different parts of a multidisciplinary organisation, even when formal contracts are not established. While both terms can be used, the term Employer Information Requirement is far less appropriate, particularly when applied in accordance with international standards. Thus, to preserve the deeply embedded EIR acronym in the BIM language, the term 'exchange,' seem to be good fit. Furthermore, to ensure that the terms and concepts used in this paper are understood, it is necessary to refer to the superseded PAS 1192 terminology, legal language, and the hierarchical project structure, all of which are combined and illustrated in **Error! Reference source not found.**. Only in the context of a contractual obligation and position within the supply chain do the multiple meanings of terms such as employer or supplier become clear.

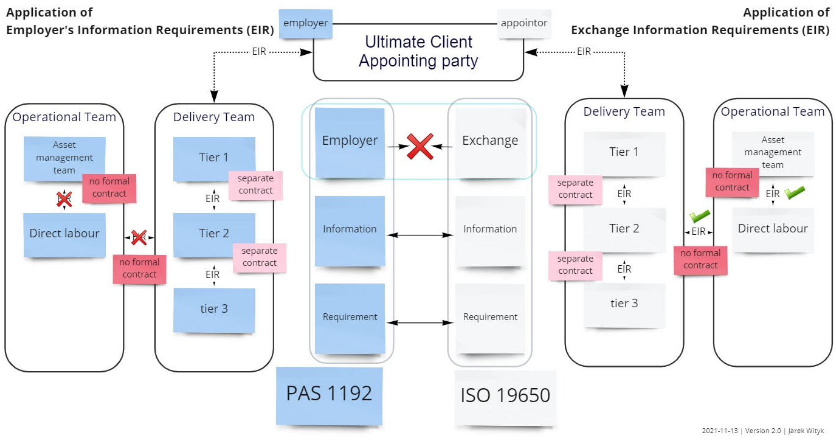


Figure 4. Application of EIR, PAS 1192 vs ISO 19650

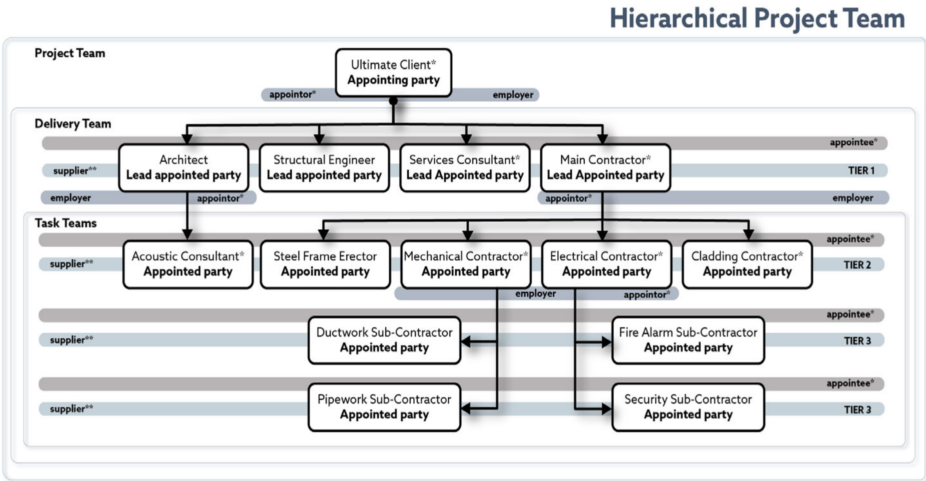


Figure 5. Hierarchical Project Team – author's interpretation

Error! Reference source not found. depicts a typical project team, which includes all parties assigned to work on the project (appointed parties), including the ultimate client – the Appointing Party. According to ISO 19650 framework, throughout the project, each function can be performed by an individual or by a team of people (task teams). As the project progresses, function responsibilities can be transferred. Thus, a project team can be made up of one or more companies or individuals who provide services or products during the delivery or operation of an asset – or it can be made up of everyone involved in the project, regardless of appointment/ contract arrangement. The term "project team" in ISO 19650 does not refer to a specific contract type, it replaces the PAS1192 term 'Project Delivery team'; the intended meaning is the same, although the ISO 19650 Framework places the client (Appointing Party) outside of the Delivery Team. A top-level client (Appointing Party) and a Delivery Team comprise the Project Team.

Error! Reference source not found. illustrates the evolution of all BIM-related guidance, standards, and reports since the publication of BS EN ISO 19650-1. The authors' literature research suggests that all the listed publications are integral to the UK BIM Framework. A Framework which is motivated by the overall need to increase productivity in the construction industry, the skill gap, and the security of coordinated administration of digital information. The development is also being fuelled by the UK government's unwavering commitment to sustainability, as evidenced by long-term goals of net zero emissions by 2050. (Priestley et al., 2019) The BIM-related guidance from **Error! Reference source not found.**, has been grouped into seven categories illustrated **Error! Reference source not found.**.

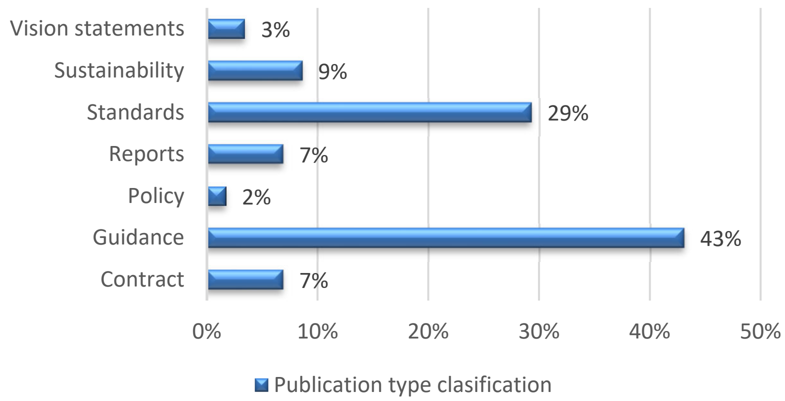


Figure 6. UK BIM Framework makeup

The standards which constitute twenty nine percent of the published material triggered creation of considerable number of guides (43%) followed by sustainability driven reports, statements and policies. Due to the rapid release of standards, policies, and recommendations, academia has not yet examined the UK BIM Framework reference material to determine their impact on the Architecture, Engineering, and Construction (AEC) industry. While the BS EN ISO 19650 set of standards forms the backbone of the UK Government's strategy and is an integral part of the UK BIM Framework, they are not the only documents that should be used as reference material. The UK BIM Framework is inextricably linked to the connected technologies that are transforming the way components, products, and assets are designed, manufactured, used, and maintained. Industry 4.0 and Construction 4.0 are frequently used terms cross-referenced to BIM. The associated technology is critical for advancing the AEC industry's productivity and sustainability; it alters how organisations use and respond to information to accomplish operational goals and continuously improve end-user and project team experiences. (Cotteleer and Sniderman, 2017).

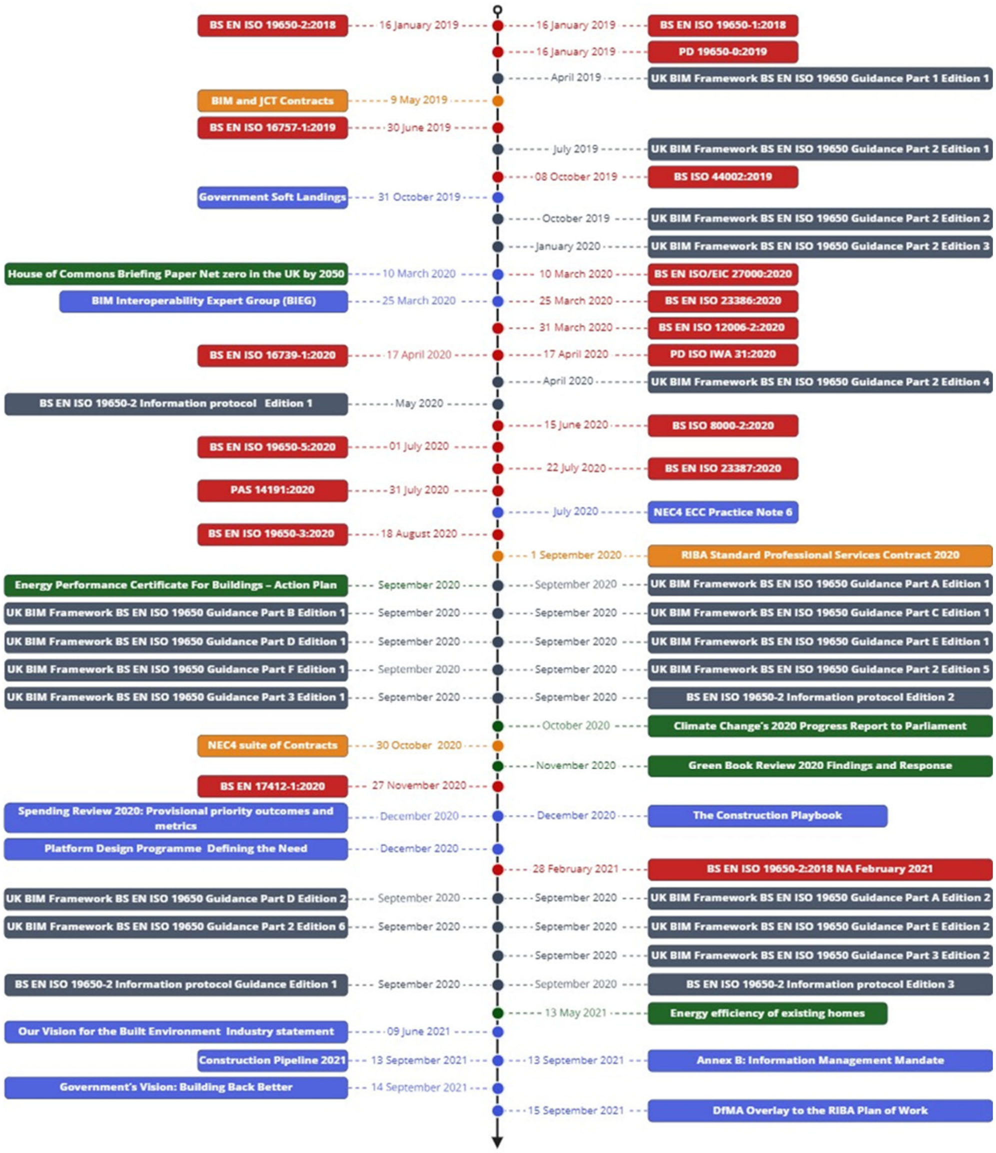


Figure 7. UK BIM Framework roadmap by the authors (detailed infographic)

3. Summary

The paper shows the evolution of BIM guidance, standards, and reports. The authors assessed ten critical ISO 19650 components and coined the term Framework Essential Components (Fec). After evaluating the BS EN ISO 19650 set of standards as well as all available publications on the UK BIM Framework, an associative concatenation has been created between the publications, by the authors, and highlighting of discrepancy between terminology assessed in light of the potential positive and negative consequences. Even though the ISO 19650 framework includes a detailed and coherent list of vital activities for allocation among the parties to ensure that parties clearly define the information and deliverables required by the 'appointing party', according to the evidence, industry participants are unsure of what data should be collected. The literature review suggests a lack of clarity in processes, risk allocation, and understanding between parties. The BS EN ISO 19650 Framework has the potential to improve digital information management but introduces some additional legal uncertainties. Incorporating the BS EN ISO 19650 Framework into binding contractual terms contributes to the standardisation and certainty of legal or contractual rights and duties.

References

Alter, S., 2013. Work system theory: overview of core concepts, extensions, and challenges for the future. Journal of the Association for Information Systems, p.72.

British Standard Institution, 2017. BS EN ISO 29481-1:2017 Building information models – Information delivery manual Part 1 Methodology and format

British Standards Institution, 2016. BS 1192:2007+A2:2016 Collaborative production of architectural, engineering and construction information-Code of practice, A2 ed.

British Standards Institution, 2018a. BS EN ISO 19650-1:2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling Part 1: Concepts and principles.

British Standards Institution, 2018b. BS EN ISO 19650-2:2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling Part 2: Delivery phase of the assets.

British Standards Institution, 2019. Transition guidance to BS EN ISO 19650.

British Standards Institution, 2020a. BS EN ISO 19650-3:2020 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling Part 3: Operational phase of the assets.

British Standards Institution, 2020b. BS EN ISO 19650-5:2020 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling Part 5: Security-minded approach to information management.

Cavka, H.B., Staub-French, S. and Poirier, E.A., 2017. Developing owner information requirements for BIM-enabled project delivery and asset management. Automation in construction, 83, pp.169-183.

Cotteleer, M. and Sniderman, B., 2017. Forces of change: Industry 4.0. Deloitte Insights, 18(1), pp.1-16.

Gorla, N., Somers, T.M. and Wong, B., 2010. Organizational impact of system quality, information quality, and service quality. The Journal of Strategic Information Systems, 19(3), pp.207-228.

Kemp, A., 2020. The BIM Implementation Journey: Lessons Learned for Developing and Disseminating City Information Modelling (CIM). Built Environment, 46(4), pp.528-546.

KPMG LLP, 2021. The value of Information Management in the construction and infrastructure sector.

Priestley, S., Hirst, D. and Bolton, P., 2019. Net zero in the UK. House of Common Library Briefing Paper, Number CBP8590, 16

Rodriguez-Trejo, S., Ahmad, A.M., Hafeez, M.A., Dawood, H., Vukovic, V., Kassem, M., Naji, K.K. and Dawood, N., 2017. Hierarchy based information requirements for sustainable operations of buildings in Qatar. Sustainable cities and society, 32, pp.435-448.

Senge, P.M., 2006. The fifth discipline: The art and practice of the learning organization. Broadway Business.

Smith, D.K. and Tardif, M., 2009. Building information modeling: a strategic implementation guide for architects, engineers, constructors, and real estate asset managers. John Wiley & Sons.

Wetherbe, J.C., 1991. Executive information requirements: getting it right. Mis Quarterly, pp.51-65.

Winfield, M., 2020. Proceedings of the Institution of Civil Engineers - Management, Procurement and Law 173.

DIGITAL CONSTRUCTION AND INFORMATION MANAGEMENT WORKFLOW

Part 2 – Information Requirements

WITYK, JAROSLAW; SALEEB, NOHA
Middlesex University, UK
Email address: jw1191@live.mdx.ac.uk
Email address: N.Saleeb@mdx.ac.uk

Abstract. The construction industry's sudden increase in digitalisation necessitates a rapid transformation of traditional processes; thus, the development of executable practical guidance is critical. With the emergence and publication of a large number of Building Information Modelling (BIM) standards in recent months, a large suite of international guidance documents supplementing the ISO 19650 framework has been developed to explain concepts and principles for digitisation, classification and organisation of information, and digital processes used in the construction industry. A comparison of these standards and guidance documents reveals ideas that are repeated or introduce uncertainty. This paper assesses appointment information needs and process dependencies. Based on the ISO 19650 framework, this paper provides practical guidance for asset owners and all parties involved in the delivery or operation of an asset.

Keywords: Construction, Digital, workflow, information

1. Introduction

Wityk and Saleeb (2021) considered the importance of communication of involved parties and its relation to outcome. Authors were concerned with how shared digital information can be organised in context of information management (IM) in the Architecture Engineering and Construction (AEC) industry and the chain of activities necessary to deliver the product or service.

It was quickly realised that AEC industry can't effectively improve methods, standards, technology, or processes. There is still a fundamental misunderstanding of what information should be gathered to support efficient asset management throughout its life cycle. Lack of clarity in terminology and the method in which BIM policies, standards, guidelines, and protocols are used and developed has led to inconsistencies between different documents. However, it is acknowledged that collaborative working has many advantages, one is leveraging all partners' knowledge, but equal is access to fully defined information requirements, which if missing can cause conflict and relationship breakdown (British Standards Institution, 2019). According to Construction Innovation Hub, the following areas have seen little development of necessary capabilities or require unification of fragmented work: 1) Governance (define the human-computer interface), 2) Value (Digital inclusion entails not excluding those who do not have access to technology or are not adaptable enough to change), 3) System thinking (Incentives for data sharing, addressing risk and liability with data sharing, process to scale solutions (Construction Innovation

Hub, 2021). ISO 19650 is a framework created to address these issues for organising, managing, and digitising asset-related data. Its goal is to create a comprehensive information schema that includes all actors involved in the construction process, clearly defining the information and deliverables that the appointing party requires. This paper analyses both efficiencies and inconsistencies of the ISO 19650 workflows in addressing industry problems.

2. Information Requirements (IR)

Information requirements for the asset's delivery or operational phase include the following: organisational, asset, project and exchange information requirements - OIR + AIR + PIR + EIR. Through sets of EIRs, the Appointing Party shall provide all asset and project information necessary for asset management and project delivery. The information should be incorporated into project-related appointments or instructions and distributed throughout the supply chain. However, Digitalisation generates a large amount of data. Information overload hampers many businesses. Overprocessing of information, and complexity of processes raises waste, costs, and risks.

2.1 IMPORTANCE OF EXCHANGE INFORMATION REQUIREMENTS (EIR)

The goal of EIR is to make information production a lean process by only requesting what is truly required at specified time, and with specific purpose in mind. (EUBIM Task Group, 2017) The EIR includes 3 main areas: Technical (e.g. platforms, levels of data definitions), Management, and Commercial (e.g. deliverables, schedules, purposes). However, appointed experts can only supply the asset and project information if the appointing party has explicitly stated expectations and requirements in advance. The importance of a lean approach is emphasised by BS EN ISO 19650 1:2018, which states that the minimum amount of information necessary to comply with each relevant obligation, including information requested by other appointed parties, should be the level of information required. Anything more than this bare minimum is a waste.(British Standards Institution, 2018a). The lean process of specifying requirements, according to the BS EN ISO 19650 Framework, shall be based on the three principles in **Error! Reference source not found.**, for example, the deliverable purpose (why), shall be relevant to the point of view of the specific project team member perspective. However, one must bear in mind that the purpose does not imply ownership of the deliverables, who performs the work, or how the work is performed. By referencing the BS EN ISO 19650 Part 2 and Part 3 information management processes, **Error! Reference source not found.**, implies the importance of considering when information may be required and provides examples of what are the types of information that may be required. (British Standards Institution, 2018a, p. 9 Table 1)

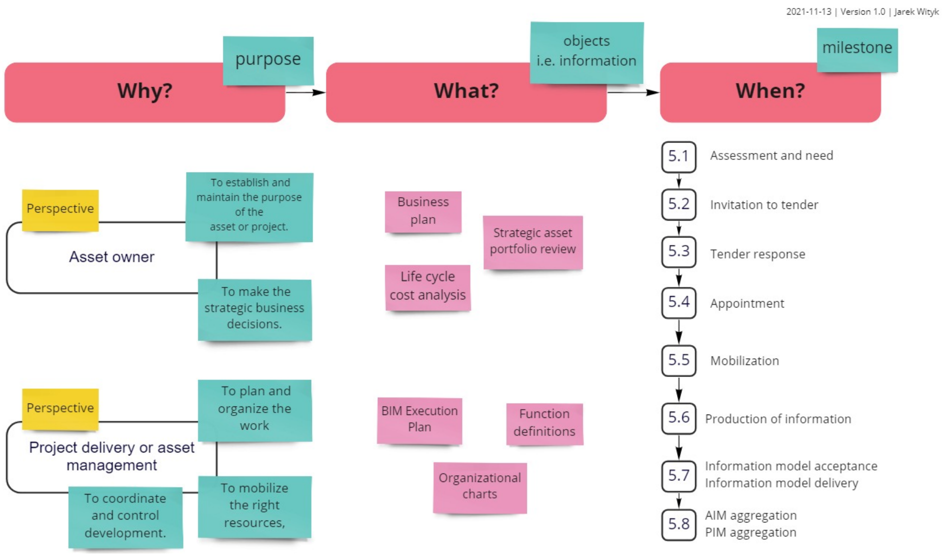


Figure 1. Three principles: Why? What? When? (diagram by authors)

2.2. ISO 19650 AND OTHER BRITISH AND INTERNATIONAL STANDARDS

The ISO 19650 information management process is based on several other standards, albeit it is not immediately clear which ones should be followed, especially in situation where clarification or more information is required. For example, the ISO 29481-1 Information Delivery Manual (IDM) process is not cross referenced in the ISO 19650 Framework except for reference to two terms 'actor' and 'BIM' in BS EN ISO 19650-1:2018. (British Standards Institution, 2018a). Nevertheless, Schooling et al., (2020) considers the ISO 19650 Framework as an excellent foundation for the AEC industry's information management (IM), with its principles based on the BS EN ISO 29481-1 Information Delivery Manual (IDM).

Evaluation of the IDM standard, suggests that it can be used to provide guidance on who and how, with the following points to consider: 1) Who is competent to describe the needs? 2) Who are the actors, what are their roles and perspectives (interests)? 3) How should the information exchange be planned and managed? (Annex A British Standard Institution, 2017). The authors suggest that the guidance contained within the ISO 19650 Framework is complex and not always cross-referenced. For instance, the road map for the UK BIM Framework demonstrates an intricate web of UK and international standards and guidance not always cross-referenced.

According to Smith and Tardif (2009, p74), many of the barriers to electronic information exchange are overstated. Examination of the BS EN ISO 19650 Part 2 and Part 3 information exchange processes reveals inconsistencies and a lack of clarity that may result in misunderstandings. For instance, while ISO 19650 Part 2 requires the establishment of Organisational Information Requirements (OIR) and Asset Information Requirements (AIR), clause 5.2.1 specifies only the need to establish the appointing party's information requirements, considering OIR, AIR and PIR in doing so. However, neither clause 5.2.1 nor other sections of ISO 19650-2 include requirements for determining the appropriate OIR and AIR. The relevant step in information management is illustrated in **Error! Reference source not found.**.

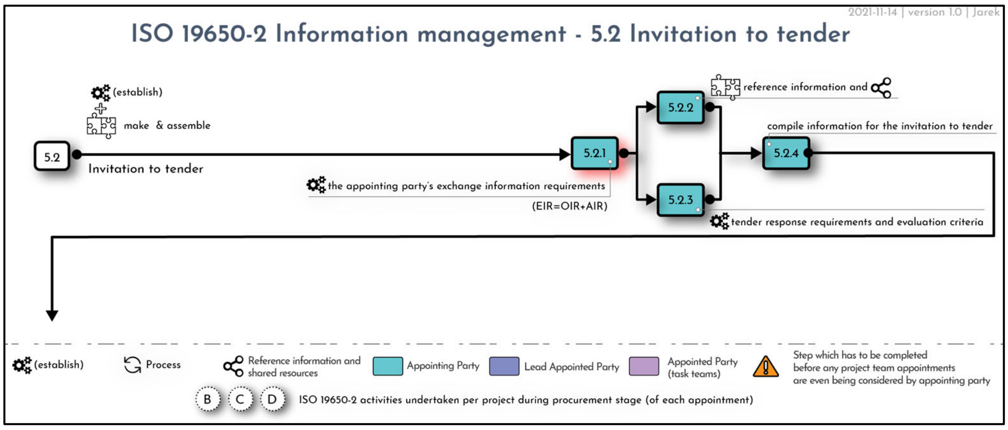


Figure 2. 19650-2, clause 5.2 Invitation to tender (diagram by authors)

In comparison, ISO 19650 Part 3 clearly states in clauses 5.1.2 and 5.1.4, as illustrated in **Error! Reference source not found.**, that OIR and AIR must be established during Assessment and Need stage. Alas, there is a lack of requirement to establish OIR and AIR during the assessment and need stage according to ISO 19650 Part 2 for the asset's delivery phase. The information exchange workflow as a comparison is depicted in **Error! Reference source not found.**. According to David Churcher (2020), UK BIM Alliance Ambassador, the omission to establish OIR & AIR in ISO 19650 Part 2 occurred because of the delay in developing the standard for operational phase of the asset lifecycle, and the belief at the time of ISO 19650-2 publication that the requirement to establish OIR and AIR could be interpreted as an operational phase (Part 3) requirement, and not as a requirement for a delivery phase.

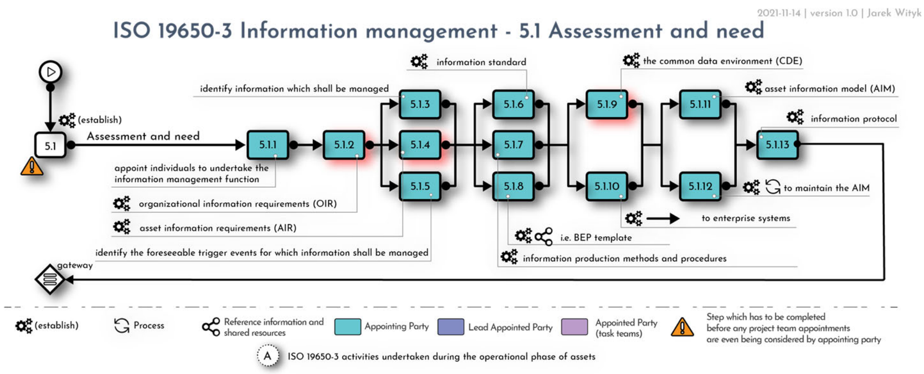


Figure 3. ISO 19650-3, clause 5.1 Assessment and need (diagram by authors)

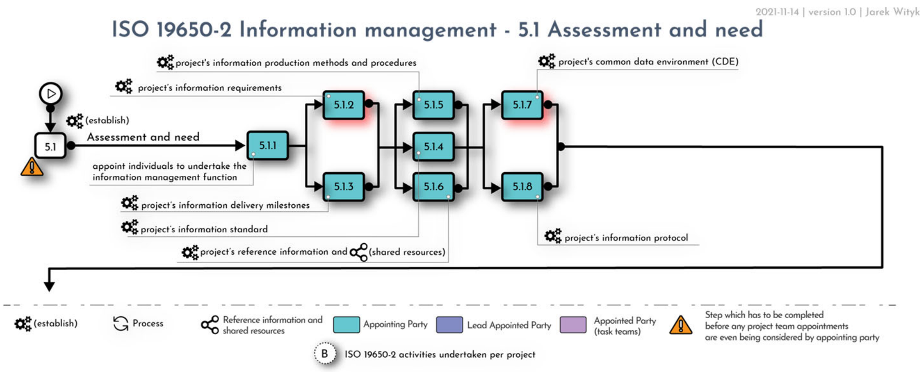


Figure 4. ISO 19650-2, clause 5.1 Assessment and need

The authors hypothesise that the OIR and AIR are equally important during the asset's delivery phase, and that their omission could result in misunderstandings and lead to disputes or litigation. Although some performance requirements may be established at a higher organisational level, for example in Organisational Information Requirements (OIR), the code of practice for asset management BS 8536-2 clause 4.3 suggests that performance outcomes and targets be project-specific, therefore aligned with project specific Exchange Information Requirements (EIR) which shall be developed based on the OIR and the project specific Asset Information Requirement (AIR) and Project Information Requirement (PIR). Consideration should be made that accepting certain qualitative and quantitative standards for information exchange is reasonable, according to Smith and Tardif (2009), if the authoring party is adequately compensated for any additional effort required to meet those standards.
Considering emerging risks that may arise because of insufficient information requirements, for example, rework or overspecification of deliverables, the BS 8536-2 indicates that prospective delivery teams may benefit from adhering to ISO 19650-3 for asset delivery. The agreement should be made at the outset so that information can be collected, updated, and saved efficiently. An incomplete brief will lead to exchange of Project Information Model (PIM) without explicit understanding of its content or expectation. If the parties cannot agree on the model's content at the outset for example because of the unclear AIR, the principle of "no fault" transfer of "found" information should apply, and the receiving party should indemnify and hold the authoring party harmless for any use of the information beyond the original purpose. (Smith and Tardif, 2009, pp. 42–43)

2.3 INFORMATION EXCHANGE PROCESS DEPENDENCY

According to Smith and Tardif, (2009, p. 173) the fundamental problem with AEC construction industry information exchange process is that it is sequential, which signifies that gains in efficiency and productivity in one part of the sequence can be effectively destroyed by constraints that occur before or after, and unsolved problems in one part of the sequence must be addressed in the next. The BIM Framework and delivery models such as Integrated Project Delivery (IPD) share an important feature: they promote processes that can be executed in parallel rather than sequentially, allowing for the optimisation of the entire business process rather than individual, sequential tasks. The workflow is redirected toward the outcome. Individual tasks are graded according to the amount of value they add to the overall product or service. Instead of being viewed as a deliverable, information is viewed as a resource to be leveraged. This is not to say that it is irrelevant when and if information requirements are defined; on the contrary, it is necessary to define requirements that allow for parallel execution of processes.

Specific information requirements must be established at specific stages, according to the BS EN ISO 19650 Framework, through ten essential components of the ISO 19650 Framework: (OIR, AIR, EIR, PIR, BEP, TIDP, MIDP, AIM, PIM, CDE). These components described as crucial within 'The value of Information Management in the construction and infrastructure sector', shall be established at a specific stage of project delivery or operation. The authors hypothesise that if these processes are ignored or poorly executed, the delivery or operational team will not be able to maximise downstream workflow, technology, and appointing party satisfaction. For example, the authors illustrated when the OIR, AIR, PIR and CDE should be established in **Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**. The workflow is based on ISO 19650 Framework utilising the Business Process Modeling Notation (BPMN), and the relevant steps (ISO 19650 clauses) are highlighted red. The BS EN ISO 19650 information management workflow specifies when the remaining essential components must be established, as shown by the steps in **Error! Reference source not found.**, the EIR, BEP, TIDP, and MIDP must be completed at a specific stage of project delivery or operation. Similarly, **Error! Reference source not found.**, and **Error! Reference source not found.**, earlier demonstrated when CDE should be established.

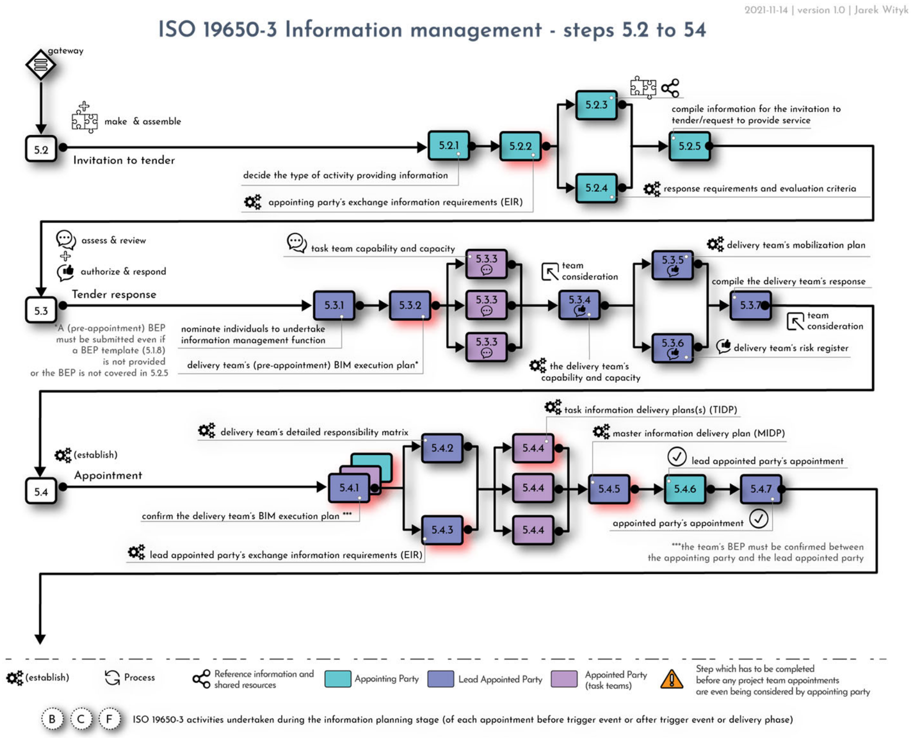


Figure 5. ISO 19650 information management steps 5.2 to 5.4 (by authors)

2.4 THE AIM AND PIM

Last two of the ten essential components of the ISO 19650 Framework are the Asset Information Model (AIM) and Project information Model (PIM). The information exchange process included in ISO 19650-2 considers progression of the PIM to another delivery team, for example the process 'A' indicated in **Error! Reference source not found.**. However, the standard does not include a process for exchanging Asset Information Model (AIM) in a situation where the asset owner already has an AIM and exchanges it with the delivery team for information, further development or updating which does occur in practice.

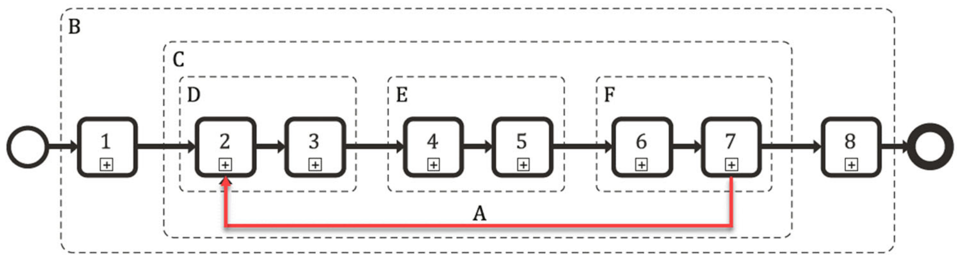


Figure 6. BS EN ISO 19650-2 Information management during the delivery phase of assets (British Standards Institution, 2018b)

Unlike in Part 2, the ISO 19650 Part 3 considers further exchange of the AIM as per **Error! Reference source not found.** but only if the appointing party still has the responsibility for the asset – indicated by decision point Q3, at which point the AIM can be exchanged further to prospective delivery or asset management team.

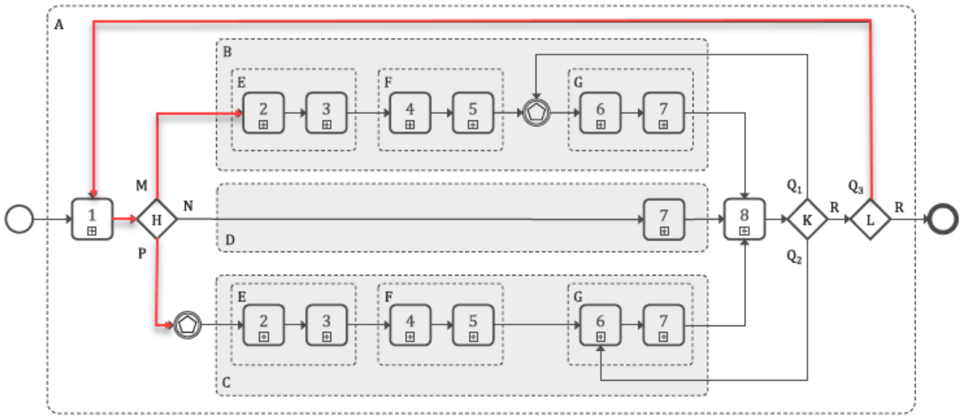


Figure 7. BS EN ISO 19650-3 Information management associated with the operational phase of assets (British Standards Institution, 2020)

2.5 LESSONS LEARNED

The AIM is reviewed, accepted, and aggregated at the closing stages of the information exchange process, as per Figure 2. Compilation of lessons learned and archiving of the AIM are not included in the ISO 19650-3. In contrast, the operational phase workflow of the ISO 19650-2 information exchange does include requirement to compile lessons learned and archive the information model. The ISO 19650-2 Project close-out phase is illustrated in Figure 3.

Logic would imply that the requirement for lessons learned be included in both the delivery and operational phases of the asset lifecycle, particularly when considering the two options presented by The Egan Report - Rethinking Construction: 1) to disregard all prior knowledge in the belief that construction is so unique that no lessons can be learned; 2) to seek improvement through reengineering construction, gaining as much knowledge as possible from those who have done it elsewhere (Egan et al., 1998, p. 18)

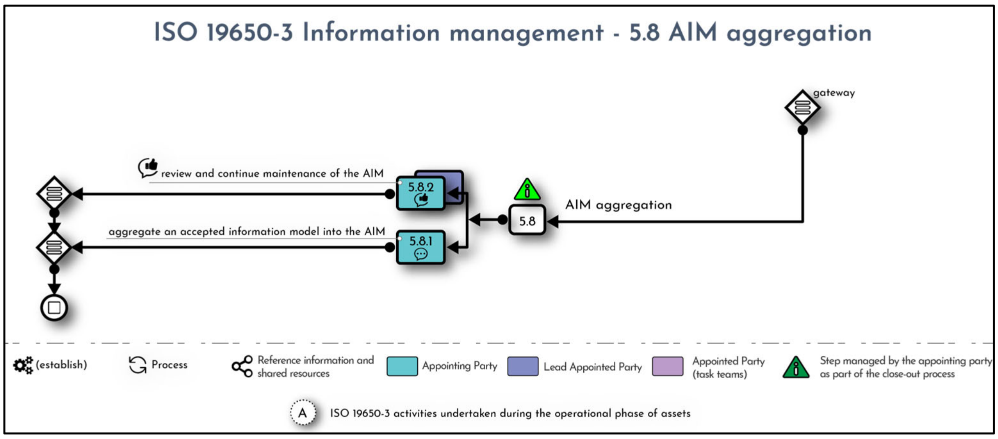


Figure 2. ISO 19650-3, clause 5.8 AIM aggregation (created by authors)

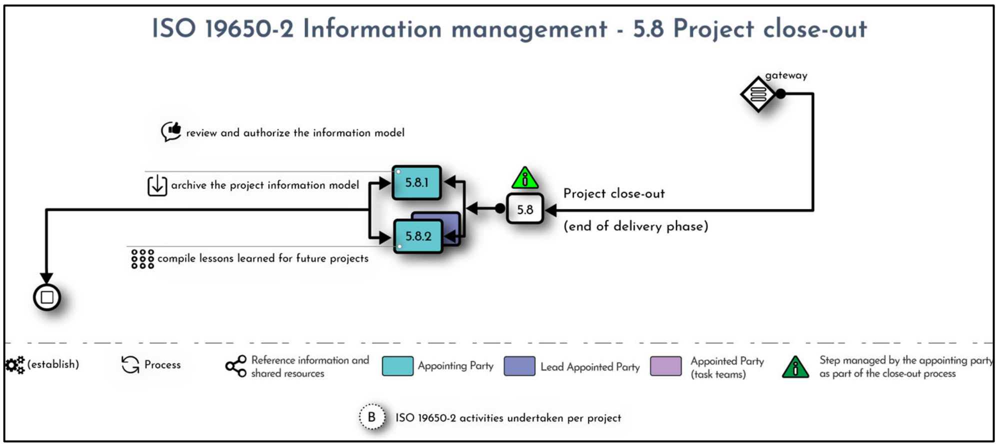


Figure 3. ISO 19650-2, clause 5.8 Project close-out (created by authors)

1. Production of Information

ISO 19650 Parts 2 and 3 contain requirements for information production, the workflow is shown in Figure 4 and in Figure 5. Both standards include a requirement to verify the availability of reference materials, shared resources, and access to the project's shared common data environment (CDE). The process specified requires task teams to assess the potential impact on their Task Information Delivery Plan (TIDP) and notify the lead appointed party, who will then evaluate the resulting causal effect on the Master Information Delivery Plan (MIDP) and thus the project's schedule (program).

Both standards emphasise the importance of not exceeding the required level of information need or duplicating information generated by other task teams. Additionally, the standards place the responsibility for resolving potential coordination issues on the task teams involved, requiring them to work collaboratively to find a solution. The distinction between these two standards is in how they define the process of reviewing and accepting information. Both standards contain clause 5.6.5 (workflow step depicted in Figure 4 and in Figure 5) which specifies the point at which the Lead Appointed Party reviews the information model (IM) received from task teams, with the CDE facilitating information exchange. At this point the Lead Appointed Party reviews the IM and have option to reject or 1) the IM goes back to the Appointed Party who re-submits the IM for review and authorisation by the Lead Appointing Party (ISO 19650-2 Figure 2-18, clause 5.7.1), or 2) authorise the IM for the delivery to the appointing party (ISO 19650-3 Figure 2-19, clause 5.6.6). The step 5.7.1 Figure 4 represents a typical logical fallacy, for example: IM received by the Lead Appointed Party from the Appointed Party will not go back to the originator only to be received again for authorisation. What occurs is what is depicted in step 5.6.6, Figure 5, the information model (IM) remains within the Lead Appointed Party and is authorised for delivery to the Appointing Party if it is not rejected. Another issue is that both workflows are missing the requirement of acceptance of the Task Team's information model (IM) by the Lead Appointed Party, shifting the burden of acceptance to the Appointing Party, Figure 4 and Figure 5 step 5.7.1. The process depicted is not an oversight; it was purposefully designed by the ISO Task Group to compel the Appointing Party to participate in and be accountable for the process, however, might cause a bottleneck in the workflow with complete reliance on the appointing party in all signoffs.

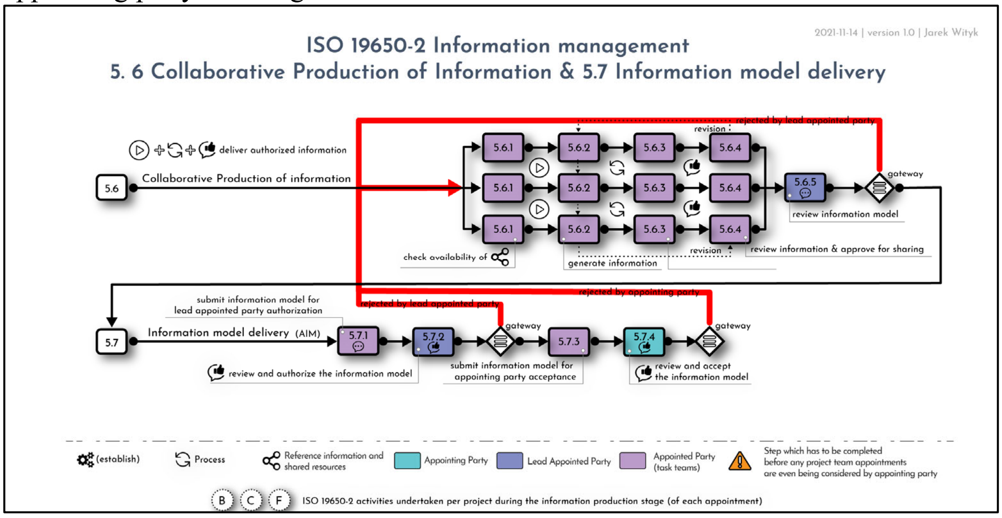


Figure 4. ISO 19650-2 Production of Information and Information model delivery phase (created by authors)

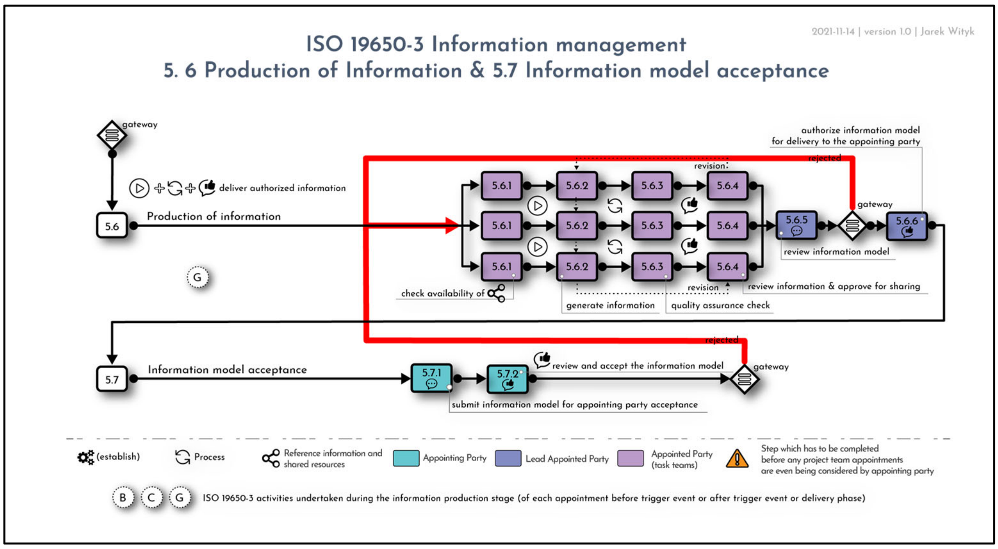


Figure 5 ISO 19650-3 Production of Information and Information model acceptance phase

Authors hypothesise that shifting the responsibility for acceptance away from Lead Appointed Party increases risk downstream of the supply chain.

3. Summary

The paper shows that Exchange Information Requirements (EIR) aims to make information production a lean process by only requesting what is truly required at specified times as emphasised by BS EN ISO 19650 1:2018. The ISO 19650 information management process is based on several other standards, and it is not immediately clear which ones should be followed due to lack of sufficient cross-referencing.

Furthermore, examining the BS EN ISO 19650 Part 2 and Part 3 processes for information exchange reveals inconsistencies that can lead to misunderstandings. A brief that is incomplete may result in the exchange of a Project Information Model (PIM) without a clear understanding of its content or expectations. If parties cannot agree on the model's content at the outset, for instance due to ambiguous Asset Information Requirements, the model will not be used (AIR). Even though the ISO 19650 framework includes a detailed and coherent list of essential activities for allocation among the parties, parties must ensure that they define the information and deliverables required by the "appointing party" in a clear and concise manner. The evidence suggests that industry participants are unaware of the data that should be collected to support efficient asset management throughout assets' life cycle.

References

British Standard Institution, 2017. BS EN ISO 29481-1:2017 Building information models – Information delivery manual Part 1 Methodology and format.

British Standards Institution, 2018a. BS EN ISO 19650-1:2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling Part 1: Concepts and principles.

British Standards Institution, 2018b. BS EN ISO 19650-2:2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling Part 2: Delivery phase of the assets.

British Standards Institution, 2019. BS ISO 44002:2019 Collaborative business relationship management systems-Guidelines on the implementation of ISO 44001.

British Standards Institution, 2020. BS EN ISO 19650-3:2020 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling Part 3: Operational phase of the assets.

Churcher, D., 2020. email to: Jarek Wityk, subject: Guidance Part 3 Feedback.

Egan, J., Raycraft, M., Gibson, I., Moffatt, B., Parker, A., Mayer, A., Mobbs, N., Jones, D., Gye, D., Warburton, D., 1998. The Egan Report - Rethinking Construction. London.

EUBIM Task Group, 2017.

Schooling, J., Enzer, M., Broo, D.G., 2020. Proceedings of the Institution of Civil Engineers - Smart Infrastructure and Construction 173, 166–174.

Smith, D.K., Tardif, Michael., 2009. Building information modeling: a strategic implementation guide for architects, engineers, constructors, and real estate asset managers. Wiley.

Wityk, J., Saleeb, N., 2021. The Digital Innovation Imperative. The Construction Innovation Hub

DIGITAL CONSTRUCTION AND INFORMATION MANAGEMENT WORKFLOW

Part 3 - risks and challenges associated with information management

WITYK, JAROSLAW; SALEEB, NOHA
Middlesex University, UK
Email address: jw1191@live.mdx.ac.uk
Email address: N.Saleeb@mdx.ac.uk

Abstract. The sudden increase in digitisation within the Construction Industry requires a fast transformation of traditional processes; thus, the development of practical guidance ready for the execution is critical. With the emergence and publication of a large number of Building Information Modelling (BIM) standards during the last few months, a large suite of international guidance documents complementing ISO 19650 framework was created to explicate concepts and principles for digitisation, classification and organisation of information, and digital processes used in construction. A comparison of these standards and guidance documents shows lack of intended reinforcement of existing publications. Instead, there is evidence of repetitive concepts or introduction of a level of uncertainty. This study analyses information management-related heuristics, challenges associated with accountability, uncertainty, and expectations, as well as related outcome expectations. Their goal is to eliminate or reduce routine tasks and enable informed decision-making.

Keywords: Construction, Digital, workflow, information.

1. Introduction

Building Information Modelling (BIM) processes brought the glimpse of promise of opportunities to streamline business information management processes and gain greater insight and control. Rapidly, it became apparent that the Architecture Engineering and Construction (AEC) industry cannot effectively enhance its methods, standards, technologies, or processes. There is still a fundamental misunderstanding regarding the information that should be collected to support efficient asset management throughout its life cycle. Guidance is inconsistent due to a lack of clarity in terminology and the method by which BIM policies, standards, guidelines, and protocols are used and developed. In this paper, the authors assess the risks and challenges associated with information management throughout the delivery and operation of assets.

2. Risks to asset delivery or operation

In this section authors evaluate ten challenges or risk factors associated with information management in ISO Standards e.g. ISO19650 as per Figure 1. These are risks that could jeopardise asset delivery or operations.

Figure 1. Risk Factors associated with ISO Standards e.g. ISO19650 for Asset Delivery and Operation (created by Authors)

2.1. AVAILABILITY (FAMILIARITY) HEURISTIC

A heuristic is a simple procedure, or "rule of thumb" used in psychology to form beliefs, judgments, or decisions. The availability heuristic was discovered by psychologists Amos Tversky and Daniel Kahneman; it occurs when the familiar is preferred over novel places, people, or things. The familiarity heuristic is practical, can be useful especially when individuals are under a heavy cognitive load, however in such situations the decision makers may revert to previous feelings or behaviours. (Kahneman, 2012). Literature review suggests that the availability heuristic due to perceived unknown new and unexplained ISO 19650 may lead to cognitive bias. For example, Winfield (2020), reported a preference for the known and familiar ways of working as well as a mistrust of the unknown and unfamiliar as most frequently encountered impediments to BIM adoption the industry, with the resultant concern that this will increase risks. In her journal, Winfield (2020), states that the majority of digital underperforming businesses understand the importance of collecting project data, but they do not yet have the systems in place to take advantage of digitisation, further implying that a lack of clarity in processes, risk allocation, and understanding between parties could indeed undo the benefits and instead increase the risk of dispute. Adoption of BS EN ISO 19650 suite could be delayed due to the availability heuristic factor.

2.2. UNCERTAINTY

According to Weible (2008), the initial phase of new policy or Standards' implementation raises a level of uncertainty. Two types of information relations govern the implementation: one is the exchange of expert knowledge related to the technical aspect, and the other is the political strategy. Both characteristics have the potential to influence policy outcomes, but in different ways. Technical information is knowledge about a specific problem that helps to improve substantive knowledge about the issue at hand. It is most often generated by scientists, but it can also be generated by consultants, policy analysts, and government specialists. Fischer et al., (2017), assert that four major drivers are expected to improve information exchange in uncertain times. The first three factors influence political information exchange, while the fourth should influence technical information exchange.

(1) **Similarity of beliefs** - Actors who share similar views on a policy are more likely to share information.
(2) **Resource reliance** - Stakeholders with significant public support or technical expertise can exchange resources with policy-making actors to gain influence.
(3) **Existing collaboration** - Participants can form a collaboration with anyone they want. As a result, actors may choose to focus on other actors with whom they already have contact.
(4) **Science and expertise** - Interactions between scientists and policymakers promote policy learning, awareness, and knowledge improvement.

The authors infer, based on Kahneman's (2012) example of 'unexplained unavailability' heuristic, that cognitive bias and resistance to adopting ISO 19650 workflow, in fact and any change, can be reduced through technical and political expectation management and inducing an awareness of the impact of new ways of working on organisational performance at the early implementation stage.

2.3 RELIABILITY

One example of reliability of information which may impact trust, is the lack of existence of original information of each data set in an information exchange ensuring that the data was compiled and verified with care for anyone who needs it. Fearing future liability, some design professionals will strip Project Information Model (PIM) of any identifying information before transferring it to a third party, effectively rendering it worthless. Building information must be attributed clearly and completely for users to assess its reliability (Smith and Tardif, 2009, p. 136), which is a crucial issue to be handled within standards e.g. ISO19650 information management processes.

2.4 INTEROPERABILITY

The report of the BIM Interoperability Expert Group (BIEG), (2020), led in partnership by the Infrastructure and Projects Authority (IPA) and the Department for Business, Energy & Industrial Strategy (BEIS) and delivered by the Centre for Digital Built Britain (CDBB), demonstrated that interoperability is critical to building on the success of BIM implementation and delivering 'whole-life' beneficial outcomes to all parties (Yandle, 2022). According to (Smith and Tardif, 2009, p. 149) the interoperability is the only challenge whose resolution is primarily in the hands of software developers. The goal of BIM is to compile comprehensive, reliable, accessible, and easily exchangeable asset information for anyone who needs it, the solution is to broaden our understanding of BIM to include not only information but also the business processes involved. Individuals must be able to communicate with one another and exchange specific information to accomplish specific objectives. This is an unalterable reality.

Smith and Tardif (2009) argue that the most effective technologies do not attempt to replace communication or workflow. Their goal is to eliminate or reduce routine tasks while increasing high-value tasks - technology is augmenting and leveraging rather than replacing the expertise of building industry professionals. AEC professionals must abandon the single asset model mindset, claiming that no one ever requires all asset's information at once and that BIM technology must be aligned to promote routine data collection and preservation. Workflow (A) in Figure illustrates a traditional uncoordinated information exchange process in which each project participant communicates with the relevant project party. A more mature concept, workflow (B) depicts use of technology, for example a common data environment (CDE), with established information exchange standards. Rather than encapsulating all data in a single building model, the concept is to exchange multiple data formats via a single exchange gateway. As illustrated in the diagram, each project member utilizes the tool that is best suited to their task (software agnostic), while sharing information reliably with the rest of the project team via a common information exchange protocol. The exchange protocol and platform to exchange information, e.g. CDE, is fundamental to quality assurance, standardisation, and resource waste management to directly benefit the project, organisation and indirectly, the environment. Inclusion of specific interoperability workflows within CDEs in ISO19650 standards would address this problem.

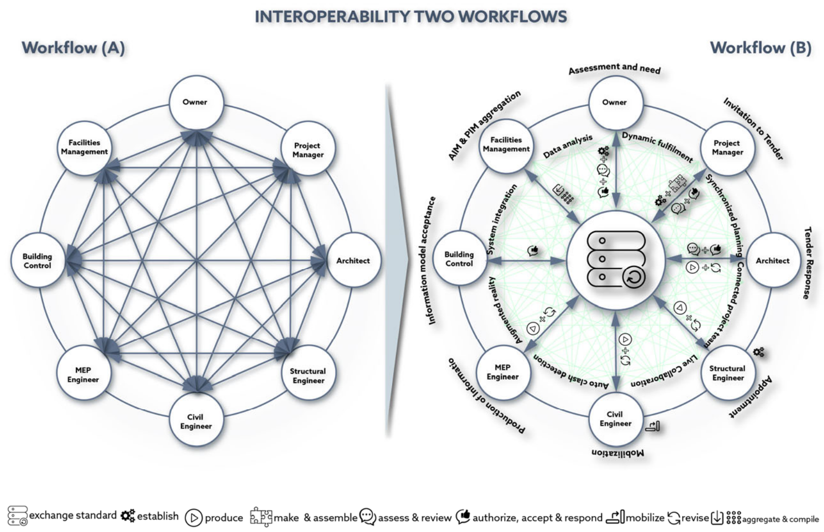


Figure 2. Interoperability 'two workflows' (Smith and Tardif, 2009)

Because the industry does not adhere to a standard format for construction documentation, prospective appointees compensate for the uncertainty by making assumptions or including contingencies in their bid prices. The AEC construction industry's core problems, according to Smith and Tardif (2009), are linked with standardisation of information formats and exchange processes. Regrettably, as technology advances and storage become more affordable, the digitalisation generates an unprecedented amount of data. Organisations and projects are frequently inundated with information, significantly increasing waste, costs, and risks. (EUBIM Task Group, 2017, p. 62). Winfield (2020) argues that standardising processes, testing, and risk management, both within the business and across industries, as well as assigning responsibility for outcomes and errors, is one of the most difficult and critical steps in implementing new digitised processes and technologies on a large scale. The current situation can be described as tension between hope and ambiguity. While organisations conceptually understand the significant changes that information technology and social media may bring, they have divergent agendas and mutually incompatible priorities, as well as a lack of clarity about how their organisations will benefit. (Winfield, 2020). When a corporate enterprise / software company / industry association asserts proprietary control over intellectual property rather than stewardship of information exchange, the entire industry suffers, including the organisation that sought to protect its turf in the first place. (Smith and Tardif, 2009, p. 8)

2.5. PURPOSE, COMPLEXITY AND ADOPTION

Significant issues arise during information exchange because of the project information model's (PIM) multiple uses. If two or more parties are responsible for different aspects of the same asset, they may have legitimate reasons to make incompatible decisions. For example, a structural engineer's layout outcome may be different than those proposed by a layout architect or service engineer for aesthetic, functional, energy-efficiency, or compliance reasons. These are perplexing situations that can only be resolved collaboratively by professional judgement. There is no information management or analysis system that can automate these types of concessions. Constantly, qualitative trade-offs must be made against cost considerations, with the decision frequently being based on cost. The most effective use of technology and information management (IM) processes is to enable informed decision-making at the right time. (Smith and Tardif, 2009, p. 174). According to Hastie (2019), a cost-based approach based on hours worked does not incentivise smarter work because it results in fewer billable hours and lower revenues. Contracts based on client value must be implemented instead.

The authors observed relationship between the discussed purpose and complexity of the task at hand. Examination of the BS EN ISO 19650 Part 2 and Part 3 information exchange processes reveals inconsistencies and a lack of clarity that may result in misunderstandings of purpose due to complexity of instruction. For instance, while ISO 19650 Part 2 requires the establishment of Organisational Information

Requirements (OIR) and Asset Information Requirements (AIR), clause 5.2.1 specifies only the need to establish the appointing party's information requirements, considering OIR, AIR and PIR in doing so. However, neither clause 5.2.1 nor other sections of ISO 19650-2 include requirements for determining the appropriate OIR and AIR. Because the construction industry is so diverse, some areas, e.g. design, have advanced more quickly than others, such as installation and assembly.

2.6 LEGAL AND LIMITATIONS

While BS EN ISO 19650 Framework makes it easier to manage digital information, it is not a magic bullet. The framework does introduce some additional legal uncertainties, which must be resolved or clarified using appropriate contractual terms. One such clause would require parties to adhere to a standard such as 'BIM in accordance with the ISO 19650 series,' although there is typically no clear definition of the requirements or a list of criteria that would satisfy them. Status codes are another potential issue. The term "non-contractual" is not used in the normal legal context. No contractual deliverables are intended, and their limited use is indicated by their status codes. For example, information for coordination, information, review, and comment. A shared information container becomes contractual deliverable only when it is published. (Winfield, 2020, pp. 4–5)

According to Turk's (2020) research, who cites Vilutiene et al. (2019), keywords such as 'organization' or 'legal' do not appear within organisational and legal aspects of Building Information Modelling (BIM). The ISO 19650 Framework does consider although indirectly the legal and security aspect of information exchange. Clause 4.6.1 of ISO 19650-5, for example, requires organisations to establish a suitable mechanism for periodically reviewing sensitivity of legal factors. Also, clause 5.1.11 of ISO 19650-3 includes need for consideration of legal requirements relating to storage of information (and particularly personal information). Authors observed that since establishing of the asset information model forms part of Appointing Party responsibility there is relational connection between the Asset Information Requirement (AIR) and Organisational Information Requirements (OIR) (British Standards Institution, 2020). The finding is aligned with Turk's (2020), view that the framework's guidance is more concerned with how organisations collaborate, than with how shared digital information will be organised, legally protected, and cyber-secured. (Turk, 2020, p. 1 – 5)

According to (Sun et al., 2017) the five major factors limiting BIM application are (listed in significance order) management, technology, personnel, cost, and legal. The lack of professionals, data interoperability, and changes in workflow are the major barriers to BIM expansion. The ISO 19650 Framework imposes compilation of the exchange information requirements (EIR) during the invitation to tender phase of a project, since successful procurement depends on EIR and considering the ISO 19650 Framework's lean approach, for example automation of repetitive tasks. It is preferred that the current human-readable documentation be made machine-readable, allowing validation of the EIR against the Asset Information Requirements (AIR) or automatic verification of deliverables within the Common data Environment (CDE) during project delivery.

2.7. COMMERCIAL RISKS

Even though BIM technologies can be used to facilitate collaboration, Dossick and Neff (2010), concluded that individual contractual obligations (scope) supplant common project goals. Furthermore, they claim that, while without strong leadership, the collaboration process can be reduced to simple information exchange rather than meaningful problem solving and optimisation, but leadership is all too often relied on as a substitute for closer communication connections among trades. When realistic expectations and a team spirit are established, technology adoption will be more successful. To assess the risks of information exchange, the activities must be defined, thus the ISO 19650 Framework specifies all information exchange activities required during asset delivery and operation. To manage information exchange effectively, the scope of the information management process must be understood, the purposes considered, and aligned with the organisation's objectives. Failure to do so would incur large project losses, hence the need for clarity and no discrepancies between standards e.g. ISO19650 part 2 and 3. The key elements to be considered: 1) objectives and decisions to be made, 2) expected outcomes from processes, 3) time, location, specific inclusions, and exclusions, 4) appropriate risk assessment tools and techniques.

2.8. TREND AND CULTURE CHANGE

Barnes (2019) asserts that a defined strategy is essential to successful BIM implementation. The BIM Strategy is vital because only when an organisation knows what it wants to achieve can it begin to imagine what a successful BIM outcome would look like and what will be required to make it happen. The Strategy must reflect the organisation’s individual ambitions and requirements for BIM for the project in question. (Barnes, 2019) An analogy used by Smith and Tardif (2009) compares biological ecosystems to information exchange processes where many organisms have little or no understanding of how their actions affect other organisms or how the ecosystem works. Ecosystems can be incredibly complex, efficient, and even smart. The environment shapes biological behaviour, and one organism's ‘work product’ becomes another's ‘found resource’, which is the case of cascading relationships in the construction industry. According to Smith and Tardif (2009), it is possible to cultivate an information stewardship business environment without disrupting existing business processes, operations, or relationships. It can provide purely internal benefits and can begin before a company implements BIM technology. Everything boils down to culture change to internal effective information management which is required before successful information modelling can take place. As Architecture Engineering and Construction (AEC) professionals gain a better understanding of the value of building information created throughout asset life cycle and business operations, more will be able and willing to engage in value-added information exchange.

The current defensive reaction to errors or problems is to identify the responsible party and assign blame. Not altruism, but economics will drive change. Getting the job done well and quickly will take precedence over blaming and collecting damages.

Transparency is enhanced by a culture of information governance and frequent information exchange. This way, everyone knows who is responsible for what, who is meeting their obligations, and where and why bottlenecks occur. (Smith and Tardif, 2009, pp. 34–37) Winfield (2020) supports Smith and Tardif's position on information governance, stating that incorporating the BS EN ISO 19650 Framework into binding contractual terms helps standardise and create certainty in legal or contractual rights and duties, as well as process clarity in the management of digital data, such as how and when acceptance or rejection of information and/or deliverables should take place under BS EN ISO 19650. Failure to comprehend interdependencies of the information management ecosystem described in the BS EN ISO 19650 Framework due to discrepancies between its different parts would cause project losses, e.g. Compilation of lessons learned and archiving of the AIM are not included in the ISO 19650-3. In contrast, the operational phase workflow of the ISO 19650-2 information exchange does include requirement to compile lessons learned and archive the information model.

2.9 ACCOUNTABILITY AND BETTER DECISION OUTCOMES

According to Ford (2021), the publication of the Information Management Protocol addresses the accountability issue raised by the BS EN ISO 19650 Framework, with the hope of ensuring that information requirements are adequately and competently specified at the appropriate time, and that a procedure for receiving, checking, storing, using, and managing information is established. The original UK BIM Mandate (Cabinet Office, 2011) did not hold anyone accountable for the success or failure of the project. (Ford, 2021). Nonetheless, the absence of a requirement for the Lead Appointed Party to share accountability for the information exchange's acceptance may increase potential risk downstream in the supply chain.

Effective information management necessitates that the right people have the right information at the right time and for the right purpose to make better decisions. The most critical steps in the project lifecycle are the establishment of the Appointing Party's requirements and the inclusion of these requirements in the EIR before any appointment is made. Based on an analysis of 303 tenders, John Ford concluded that most projects lack sufficient and project-specific Exchange Information Requirements (EIR), and in rare occasions where the EIR’s are adequate, the requested information is not used for Facility Management (FM) purposes. (Ford, 2020)

2.10 INFORMATION MATURITY AND QUALITY

According to the author's research, the Architecture Engineering and Construction (AEC) industry is currently at the stage of refining individual tools and processes in terms of overall business process maturity. As asserted by (Smith and Tardif, 2009, p. 154) once the AEC industry integrate these tools into an overall business process, we will be able to manage the transformation of an asset's entire life cycle. Although, the AEC industry has access to technology and infrastructure for business process, before relevant facility management information can be consistently and effectively communicated to facility managers, the record of asset information during design and construction, and the accompanying electronic information exchange protocols, must be mature enough (Smith and Tardif, 2009, p. 15). For instance, ISO19650 part 2 alludes to that the CDE solution and workflow can allow configuration that restricts access to information containers that have not reached a sufficient level of maturity. However, details of levels of information maturity for exchange eligibility are not clarified.

3. Summary

The authors evaluated the objectives and activities associated with information management, as well as adoption barriers such as cognitive biases. The authors discussed the significance of a lean approach, as emphasised by ISO 19650, along with the complexity of information exchange and 10 potential risk factors that could arise upon usage of the BS EN ISO 19650 Framework of standards. The inconsistency of the guidance has been evaluated in light of potential positive and negative outcomes. Concerns have been identified regarding accountability, the absence of a requirement for the Lead Appointed Party to accept information, and the absence of lessons learned within the information exchange requirement during the operational phase of the project. Threats such as a lack of clarity in processes, risk allocation, and miscommunication between project parties have been discussed, along with four expected drivers for enhancing information exchange. The literature review suggests that ISO 19650 may lead to a preference for known and familiar methods of work and a mistrust of the unfamiliar and unknown. A lack of clarity in processes, risk allocation, and mutual understanding between parties could negate the benefits of digitisation and increase the likelihood of litigation. Actors with similar views on a policy are more likely to share information with one another. The exchange of resources between stakeholders with significant public support and policy-making actors is possible. The interactions between scientists and policymakers increase policy learning, awareness, and knowledge. Until the AEC industry transforms into a "learning industry," it cannot confirm whether or not the constructed assets function as intended. Collaboration has many advantages, but it is essential to have access to fully defined information requirements to avoid conflict and relationship breakdown.

References

Barnes, P., 2019. Managing BIM, in: BIM in Principle and in Practice. ICE Publishing.

BIM Interoperability Expert Group (BIEG), 2020. BIM Interoperability Expert Group (BIEG) Report.

British Standards Institution, 2020. BS EN ISO 19650-3:2020 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling Part 3: Operational phase of the assets.

Cabinet Office, 2011. Government Construction Strategy.

Dossick, C.S. and Neff, G., 2010. Organizational divisions in BIM-enabled commercial construction. Journal of construction engineering and management, 136(4), pp.459-467.

EUBIM Task Group, 2017.

Fischer, M., Ingold, K. and Ivanova, S., 2017. Information exchange under uncertainty: The case of unconventional gas development in the United Kingdom. Land Use Policy, 67, pp.200-211.

Ford, J., 2020. Why it's time for a BIM reboot [WWW Document]. BIM+. URL https://www.bimplus.co.uk/why-its-time-bim-reboot/ (accessed 9.18.22).

Ford, J., 2021. Why we need the new BIM mandate - BIM+ [WWW Document]. BIM+. URL https://www.bimplus.co.uk/why-we-need-the-new-bim-mandate/ (accessed 9.18.22).

Hastie, A., 2019. Is construction ready for industry 4.0. The Civil Engineer Blog, 7.

Yandle, N., 2022, February. How the UK government plans to transform infrastructure performance this decade. In Proceedings of the Institution of Civil Engineers-Civil Engineering (Vol. 175, No. 1, pp. 10-10). Thomas Telford Ltd.

Kahneman, D., 2012. Ons feilbare denken: thinking, fast and slow. Business Contact.

Li, J., Kassem, M., Ciribini, A.L.C. and Bolpagni, M., 2019. A proposed approach integrating DLT, BIM, IOT and smart contracts: Demonstration using a simulated installation task. In International Conference on Smart Infrastructure and Construction 2019 (ICSIC) Driving data-informed decision-making (pp. 275-282). ICE Publishing.

McFarlane, D. and Cuthbert, R., 2012. Modelling information requirements in complex engineering services. Computers in Industry, 63(4), pp.349-360.

Smith, D.K. and Tardif, M., 2009. Building information modeling: a strategic implementation guide for architects, engineers, constructors, and real estate asset managers. John Wiley & Sons.

Sun, C., Jiang, S., Skibniewski, M.J., Man, Q. and Shen, L., 2017. A literature review of the factors limiting the application of BIM in the construction industry. Technological and Economic Development of Economy, 23(5), pp.764-779.

Weible, C.M., 2008. Expert-based information and policy subsystems: a review and synthesis. Policy Studies Journal, 36(4), pp.615-635.

Winfield, M., 2020. Construction 4.0 and ISO 19650: a panacea for the digital revolution? Proceedings of the Institution of Civil Engineers-Management, Procurement and Law, 173(4), pp.175-181.

DEVELOPMENT OF THE EXISTING OLDER BUILDING STOCK

PETER JOHN ANDERSEN, SØREN SCHALDEMANN
University College Lillebaelt, Odense, Denmark
Email: pja@ucl.dk
Email: ssha@ucl.dk

Abstract. This paper questions and challenges the state of the ongoing development of the existing building stock. This paper attempts to approach the many and often mixed handling of the existing (older) building stock as an alternative to demolition to clear sites for new build. At present the recycling of materials is seen as a major contributor towards a sustainable building industry, but one might expect that a continued use of the existing buildings would be a much more sustainable approach. The focus of the paper is limited to buildings erected before modernism, as most projects for revitalization of buildings concentrate on the newer and often much larger building stock, to which technical solutions are less complex and the economic results more obvious.

Revitalization of the older buildings should be a key factor, not only from the sustainably point but also for solving a number of other environmental issues & values. These buildings include history and tradition, and often they represent state of the art of their time.
Through a thorough review of the major ways of re-using these buildings refurbishment, infill, transformation, extension, renovation, restoration, etc. as well as the different issues each of these include the overall conclusion pinpoints areas of certain concern as well as indicating an approach for further development without wrecking the environment, street views, aesthetics etc. Whilst the external qualities, in contrast to much of the new build, may be obvious, the interior of the old building stock often includes serious issues to be countered. Indoor climate, heating, daylight, access and fire issues will always need great attention and should match contemporary demands. Also, the many inter-linked issues such as maintenance, facilitation, preservation of local environments, tourism, architectural, and historical gems etc., are taken into consideration, including the economic and individual gains.

Through a variety of examples from own and others' work some specific solutions of better or worse conduct are presented and explained to back part conclusions on the various issues.
Obviously, the paper cannot present one final conclusion for such wide span of issues but should be seen as an attempt to join the variety of alternatives to the on-going grand scale demolition, that if not countered continues in order to make space for the erection of architectural anonymous buildings going up with no interaction with the surroundings. As such the paper could set the grounds for qualified discussions.

Keywords: sustainable renovation, infill, transformation, refurbishment,

1. Introduction

The This is not an attempt to advocate sustainability. It is much more about reusing the old building stock as it is and where it already has made its imprint. Nor is this an attack on new constructions of steel and glass. It is much more about how and where, we have what. It is less of a scientific paper, and more a scientific essay to advocate the fact, that a general critical attitude is experienced towards the contrasts created by non-compliant buildings; contrasts that the professionals often seem to pass over undebated. The criticism might be put aside as conservatism.

Figure 1. Torvegade, restauration of the old half-timber warehouse in the yard, facing the fiord –

1.1 LIMITATION

First of all, renovation issues for existing modern buildings up through the 20th century has been deselected as a focus area in this paper, as countless initiatives have already been initiated to improve their constructions in various ways. At the same time, the aesthetical differences of the buildings of the last- century, as compared to everything that precedes such, is so markedly different, that it must be reasonable to relate separately to the 20 - 25% of the
existing building stock, which was built before the introduction of modernism. Furthermore, the paper is generally based on the town houses in the older part of the Northern European building stock. These are seen to have the most significant issues within the topic of the paper. Many old towns or town centres have often been left mostly untouched by developments of the last century and what basically is due to a lack of development initiatives. However, this is now appreciated as unique and interesting. Nor will the buildings and towns protected by national/international heritage be included, as the founding and demands for such museum-like achievements are of a separate kind.

1.2 BACKGROUND

For millennia, the European building design has followed basic aesthetic ideas as laid down by the Greeks, which the Romans put into system and implemented throughout their empire, and especially the church preserved through the Dark Ages. Technical achievements mostly affected the design in terms of size, but the basic rules were maintained as a common fundamental base.
With the" reinvention" of Vitruvius' treatise as a foundation, these became virtues, and aesthetics were refined as a central element of construction in the hands of Brunelleschi, Palladio, da Vinci and many others. The subsequent centuries of baroque and romanticism never questioned the golden ratio aesthetical pleasing, the set formats and this continuous pursuit of greater beauty in construction. The master craftsman had become an architect.
In the late 1800s, parts of the classical architecture were challenged, as national romanticism introduced local historical elements and sought a national identity, rather

than the classically based styles, but still with an expression based on the same virtues. In addition, the more flamboyant style of Art Nouveau (Jugend) was introduced, albeit short-lived, and made an imprint during a booming period of construction but the past without seriously challenging the basic rules of traditional building art.

With the gigantic leap of functionalism and modernism leading away from the façade-based architecture and towards a focus on the inner values, all connections to the architecture of the past were broken; facades should now reflect the content of the building. Architecture should again be global architecture regardless of geographical, climatic and cultural differences. In addition, a quest for volume arose, which completely disregarded previous value sets. Building art was reduced to become a decorative collage at the bottom and on top of a box-like glass and steel monument. Take a walk through any older town and you will encounter a varied range of buildings. Many have been rebuilt several times, new stories have been added, old half-timbered walls plastered over, thatched roofs replaced with tiles or slate, and generally, over the last 50 – 70 years the lower floor of the city centre buildings has been completely replaced to make way for shops with large glass show case facades. This alone has been an enormous change to the appearance of the town centre. Just the last couple of generations recognize a town as a shopping area, previous to that town dwellings reached street level, shops were almost non-existing and the open town markets handled most of the commerce, these spaces long since taken over as parking areas etc.

But in general, people find these old street environments nice and cosy, tourists photograph every angle, and should there be a single building built to today's style and standard, it is usually overlooked, or the camera angle changed to avoid it.

Often new buildings, stylish as each of them may be individual are not seen to match the urban spaces at all; the buildings of more recent times do not play by the same easily recognizable aesthetic rules. In most of the recently constructed buildings the concept of building art, which used to include a conscious aesthetic approach to the appearance of the buildings, seems completely disregarded in pursuit of the ultimate degrees of utilization, dominant construction considerations and contemporary technical solutions. Modernism has, in a way, become an architectural concept that excuses a lack of architectural approach.

No wonder many town councils have made strict rules, which preserve their city's centre, to allow tourists and others to experience a harmonious urban environment. Nevertheless, it is certainly not without cost. Renovations are typically much more expensive than new constructions, and modern standards have not been invented for fun.

Repeatedly, we are confronted with wholehearted attempts to bring the many issues mentioned above together, where street environment, construction economy and modern requirements unite. Moreover, repeatedly, the architects are criticized for a lack of aesthetic sense, too few visions, poor financial understanding, and disregard for formal requirements.

There is a lack of common understanding here. Not without reason, because the quantum leap of functionalism was defined to lead away from the conventional building style - there should be no link to the past. Thus, if there is to be, we face a huge professional challenge.

Many attempts are made, consciously or unconsciously. The economy is balanced between demolition to make space for new construction, simple renovation or the more expensive restoration. The many limitations in terms of utilization rate, requirements for integration, environment, fire, materials, energy, sustainability etc. are used politically as arguments for exemptions and changes to local requirements. However, neither of these tend to generate architectural qualities and jointly they may even prevent or destroy any possible progress.

The preservation of our older buildings allows us to go in, feel, and sense history; something to tie ourselves up to, an opportunity to connect our existence with the past and ourselves to history – look forward and at the same time back. (unreferenced)

If and when, in a future not far away, the number of shops is decimated or they are gone completely, as a result of e-commerce and the like; should the facades be restored? Will there continue to be a desire for romantic urban environments, if the town centre is emptied of traders? Should our towns be the backdrop for tourism, where only the facades are preserved or reversed through expensive renovations to museum towns, and if so, what architectural period should be chosen, as they have developed and redeveloped over many centuries.

Alternatively, should new constructions be let loose, in some towns causing expensive land prices requiring high utilization rates; and where a building is to be demolished to make room for a new one, this obviously increases the cost, and thus the rate of utilization may need to be even higher in a self-reinforcing spiral. In other towns with a declining demand, due to a vanishing commercial usage, the city centre may die out completely with no need for new build nor renovation of the existing.

2. Urban Issues

How much can we / our cities be burden with what are the costs?

The migration from country to city continues at a growing pace. While around 80% of the Danish population lived in the countryside in 1850, almost 40% lived in towns in 1901, and in 1999, this had grown to 85% of the population. No matter how much we talk about home jobs and job relocation, cities continue to grow. In any case, the population is growing and until someone sets a limit on this, the population growth rate will probably be the main cause of our social & environmental problems, be it raw materials shortage, air pollution or epidemics. Changing shops and office buildings into dwellings may save existing buildings and lessen the demands for new residential buildings, but that will at the same time add to other issues due to higher numbers of inhabitants. Already now, Mexico City and other major cities suffer as supply chains and logistics have been stretched to the maximum.

Urban and rural development is subject to legislation limiting the extent of new buildings in the open countryside, thereby preserving nature in the best possible way, but implicitly the increased growth of the population is concentrated in the cities. Rarely new towns are planed from scratch. Thus, our towns continue to grow around old centres with their street layout and the houses dating back to the Middle Ages.

2.1 LOGISTICS – PARKING, TRANSPORTATION

This growth in population increases the need for transport to and from our cities, as well as within in the cities. The transport problem itself is dealt with in various ways, and everything from car-free neighbourhoods, periodic driving bans, bicycle-“superhighways”, reintroduction of trams / light rail, to underground road systems, are in play. This area is unlikely to be resolved in the near future, not least taking into account the rapidly increasing number of cars including an equally rapid changeover to electric cars. In any case, the parking problem is growing day by day, and many are now spending more time on parking than on the transport itself. Parking garages are sometimes with some success concealed in shells of "wanna-be" town houses, and some have even gained architectural recognition for this! Other carparks are carried out as underground elevator towers. At least that way the cars do not fill up the streetscape. It is a continuous debate to what extent the cars are part of town life, in some areas the coming and going of cars is seen as an activity, other areas see the possibility of parking as a necessity for upholding shopping as part of the town life.

Trains, buses, trams and monorails are popular alternatives in the big cities, but also these services seem to be stretched to their limits during rush hours. Making room for these or to increase these activities to down scale the number of cars in the city centres is a very difficult process, often generating other issues. In the centre, the spaces between the buildings are narrow leaving no room for further activities.

2.2 SEWER & SUPPLY - ELECTRICITY, WATER, GAS, DRAINS, WASTE

All around the globe are examples of urban communities where public sewerage and other utilities are collapsing. Maximum capacity has long since been reached at several locations and alternatives do not exist. In these places, there is hardly much sympathy for urban conservation and the like, when struggling with major survival problems. This does not alter the fact, only underlines it, that building and urban renewal must also ensure that future supply and sewerage needs are met.

A growing concern for garbage disposal is through sorting and part recycling, but especially in the older parts of the towns, this generates a new issue, as there is no room for the many garbage bins, neither in the streets nor within the individual property. An acceptable but costly solution seems to be the underground garbage systems with disposal boxes strategically placed around town, though these are vulnerable if the preceding individual sorting is not carried out correctly.

Should the recycling of building materials take place on a larger scale than today, ETA and then the following CE marking is clearly the right course of action. But for it to make economic sense, it requires a large number of uniform recycled materials – that is, almost an industrialized process that can undergo a fixed quality control with tests, analyses, etc. As a rule, this is not the case for reusable construction products. (M. Ekblad, 2021)

2.3 HEALTH - MENTAL, SOCIAL, POLLUTION

Building and urban conservation have other aspects than just the possibility of increased revenue through tourism. It has been shown that people find it attractive to live in and around historic buildings, that we find it mentally healthy and life giving. The fact, that these factors can be shown to be economically positive in terms of increased property prices, should make it easy to give priority to building preservation.
The studies show that the building heritage has a value for the people who live in the buildings and live in the urban spaces where the building preservation exists. Thus, house prices for preservation-worthy homes are up to 20% higher. The studies also show that the building heritage is often worth more to the neighbours than to the owners, who are faced with more expensive maintenance, while the neighbours can enjoy the sight for free. (Realdania, 2015)

3. Construction Issues

3.1 RENOVATION (RESTORING, MAINTAINING)

Bringing an existing building up to contemporary standards is a real challenge for any architect. Modern demands and standards include better insulation, modern bathrooms and kitchens, accessibility issues (adapt for the disabled) and new installations for electricity, heating and ventilation.
An extremely difficult exercise lies in insulating our existing buildings to meet modern standards but without destroying the existing structures. If undertaken with insulated stud walls on the inner leaf then the placement of damp proof membranes generates countless challenges e.g. where the trusses etc. pass through, and all too often mould and fungus with resulting rot problems are seen to follow. Membranes cannot be placed uninterrupted without taking out all existing floor and wall constructions. Any dampness that previously effected the whole wall surface will concentrate around these cold bridges, which is exactly where the effect will be worst, as the wooden trusses obviously are much more at risk than the non-organic brick surface in general. At the same time, the internal insulation setup will involve destroying any refined craftsman’s work on ceilings, walls and window casings, as well as a non- favourable reduction in the usable area.
Where to put your focus when a building is to retain its unique appearance, and at the same time the building needs to obtain the demands that it needed at the present moment. This may be both outside and inside the building that one's focus needs to be placed, and both can also in most cases be possible, however there are a number of newer demands inside that are necessary to fulfil e.g. ventilation, heat supply, and fire requirements, such as ventilation drafts and air supply, as well as fire sensors, etc. Some of these topics may be included in the construction and design, and thereby hidden or partly hidden, it is even conceivable that this construction can have a positive impact on the interior design, and at the same time relate to a design that seems of older date, perhaps even from the time of the building's origin.

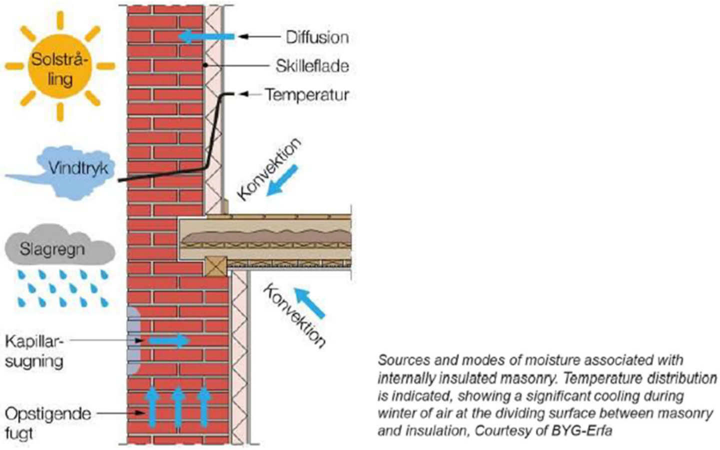


Figure 2. Sources and modes moisture associated with internally insulated masonry

Many older buildings were originally built without gutters, instead the pavement under the eaves was designed so that rainwater that drips down from the roof and hits the pavement in front of the building, is "sent" away from the facade and therefore it doesn't moisten the facade. Stone paving was in most cases made of pumice, and these can still be used for renovations of buildings where gutters are not desired to be made. However, the execution of the pumice stone requires expertise and experience for proper execution, if the pavement is not executed correctly, the opposite effect and risk of wetting the facade might be the result instead. (Fig. 3 below)

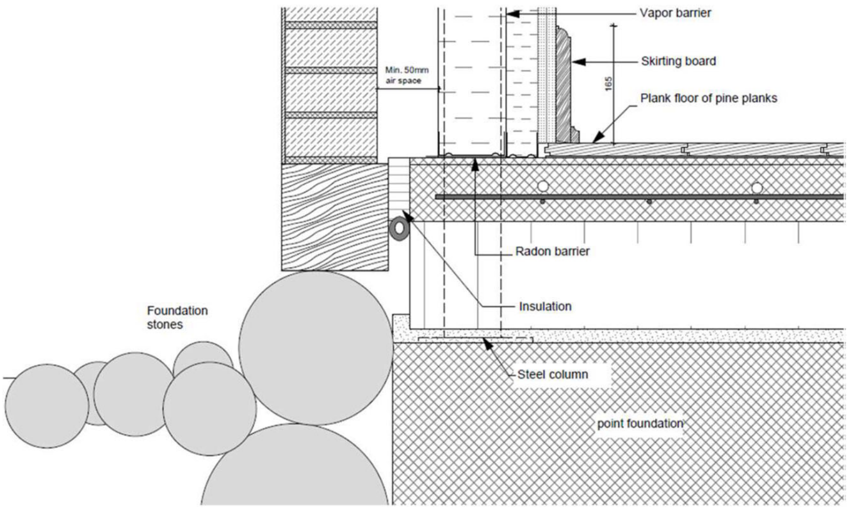


Figure 3. Detail with stone foundation

As also shown in the Figure 1, it is important that the back of the facade is kept free and with a good distance from the internally insulated wall construction. This is to ventilate any condensation / moisture away from the back of the facade.

It is important that the detailing of the original building is kept in the renovated building. The front door is especially important as this is used a lot both by the owner, as well as by guests, Figure 2. This is where you get one of the first impressions of the building, and it may therefore be important to care a little extra about particularly this front door. Many front doors have different cut-outs, mouldings and artistic finishes on and around the door worth saving. If there are steps up from the pavement, this, like so much else, should be kept in the style of the original solution, which was often a large granite / table stone. In many cases, it may be necessary to construct an entrance made for wheelchair users, and it is therefore necessary to make a separate entrance with level-free access as shown in Figure 3. The challenge with level-free access will obviously arise in the connection between the terrain and the building, in how this is undertaken and in how the drainage of rainwater is handled.

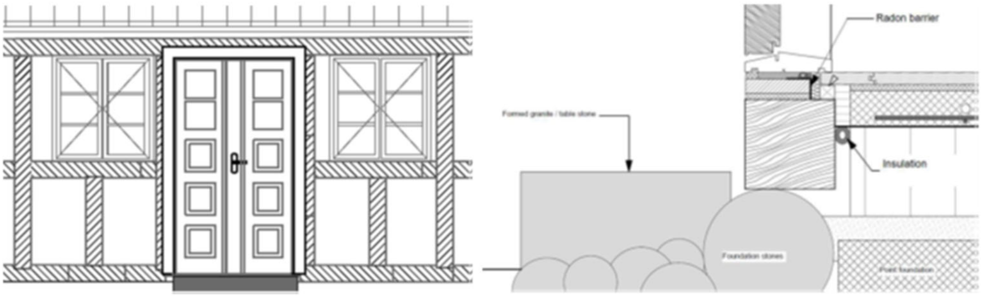


Figure 4. Front door and detail with large formed granite / table stone. Drawings with permission from ISAGER Architects, Odense, Denmark

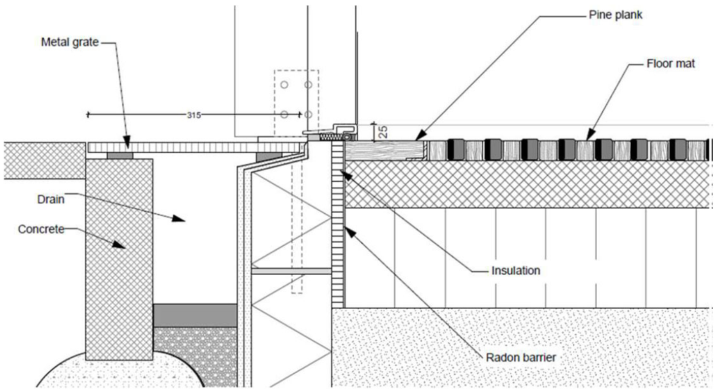


Figure 5. Entrance with level-free access. Drawings with permission from ISAGER Architects, Odense, Denmark

It must be expected that the half-timbering incl. the brick noggin itself will have to be repaired or redone as it was originally, likewise with the use of e.g. foundation stones as a base, supplemented by any new foundation made on the inside for carrying e.g. a new inner leaf.

An important detail of several older buildings is the chimney of the building. Often these chimneys are made as chimney substitutions, Figure 4, and can possibly be used for connection with ventilation, allowing for the inner core of the chimneys to be used for exhaust or supply air. There are many designs on the chimney from earlier times, these were undertaken as masonry and with variation in the courses to fit the specific roof cladding.

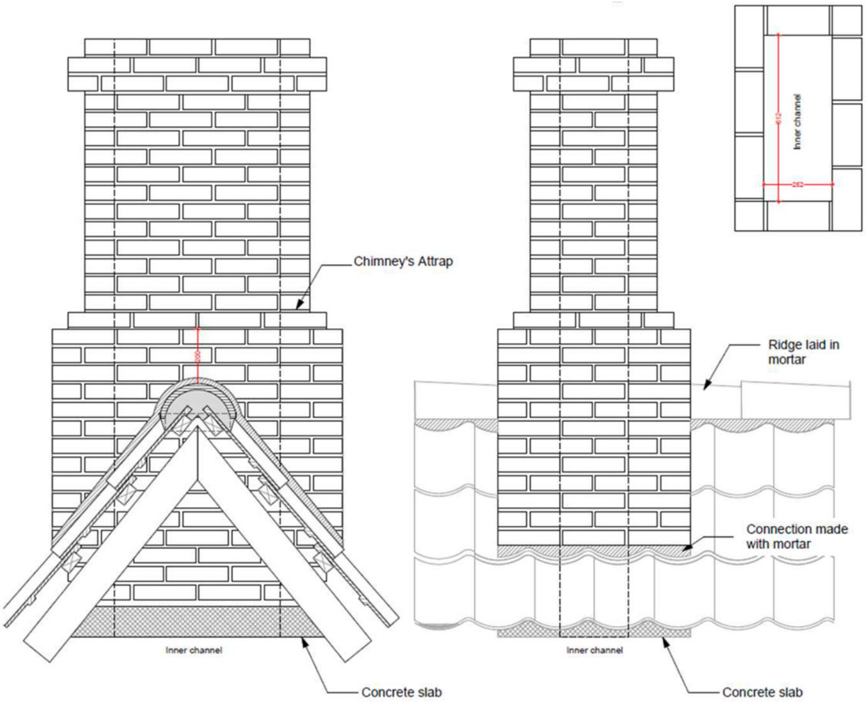


Figure 6. Chimney substitution. Drawings with permission from ISAGER Architects, Odense, Denmark

Inside, solutions can be thought of in several places which make the building's interior appear with a combination of old and new. Sockets and other technical outlets may e.g. be undertaken concealed in a foot panel construction Figure 7.

The ceiling height is often low and a challenge in older buildings, here it is usually possible to pick up approx. 100 mm / 4 in., if beams are not already visible. This can be done by placing the ceiling above the beams and thereby leaving the ceiling beams visible. The beams may be supplemented with substitution beams, Figure 7, for symmetry as well as the need for additional beams.

An insulation concept on the exterior wall would involve concealing the individual characteristics of the buildings, be they bricked lintels, ornamentation, or the like. Roof overhangs are reduced, and cold bridges become an almost insurmountable challenge at the windows and doors. In such cases, the identity of the building disappears completely, and the older building has been mutilated.

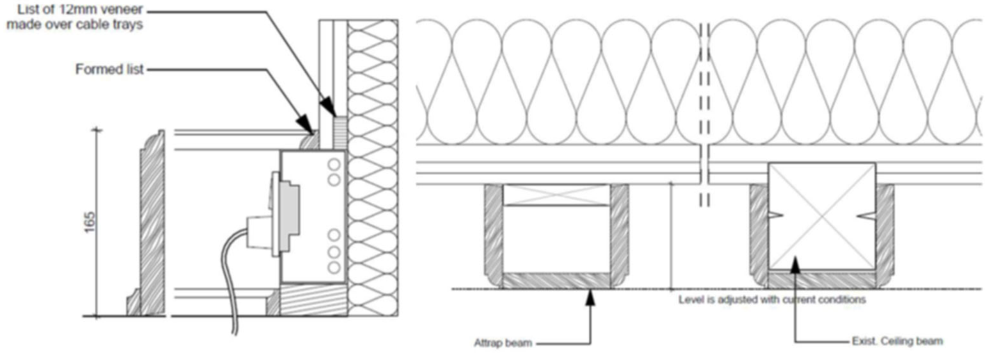


Figure 7. Sockets and other technical outlets and substitution beam. Drawings with permission from ISAGER Architects, Odense, Denmark

3.2 BATHROOMS

Establishing bathrooms to the existing structure is a very complex undertaking. The challenges lie, not only in establishing watertight constructions, but also in the penetrations of existing floors and walls when placing water and sewer pipes. Add to that the sound issues, which are not always taken lightly by neighbours in underlying flats.

Figure 8. Wet room disaster, water penetrating from a bathroom above, where the membrane was omitted. Photo by the Author

A solution example with dove tail steel boards on the existing trusses as underlay for a concrete bathroom floor. Mock up 1:1, U C Lillebaelt. Photo by Author

Establishing the bathroom as a basin, either by adding membranes on plywood to the existing wooden construction or adding a steel plate as underlay for an in situ cast concrete floor generates different issues. Just tiling walls and floor is often hazardous as movement in the underlying construction generates cracks and the continuous and perhaps growing amount of penetrating water generates fungus and rot in the wooden construction. Membranes can be added, but they too may be short lived if the movements are not countered.

Constructing a stable concrete floor on dove tail steel plates includes bringing in wet concrete, and though much more secure it should be undertaken with great caution, as the dampness during the curing period adds to the moisture problem.
In some cases, it is possible to bring in complete prefabricated bathroom units; these may not have the same issues as the previous solutions but will demand both space and often the possibility to lift the unit in by crane, thus a hole in the roof may be an undesirable and costly extra task!
In all cases, it is a great issue to secure that condensation on sewers and water pipes is avoided and that these installations are insulated and placed at a proper distance from the wooden construction parts.

3.3 THE TECHNICAL ISSUES

The attempts to secure contemporary standards in the older part of the existing building stock include technical solutions that not only change the appearance, but often also introduce problems that in worst cases accelerate an ongoing decay.
Examples of such could be the interior insulation, which in many cases is erected as insulated stud walls. Such components are normally fitted with a Damp proof barrier to prevent the dampness from penetrating into the construction. This could be acceptable, but the problems arise where the floor construction meets the wall, and where the DPM cannot be continued past trusses etc. Likewise, the construction of stud walls will be challenged at window openings, where a cold bridge will be unavoidable, and where internal walls meet the external walls with a similar problematic insulation situation.
The obvious result of such setups will be fungus on the parts where the insulation cannot be fulfilled in a satisfactory manner. Thus, the attempt to create a contemporary insulation standard has generated an undesirable health issue.

Windows have for centuries been the “eyes” of the buildings, and if the need for contemporary standards should include changing the windows, this should be handled with great awareness, to avoid spoiling the buildings appearance. New windows with standard thermal glazing are fitted with glazing bars of quite different dimensions than those for the original single panes fitted with putty and slim bars.
In some cases, the original window may be restored and a second frame with thermal glazing be attached to the inside of the original. This solution generates a fine u-value for the window without spoiling the external design, but it is also quite expensive.
Dormers are rarely original for the older buildings; they were introduced to exploit the attics as rentable areas and as such rarely of high quality. Nevertheless, if they are to be kept the concerns and issues mentioned above for windows and internal insulation are just as serious here. Rarely there is much room for adding extra interior insulation and if added to the outside the dormers will increase in seize which may well be undesirable. The right approach would probably be to dismantle the dormers and revert the attic to the original empty space, thus creating a sounder roof construction with far fewer problematic penetrations, but the owner of the buildings may well have objections to this reduction of sqm. moreover, others may well point out the dormers as a cute part of the old scenery.

3.4 PROTECTION AGAINST FIRE.

A very big issue when dealing with the older buildings is how to generate an acceptable fire protection without demolishing the whole building. Especially the floor constructions with timber trusses and wooden floorboards are a hazard in buildings with several dwellings. The original floor is usually built up with the floorboard mounted directly on the trusses and furring for a plaster ceiling underneath. In between, we find a layer of clay pugging on boards acting as sound insulation as well as preventing smoke from penetrating. This will not be acceptable by modern fire standards.
In some cases, the construction may be kept if the void between the trusses is filled with mineral wool and a fire protection board placed on top just under the then refitted floorboards, supplemented with extra layers of fire protection boards under the plaster ceiling. This may save the main construction but will include demolishing any ornamental ceiling parts and likewise electrical fittings in the ceiling will not be accepted.
Though not fulfilling the demands for a REI60 construction as it includes wood, but like the increasingly popular cross laminated timber structures it could be acceptable if all measures are taken, such as extra fire escapes and adding a wide layer of fire stopping insulation bats under door openings towards the stair wells.

Installations for water, heating and electricity are often seen as risky areas, as previously mentioned, these late additions to the old building may be mounted into fire partitioning constructions, (in some cases the installations penetrated to the opposite side), whereby the smoke and fire protective dimensions are less than they should be. Old electric wiring will typically need to be renewed or replaced due to the insulation around the old wires, which was made with asbestos.

3.5 RE-CYCLING

How should we define re-cycling? Would it be recycling, when 50% is crushed and reused as additives in new production? When 10 % is taken and reused as original while the rest is composted or used for heating? On the other hand, is it when 100% (the whole building) remains and is used for the same or other purposes? The sustainable impact from renovations is much lower than that of new constructions. There is a big difference between a product being taken for direct recycling – and here come issues such as: lack of ETA /CE marking, control of compliance with requirements for e.g., u-value (windows), and, moreover, generally the presence of just small quantities – or the same product being taken for recycling as a substitute for "virgin" resources in slabs of wood or concrete.
With products such as bricks, roof tiles, slate and beams, it is often possible to recycle without significant adaption. Of course, a smaller percentage may break during the dismantling, but the vast majority can usually continue to be used for the original purpose without laborious treatment.
Other products, such as concrete and insulation, are primarily recycled in a degraded form, for example as additions in new concrete or as sub-product in new production, which saves on raw materials but still requires lots of energy, and thus is less sustainable.

Windows and doors could certainly be recycled, if the dimensions were adapted to traditional units of measurement (inches and feet), but here too, requirements and ETA markings are problematic to meet and document. Thermal glazing if present also has issues on lifespan and in some cases content of gasses. Some companies have introduced reusable concrete elements, which after dismantling can be re-set up. However, there is a lack of good examples of implementation, as this would require the new project to match precisely in a format like the previous one. If a prefabricated concrete element is processed, problems such as reduced strength and decomposition quickly become major issues, as a result of cutting and exposing the steel reinforcement. In any case, these are typically used in more recent buildings, and therefore on the periphery of this Paper.

Surface treatments over decade or centuries will often influence the possibility of recycling. Likewise, old nails may be impossible to pull out, and might cause damage to tools when refitted. Technical systems for ventilation, water installations, electrical leads, radiator heating and the like are rarely recycled. In the original fitting, the possibility of later upgrades and dismantling for reuse have hardly been considered. Cables and pipes, on the contrary, are often placed destructively, grooved/carved in the original structures, thereby reducing the possibility of reuse of both installation and material.

4. Renovation concepts

4.1RESTAURATION (RE-ESTABLISHING THE ORIGINAL)

Few clients can afford, let alone have the time, for their old building to be restored. The process of replacing damaged parts according to traditional craftsmanship, re-establish what may have undergone inappropriate modernization over the years; restoring to the standards and likewise treatment of the past, requires a highly professional approach from both architects and craftsmen. Often it can be a challenge just to get craftsmen with proper knowledge and experience of the construction methods of the past. In many ways' restoration may be seen as a belated maintenance of the often originally well-built buildings.

Figure 9.6 Almarksvej 2, Horne. Private client. Total renewal of an old farmhouse, no stone untouched. The thatched roof is only kept as a temporary cover during the reconstruction. Photo & Project work 2022/PJA

The buildings listed as national or world heritage will need such handling, and the client will be restricted in regards of the future use of the building, alterations will need preceding approval often limiting the options for modern installations and constructions. The energy consumption will rarely be reduced to something that is just vaguely matching to the contemporary standard.
Many restorations are therefore placed in the hands of conservation organizations in close collaboration with foundations with deep pockets, great patience and high expertise in the field. In some cases' the building can be seen as a historic gem, representing the past, and as such often seen as an item which also influences the value of the surrounding developments in a positive way. With such an effort invested, the client would hardly welcome a neighbour building clashing in style and shape.

4.2 PRESERVATION - STREET/FAÇADE (NEW HOUSE IN OLD CLOTHES)

In many places, a set-piece approach is used in building preservation. Here, the street facade and roof construction are preserved as best possible, while a completely new building is erected behind. The "unification of the better of two worlds" would hardly be accredited as actual building preservation, but contributes to a cohesive urban space, where the buildings continue to hold the same exterior values.

By demolishing the old building, except for the façade, the architect is free to establish a building with modern constructions, utilities, building layout etc. The street façade is usually kept in place by a steel construction that is concealed in the new structure behind. As this is a much cheaper process, it is often put in use where local planning allows for such. In special cases, this process is carried out backwards, with an ill-fitting modernistic building being refitted with an external shell, that makes it appear, as if it was constructed much earlier. There are a number of buildings from recent years that one might be tempted to give such treatment.

Figure 10. Street façade in Palma de Mallorca, the brick façade has been kept to ensure the street environment, behind the façade, a new building will be fitted. Photo by PJA

4.3 EXTENSION

A special, and for architects' classic challenge, lies in the addition of extensions to existing buildings. This is a clear trade-off between the continuation of the original building in shape & style and the establishment of an extension, that clearly shows that it is new and is undertaken with respect of the original building. Quite often, we now see the classic rules for this kind of approach set aside: new is good, big is better, and fast is perfect.

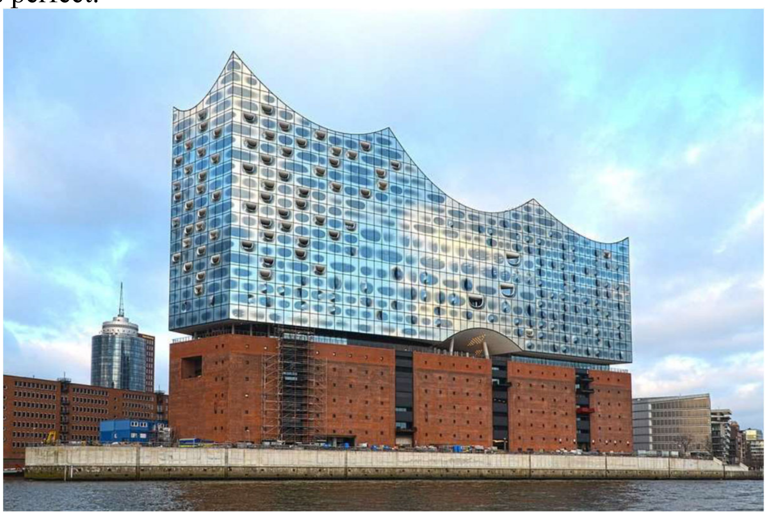


Figure 11. The Elbphilharmonie in Hamburg is an amazing example of an old building with vertical extension. The old red brick warehouse building (parking) is kept and matches the surrounding, whilst the new glazed concert hall, hotel and restaurant building rests on top, thought to resemble a block of ice. Photo by PJA

The horizontal extension may be undertaken in a contemporary style, but in a respectful attempt built as separate building part with a link – often glazed - to the older part. The vertical extension is less simple, as it not only involves major static issues in handling the extra load within the older part, but also visually. Changing materials will underline what is a new addition, but a modernistic approach in shape will be difficult to join with the existing buildings classical geometry. The golden ratio is stretched, the perspective is unpleasingly out of proportion. Whichever of the above is considered, also the functionality of the building is an essential aspect. The challenge of fulfilling the client's needs through the extension may be less due to more sqm. However, the limitations in design may not be so easily overcome.

4.4 TRANSFORMATION

If the building is preserved with changed functions, there will often be challenges due to special technical requirements (fire, ventilation, etc.) Architecturally, the pursuit of as much identity as possible would be desirable, but for some the concept of transformation also implies a desire to show that the transformation has taken place. These buildings, as often, receive great attention, and the result ranges from fantastic to tragic, depending on who is reviewing them. The same issues and limitations mentioned during enlargements apply to the transformation.

Figure 12. The Kings Castle, Berlin, was left in ruins after WW2. Later it the ruined castled was demolished. A costly and time-consuming project recently finished. Restoring the historic building and national symbol of pre-war Germany and turning it into a museum includes adapting some much-discussed elements that differ in style and to some brings in unfitting neoclassical elements. Photo & illustration: Curtesy of Humboldt-Forum/ Staatliche Museen zu Berlin

4.5 INFILL

The most difficult architectural exercise of all, to fit new between old buildings, is not solved just because you adapt in height and place your building in the same façade line. However, it might help. Unless the empty plot already exists, it might be a difficult exercise to choose between rebuilding an existing building to achieve contemporary values, and demolition (if allowed) of the same to make room for the establishment of an infill building. Especially, if the latter is perceived as a pure plagiarism on the architecture of the past.

Through the ages, similar processes have been carried out, and we usually accept that Rococo, Baroque and Renaissance buildings are mixed with National Romanticism, primarily because they all have the common offset in the formats, materials and construction conditions of the tradition. If the architect can find a similar starting point for his contemporary construction, I doubt that future generations will blame this as completely inappropriate.

Figure 13.7 The old town square is surrounded by picturesque old buildings, with the exception of two large buildings in very dominant positions. These were modernized just after the war, making room for a new bank. The modernistic building was given the Danish architecture award in 1946. The low neighbour building was allowed to add 2 stories. 20 years later the bank was given a new modern façade, and the neighbour had insulation panels added, neither generating a link to the surroundings. One might hope for a future development of a more fitting nature.
Left photo: Recent photo by PJA. Right Photo: Curtesy of Faaborg Byhistoriske arkiv.

5. Era and style

As mentioned above, there is a separate problem in regard to era, when determining the attachment of buildings to the surroundings. Over the years, the fashion and requirements of the time have influenced the appearance of existing buildings.

Thatched roofs have been replaced with tiles or slate for fire hazards. Elements drawn from other countries, such as the frontispiece, have been added in an attempt to impress through images of power and wealth.

Half-timbered facades have been plastered or added with brick facing to resemble stone houses during a period, when stone houses were considered finer. The fact, that fire conditions may have been improved at the same time, was hardly the most important factor.

Stepped gables may have been added following Dutch inspiration, often as extended masonry above or in front of the existing rolled roof. Window openings have been increased over time whenever technical progress has allowed for more daylight, and access conditions have changed from side entrances in gate ways or porches to front doors with imposing access steps to, at worst, sliding glass panels at street level. The latter often in the context of a total conversion of the ground floor into a glass façade for a shop, whereby the once classic building becomes ridiculous as it takes on the character of "the sawn-off lady".

A very particular issue is posed by the historical re-creations – e.g., buildings that have destroyed as a result of wars or fires – where the choice has been between completely new or rebuilt as original. Or where developments over the years have radically changed the shape of the building. Which is the one to be re-created.
Here we find many different approaches, and most of all we are faced with the problem: Which historical/architectural period is the "right one". Is it the most recent known? The one the local inhabitants still “remember”? The one from the same period as the neighbouring houses? The earliest known? or, the one that some "random city architect" liked the best?
It is a well-known fact that many of our buildings are located, where previous buildings have stood. It is not only Rome that embodies a multitude of historical layers below, which meter after meter contain reminiscences of former buildings. Our stone churches with their many additions and conversions are built where there have previously been smaller wooden churches, and these were typically located, where repressed religious shrines (sacrificial sites, temples) lay in ancient times.
Which, if any, of all these would one wish be rebuilt, if the current building disappeared?
Where do we draw the line - are backdrops acceptable or just a populistic asset with no architectural relevance? Do we have the right rules to control development, to ensure that the new developments do not necessarily end as a contrast to the (historic) existing building stock? Who should set the agenda: developers, neighbours, architects, or politicians? The result will properly not be the same. As the value of buildings is generally increased in preserved urban areas- compared to general, this must be seen as an indicator of a common interest in securing them, both for the individual owner but certainly also for the neighbours in the area (SAVE). However, could we also demand existing, non-fitting buildings redeveloped to match the surroundings?

6. Commented examples of local attempts.

6.1 EXAMPLE 1 – TORVEGADE 25, FAABORG

This property in the centre of an old market town originally consisted of the residential front building, a side building (stables) and in the back a warehouse with access directly to the harbour just behind. The earliest registration shows a continuous half-timbered building of one storey. At the end of the 18th century, the front and back building was increased to two storeys, and around World War I, the residential building was further developed into flats plus two shops at street level and ended up including five storeys in all. The stable wing was later used as storage for the ground floor shops and recently turned into two flats.
The rear building is now listed as national heritage, while the side wing and front building are listed for preservation. When recently rewarded for the renovation especially the rear building was emphasized, although few people ever see it. The front building dominates the surroundings, and although carefully renovated and undertaken in all ways traditionally, the volume itself is debatable. Nevertheless, it is hardly imaginable to get the client to remove a few financially lucrative floors just to please the architect.

Figure 14. Torvegade 25 was given the renewal reward in 2018, for bringing the building back to its original style. Photo: Faaborg Byhistoriske Museum / Maria Retoft Pedersen – Photo & Project: PJA - Own work 2018. Looking at a photo from 100 years before, that old style seems to have been forgotten, and even then, it was a rendered and upgraded old half-timber building from the 1730's.

6.2. EXAMPLE 2 – ØSTERGADE 49, FAABORG:

This very special project in the same town involved the rebuilding of what appeared to be a building from the '60s. The ground floor had been a shoe store with large glass sections and included a glazed passage through the building, and the upper floor was therefore carried by concrete columns. An older two-storey rear building was connected at the back. Since the building is located prominently and as a neighbour to the city's old and listed art museum in neo classical style, it was a wish that the conversion subordinated itself. By establishing a façade in the traditional style of the old town, the result was that tourists are now seen taking pictures where this "cute" building is included, without them knowing that it is a clean backdrop. What appears to be a blinded door hole is simply where a large concrete column hindered the possibility of placing a centred window; a virtue made out of necessity.

Only one half of the building was included, which is why we can still see the not-renovated part, which still appears as it was erected in the '60s, next to the renovated. A curious mix of modernism and recreated classicism. Unsurprisingly, the redevelopment came across remainders of walls and foundations from a former house, which had been demolished in the 1960s. The circle was closed.

Figure 15. An old town house gave way for a modernistic renewal and extension during the 60'iesonly to be followed by an "old style" renovation of the one-half during the early 90'ies. Project work undertaken by PJA for S Kiersgaard 1992. Photo : Faaborg Byhistoriske museum / PJA.

EXAMPLE 3 – TORVEGADE 12, FAABORG:

The town's once very posh hotel was developed into flats in 1979. To preserve the street environment, the façade was not demolished, braced with a standing steel skeleton whilst the rest was completely demolished. The elaborate details of the old façade contrasts with a coarse interior and simple
red brick facade of the rest of the building. A concrete brutalism with a mixture of dark masonry and smooth concrete surfaces dominates the back of the building in a strange contrast to the light and classic street front. Since the façade conservation was expensive, the choice of material in the other parts became simple and inexpensive. Of course, the bank financing the development was allowed to "cut out" the ground floor so that there could be the "mandatory" glass sections. Needless to say, inside there is not a trace of the original building.

Figure 16. The classical façade before and after the renewal during the early 80'ies. The bank disappeared but the lower façade was kept in an unstylish version. Photo: Faaborg Byhistoriske Museum / PJA

This kind of preservation is practiced globally, and is consequent a way of solving some of the most obvious issues: remaining the street façade and attractive old town environment, at the same time as generating contemporary
housing for the residents. Being cheaper and technically less risky than a full renovation, this will appeal to many developers. However, the historic value of the building will be low and likewise the sustainability of keeping the old buildings in use.

Examples from Lübeck, Germany :

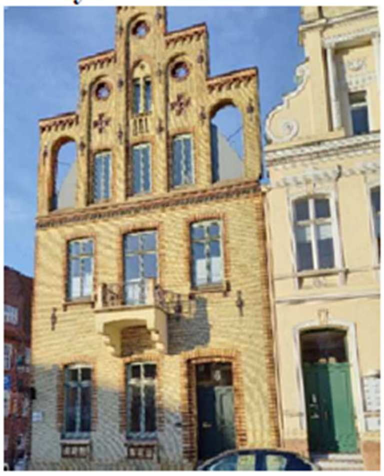


Figure 17. A watch tower erected in the 13th century as part of the old town wall, later (1670) served as part of a small building and later again extended with a half-timber upper floor. Photo PJA

An old half-timber house with a pitched roof, later fitted with an oversized classic façade evidently surpassing the pitched roof behind. Photo PJA

The world heritage protected old Hanseatic city consists of a great number of charming old buildings, of very high quality despite their soon-to-be 1000-year history. Many are beautifully maintained, restored or rebuilt after the ravages of many wars. For the relatively large city, the old town remains the central social and tourist hub. The harmony between the many houses creates a beautiful setting despite the fact that in many places there are far more than 500 years between the dates of construction. The tradition of form and materials has been preserved.
Here, too, these are often buildings that have evolved over the ages, the well-known stepped gables are not necessarily an original building part for the oldest houses but have in many cases been added as the owner's status or economy has evolved. The later installation is often seen as a stylish appendage to the original hipped roof.

The number of stories in these buildings has increased over the years and the backyard houses have followed and gone from warehouses and stables to worker homes, so that the individual property has developed into a small village with up to 100 inhabitants on the parcel.
Some newer buildings do not match in scale and style and break the idyllic atmosphere, while a few others have managed to find their own modern identity within the classic setup, so even tourists are tempted to take pictures of them, even though the “cuter” buildings are right next door. Perhaps a confirmation that today's architecture can deliver the product when the will and ability is present.

7. Final comment.

If the preceding considerations can be accepted, that - if undertaken correctly - the benefits socially, economically as well as visually of preserving the buildings and environments of the old town may be great, then the architects, engineers and

architectural technologists must lead the debate to ensure that the right solutions are put in use.
One might consider to what extent the town re-scaping should be taken. Will we accept singular contemporary buildings within the midst of our old towns; or should such existing modernistic buildings be replaced or fitted with a classic façade to fit the image of an old town, and most important, who is to decide and not the least pay for such undertakings.
Dare we demand that the inhabitants are to live in museum towns, or dare we demand that owner of non-conform building adjust to a popular visual concept of the old town or will we just cross our fingers and continue to hope for the best.
Finally, there is a lack of trained professionals with insight in these often old technical and practical issues, who can secure the professional basis of both future advisers and future craftsmen. If we continue to focus on new build and to some extent the renovation of buildings of a not so far away past, the coming generations will have little, if any, background knowledge for the maintenance of our older building stock, let alone the concerns of building in a style that respects these often fine and charming old buildings. That may well result in decay and final demolition, leaving us without these important links to our historic past. Preservation starts with continuation through education but has this already been omitted from the professions.

8. Right or Wrong

Figure 8 Figure 18. Should a modernistic building be fitted with a more traditional façade to meet a public demand for a cohesive style in an old town centre. The modernistic bank building from 1946 (now out of use) dominates the old town square, (see more photos under Infill.) Photo by PJA

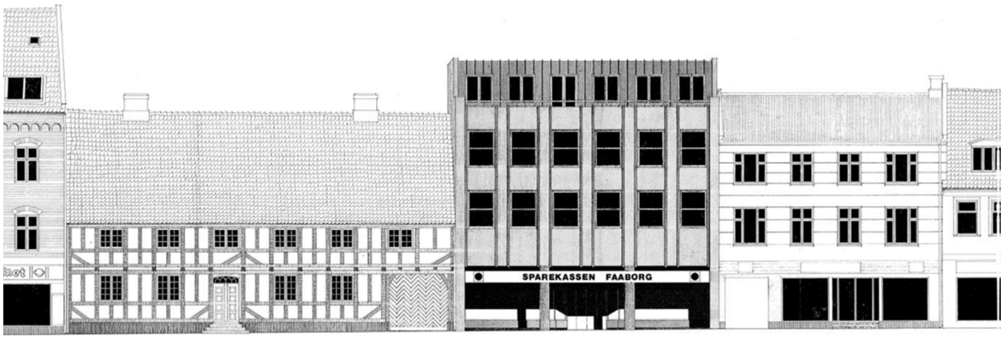


Figure 9 Above: Drawing for the refurbishment of the façade, by S. Kiersgaard, 1984.

Figure 10 Below: Sketch for a traditional alternative by PJA, 2022.

References

Andrea Palladio, 1570. QUATTRO LIBRI DELL'ARCHITETTURA -

LIVSCYKLUSVURDERING AF STØRRE BYGNINGSRENOVERINGER – SBI rapport 29, Statens Byggeforskningsinstitut – 2015 ANALYSE AF CO2-

UDLEDNING OG TOTALØKONOMI I RENOVERING OG NYBYG - Renovering på dagsordenen - Lise Hvid Horup Sørensen & Mathilde Mattson, Ramboll, 16.10.2020

BYGNINGSBEVARING (Preservation of buildings) -Ulla Tofte, cand. mag. hist. - https://www.youtube.com/watch?v=E_4XoevHO3I

Maria Ekblad. ÆGTE GENBRUG AF BYGGEVARER UDFORDRES AF SMÅ MÆNGDER - Projektleder, MSc, Environmental and Marine Biology, VCØB – Videncenter for

Cirkulær Økonomi i Byggeriet, 21.01.2021 - https://bygherreforeningen.dk/aegte-genbrug-afbyggevarer-udfordres-af-smaamaengder/?utm_source=rss&utm_medium=rss&utm_campaign=aegte-genbrug-afbyggevarer-udfordres-af-smaa-maengder

CIRKULÆRT BYGGERI KRÆVER NY FORRETNINGSMODEL OG TANKEGANG - Graves Simonsen, Projektchef, Bygherreforeningen, 17.12.2019 - https://bygherreforeningen.dk/cirkulaert-byggeri-kraever-ny-forretningsmodel-og-tankegang/

TRANSFORMATION OG ADAPTIV ARKITEKTUR – ET NØDVENDIGT GRØNT

PARADIGMESKIFTE - Lars Køhler, byggeri, energi- og klimarådgiver, Rådet for Grøn Omstilling - 3.9.20 - https://rgo.dk/transformation-og-adaptiv-arkitektur-et-nodvendigt-grontparadigmeskifte/

LIVSCYKLUSVURDERING AF STØRRE BYGNINGSRENOVERINGER – SBI rapport

29, Statens Byggeforskningsinstitut – 2015 ANALYSE AF CO2-
UDLEDNING OG TOTALØKONOMI I RENOVERING OG NYBYG - Renovering på dagsordenen - Lise Hvid Horup Sørensen & Mathilde Mattson, Ramboll, 16.10.2020
BÆREDYGTIGHED, KVALITET OG EFFEKTIVITET ER NØGLEORD FOR GODE RENOVERINGER - Martha Katrine Sørensen, Teknologisk institut / REBUS – 15.4.2021 - https://bygherreforeningen.dk/baeredygtighed-kvalitet-og-effektivitet-er-noegleord-for-goderenoveringer/
RENOVERING ER OP TIL FEM GANGE BEDRE FOR MILJØET END NYBYGGERI - Ulrik Andersen - https://ing.dk/skribent/ulrik-andersen
NYT I HERNING ELLER RENOVERET I VEJLE? - Dennis Nielsen, direktør Energirenovering i NCC Danmark – 8.2.2017 - https://bygherreforeningen.dk/nyt-i-herningeller-renoveret-i-vejle/
LCC PÅ BYGNINGER: RENOVERING KONTRA NEDRIVNING OG NYBYGGERI - Kim Haugbølle, SBi/Aalborg Universitet for Trafik-, Bygge- og Boligstyrelsen - https://vbn.aau.dk/ws/portalfiles/portal/251433740/LCC_eksempel_bygning.pdf
VÆRDIEN AF BYGNINGSARVEN - Realdania marts 2015 - file:///C:/Users/PJA9307/Downloads/V%C3%A6rdien%20af%20bygningsarv.pdf
BEBYGGELSESBEVARING - Center for Byudvikling Økonomiforvaltningen - https://www.kp19.kk.dk/sites/default/files/2020-12/retningslinjer_bebyggelsesbevaring.pdf
LCA FOR BYGNINGER - Videncenter for Cirkulær Økonomi i Byggeriet - https://vcob.dk/media/1555/vcob_kvikguide_lca.pdf
REALDANIA, 2015. VÆRDIEN AF BYGNINGSARVEN –
MARIA EKBLAD , 2021. ÆGTE GENBRUG AF BYGGEVARER UDFORDRES AF SMÅ MÆNGDER, Projektleder, MSc, Videncenter for Cirkulær Økonomi i Byggeriet

A BIM+BLOCKCHAIN APPROACH TO ENSURE TRANSPARENCY IN THE STRATEGIC HOUSING DEVELOPMENT PLANNING SYSTEM

CARLO ORANI, DR MALACHY MATHEWS
School of Multidisciplinary Technologies, Technological University Dublin
E-mail: D18127028@mytudublin.ie
E-mail: malachy.mathews@tudublin.ie

Abstract. The introduction of the fast-tracking housing regulations in Ireland has modified the dynamics in which democratic participation is deployed in planning decisions. The resulting planning process has favoured inequality phenomena and has strengthened the position of construction lobbies in large-scale developments. This paper enforces citizen engagement in the Strategic Housing Development (SHD) framework using Building Information Modelling (BIM) and blockchain technologies to build digital trust. Digital tools have enormous potential to deliver more transparent planning by establishing proven accountability for building permissions and promoting trusted interactions between citizens and local administrations. This study first describes all the reasoning underpinning the de-democratisation process of Irish planning after introducing SHD regulations. Based on the previous findings, a theory-driven, inductive case study is proposed. The case study offers an integrated framework that combines the improved visualisation properties of BIM with the immutability characters of blockchain. Results indicate that such a methodology successfully addresses the problem of trust and transparency and brings additional intrinsic benefits due to the use of digital solutions in planning.

Keywords– Building Information Modelling (BIM), Blockchain, Planning, Transparency, SHD,

1. Introduction

Despite the progress made by the Planning and Development Regulations 2001-2020 in clarifying and simplifying the planning procedures, the legislation has not yet completely taken into account the contribution of information technology (Monaghan, 2015). Currently, the application lodgement is characterised by inefficiency and redundancy, requiring multiple hard copies to be posted to the local office and then manually scanned before being uploaded to the relevant Council e-portal. As a result, the administrative process associated with standard planning applications involves cost issues related to the storage of significant amounts of paper and potential risks of losses in the event of a fire (Monaghan, 2015). The current planning process is also perceived to be slow and subject to numerous delays, primarily if requests of information are issued by the Public Administration (PA) or in case of appeals to An Bord Pleanála (Lennon & Waldron, 2019). Several studies (Reddy, 2004; Lennon & Waldron, 2019) also agree that inconsistencies and arbitrary interpretations of the planning legislation by the local authorities add additional uncertainties and associated costs for future developments. For designers, the advent of the fast-tracking legislation has highlighted the importance of
providing the right set of information to enable An Board Pleanála (ABP) to form an opinion around a particular planning decision. In such environment, significant effort

is required by designers in the production of detailed drawings ahead of preplanning meetings. Also, if substantial changes are required to the initial design, this might result in delaying the permission process with serious cost implications (McNally, 2019). - The integration of blockchain solutions with other types of technologies such as BIM is the subject of development and research focus. While the introduction of BIM procedures has emphasised the importance of collaborative processes to create and manage building data, the current practice presents difficulties in assigning liabilities due to the overlapping of roles, guaranteeing intellectual property protection and third-party dependence. In this context, Blockchain is a possible solution to provide "evidence of trust" (Mathews, et al., 2017; Pradeep et al., 2020) which would create value for the AECOO (Architectural, Engineering, Construction, Operations, and Owners) industry and overcome many legal complications that occur in the current BIM practice.

2. Literature Review

a) Planning

This section will give a summary of the Irish Planning system and is particularly focused on the dynamics which underlay the recent "Fast-Track" planning process after its introduction by the "Planning and Development (Housing) and Residential Tenancies Act" (2016). The Planning system in Ireland operates at local, regional and national level. At the highest level, the National Planning Framework and National Development Plan (2018-2027) are merged to form Project Ireland 2040, which supports the government's long-term strategy under the planning and infrastructural perspective (Williams & Nedović-Budić, 2020). At regional level, there are three Regional Assemblies accountable for the preparation of the Regional Spatial and Economic Strategies (RSES) which prioritise investments to promote the strategic growth of the region, ensuring compliance with EU guidelines and local development plans (Williams & Varghese, 2019). At a local scale, Development Plans represent the primary documents to deliver planning by the local authorities. These policies last for six years and describe between a set of maps and written statements how the local municipality intends to use certain areas along with their development objectives. Development Plans are often accompanied by a significant political debate, and, in most cases, a certain number of amendments are ratified due to public consultation.

The Irish Planning system presents two unique features: the establishment of an independent planning appeal board (An Bord Pleanála) and the possibility of public appeal to a decision issued by the local planning authority. As consequence of this configuration, the right to build and develop is formalised with the grant of a planning permission after the submission of an application to the appropriate City or County Council. The application, to be successful, needs to be assessed against the national planning principles and the appropriate local authority development plan (Lennon & Waldron, 2019). In particular, the Planning and Developments Regulations (2001-2020) establish the steps that must be taken when filing an application or appealing to An Bord Pleanála and the types of exempted developments.

In 2017 the housing crisis resulted in the development of a new "Fast Track" planning procedure, with the attempt to prioritise large student and housing developments (Lennon, 2019). This protocol was introduced by the Planning and Development (Housing) and Residential Tenancies Act 2016 and is also known as Strategic Housing Development (SHD). The SHD is used to streamline housing developments of more than 100 dwellings and student accommodation of 200 or more bed spaces. The relative applications could be lodged for consideration directly with An Board Pleanála with a three stage process (McCarthy, 2018). Initially the prospective applicant is required to initiate a consultation period with the Local Planning Authority; at this stage a meeting is held within four weeks after the date of request and the prospective applicant is required to provide all the appropriate information two weeks prior to the pre-planning meeting for the attention of the PA. The second stage consists of a 9-week pre-application consultation period with An Board Pleanála, at the end of which the Board will form an opinion whether the documents submitted constitute a reasonable basis for an application or require further consideration and amendment. During the third and last stage the planning application is submitted to the Board and a decision is to be made within 16 weeks. This could result in a decision being taken within 25 weeks of the process's commencement. As result, for the first time in Irish Planning history, a decision is guaranteed within a well-defined time limit (McCarthy, 2018). Figure 1 covers in detail the current SHD process including time frames and actions required by the main parties.

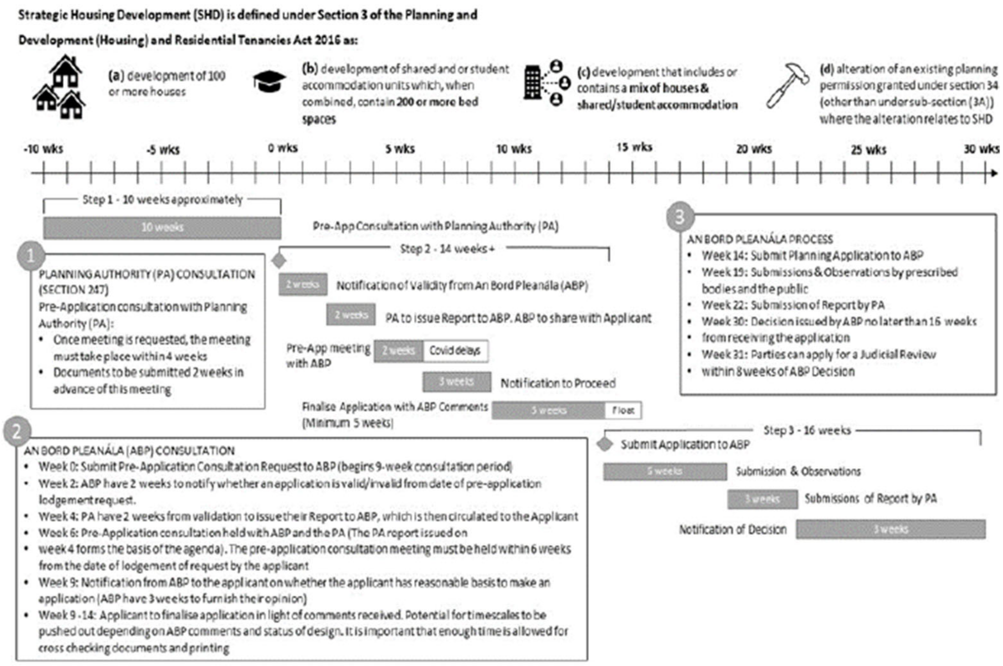


Fig. 1: SHD Planning Framework (Mitchell McDermott,

However, this approach has been subject to criticism in relation to the education of the local authorities' power stemming from the centralisation of the planning system

and the absence of third-party appeals as a decision-making instrument (Williams & Nedović-Budić, 2020). With third-party ppeals, stakeholders can claim protection of property rights but under the new system there is no possibility to appeal a decision being made by An Board Pleanála afterwards. This can be seen as a first degree of de-democratisation of the Irish planning system by putting the interests of developers ahead of public participation (Lennon & Waldron, 2019). Also, under the "fast track" scheme the large residential and student developments are assessed at national level in place of local planning authorities with the result of boosting a process of centralisation that prioritises a certain type of development deemed to be of highly strategic importance for the economic growth of the nation (Lennon, 2019). According to Lennon & Waldron (2019), this mechanism further reduces public participation in the planning system because it effectively removes the importance of city and county development plans and bypasses a full assessment of an application by the local planners. In this perspective, the local development plans, which represent the democratic expression of a local municipality's intent for land use, are weakened by policies introduced by national politicians rather than local elected representatives. Moreover, An Board Pleanála being an independent body, the decisions under the SHD system are unaccountable
to any type of electorate, making the system vulnerable to lobbying, political interferences, and corruption (Lennon & Waldron, 2019).

b) Building Information Modelling

In circumstances similar to the fast-track process, where meetings create commitment to quick and irreversible decisions, it is essential to have effective visualisation and decision-making instruments at one's disposal. Kim, et al. (2015) highlighted that in the current practice there is a lack of an integrated method to evaluate multiple scenarios and metrics as well as an absence of a comprehensive representation of such information. This could result in evaluating fewer scenarios with the associated parameters being assessed only at a few points in time based on a fragmented understanding of the project's deliverables. They assert BIM-based workflows could support planners to make timely and more informed decisions, create different scenarios, assess changes on top of simple metrics and visualise over time the results in a more integrated way. The availability of information that a planning body has at its disposal for supporting a planning decision has brought a degree of transparency that was impossible to obtain with a standard 2D process (McNally, 2019). This will also benefit the democratic participation and in particular the ability of third parties to visualise how developments impact the surrounding landscape and buildings. The availability of information based on a 3D representation will consequently make appeals more informed. Consequently, the improved understanding of project deliverables at building and neighbour level might create a collaborative culture among all the stakeholders. According to Kim, et al. (2020), the adoption of BIM methodologies will have the immediate effect to automate a significant part of the planning process and speed-up the period for granting of permissions. The time required to respond to changes, issue and review drawings by the designers is significantly reduced with the use of BIM software and workflows, bringing a large degree of automation as well better future proofing for the design (McNally, 2019). It is deemed (Ullah, et al., 2020) that in the long-term, the automatization could make the planning application process cost-effective, saving time and resources for both public administration and designers.

The possibility to run computer-based checks on BIM model submissions is a key component of the automation process. The current research around the possibility to provide e-submissions for planning permission suggests a significant benefit in eliminating human error and arbitrary interpretations of the planning legislation, thus strengthening the planning system's transparency. BIM models could be submitted in a central system administered at County or national level at a defined level of development (Monaghan, 2015). Such models are then assessed automatically with an algorithm against the current planning legislation. Other countries such as Singapore (Plazza, et al., 2019), Norway (Hjelseth, 2015), South Korea (Kim, et al., 2020) have successfully developed an e-submission technology system. In Singapore, the e-PlanCheck function of the CORENET system was developed to perform electronic checks against planning and building codes using automated procedures instead of a paper-based process. At present, nearly all the planning applications in Singapore are submitted using the e-submission system. The checks are performed by building additional intelligence from IFC models submissions (Hjelseth, 2015). In parallel, an integrated platform such as KBIM (Kim, et al., 2020) can also be developed to support the electronic submission module. This platform will be capable to gather non-BIM type of planning information including planning and agreement documents. McNally (2019) suggests that a project dashboard built on top of such a platform could improve the collaboration among the planners and the design team. The submission of BIM models will necessarily require establishing a minimum level of detail (LOD) prior the system is developed (Ullah, et al., 2020) so they could correctly conform to a defined checking standard (Kim, et al., 2020).

However, the implementation of such a solution is obstructed by factors that are not just technological barriers or resistance to change, and that partially justifies the fragmented and delayed adoption of these processes at country level. In the first instance, one of the main obstacles is represented by the planning legislation itself, which is specific to country and regional level and requires a significant amount of work to be converted into code. According to Olsson, et al (2018) the planning code is composed of qualitative, quantitative, and visual criteria. Quantitative and visual criteria can be supported by a BIM methodology, respectively, with automatic checks and digital representation of models. The qualitative criterion presents more difficulty as it concerns the adequacy of a building in a broader planning context, thus requiring human participation. Another important factor is the choice of file type for the planning submission. While GIS files are capable of covering large areas, BIM files, including IFC format, are suitable for a local and very detailed approach (Van Berlo, et al., 2013). GIS files do not store all information required by planning codes and BIM files cannot manage geographical type of information (Altıntas & Ilal, 2021). Although their interoperability is very limited, more recent literature (Olsson, et al., 2018) has emphasised the potential of integrating GIS data with BIM to enhance more effective compliance checks.

The employability of such solutions in an international planning context is yet to improve. Literature has shown a significant added value in terms of improved transparency, reduced costs and better decision making. In the Irish framework this can justify government investment into this technology for the SHD system; technical evaluations will determine whether to emulate other countries' planning systems or proceed with Ireland specific solutions.

c) Blockchain Technology

Since the invention of the Internet, Blockchain has been considered the most impactful technology innovation (Cong, et al., 2017). This technology is essentially a decentralised database that enables new digital possibilities without depending on a third entity to store, verify, transmit and communicate network information across its own distributed nodes (Xu, et al., 2021). In its simplest form, blockchain technology validates a set of transactions using a decentralised peer-to-peer network. Once the transactions are verified, they are combined into blocks. A single block is capable of storing the information associated with each transaction in the form of encrypted data. The preceding block's hash is included in the updated block so each block can be traced back to its parent with a complete history of the changes (Safa, et al., 2019).

Since the introduction of blockchain technology, smart contracts have been one of the most sought-after applications. In a blockchain framework, a smart contract is a novel technology that can autonomously negotiate, fulfil, and enforce the terms of an agreement. Smart contracts, unlike real-world contracts, are entirely digital and contain lines of code that triggers computer protocols. Those protocols could be self-executed and self-verified after being created and implemented without the need for human involvement (Xu, et al., 2021). Due to this characteristic, a smart contract can increase trust among parties, lower transaction risk, operational costs, and maximise business productivity. The development of smart contracts lowers the potential for corruption and fraud in distributing and transferring money. Non-currency types of data can also be stored on the blockchain thanks to the recent adoption of smart contract applications by Ethereum (Buterin, 2014). Moreover, users may accomplish seamless and secure peer-to-peer data sharing without worrying about data leaks or manipulation by establishing access rights through smart contracts. One common misconception (Mason, 2019) about smart contracts is that they are difficult to code and understand. The reality is that users do not have to comprehend how smart contracts operate to use them. Following the example of the most widely used mobile applications, people will just be engaged with foreground functionalities in a user-friendly environment.

For its nature, blockchain is particularly useful in addressing problems related to the centralisation of information, trust, and transparency. With an authorisation system based on blockchain smart contracts, it is possible to allow decentralised and democratised authorisation delegation without relying on a central authority. This can only happen if a trust system is built around the network itself, making the 3rd party facilitators obsolete. According to Nawari & Ravindran (2019), trust derives from the network's capacity to validate data transactions, and it can only be achieved when shared/distributed ledgers handle transaction and ownership. This means that all construction and design activities under the form of "value transactions" are recorded into a ledger, timestamped and via consensus enclosed into a block (Mathews, et al., 2017). These data are accessible to all users and thus become visual evidence of trust. The trust model is consequently altered when new players join the network and implement a new blockchain application. Safa, et al. (2019) emphasise that blockchain technology is not meant to substitute BIM, but it can be seen as innovating the existing BIM processes. This is reinforced by Mason (2019), who asserts that smart contracts are a "complementary" technology, which might be the key for BIM to succeed. Andersen, et al. (2018), had shown the potential of blockchain in the facility maintenance phase for the safe storing of sensitive sensor data acquired by building operating systems (BOS). In construction payments, it was shown (Ye, et al., 2020) that it is possible to achieve automatic and simple payments during the construction phase by using a combination of BIM model-driven data and smart contracts. Turk & Klinc (2017) Implemented an architecture for managing BIM information in the form of files through a blockchain enhanced BIM server. The idea behind this solution is to store construction files in an unchained scheme. While files are saved in the cloud or a cold server, the associated metadata or the fingerprints is stored in the blockchain. In this way, all stakeholders can retain a copy of the blockchain with the proof of existence of a file at a certain point in time. Dounas, et al. (2021) designed a BIM+Blockchain approach that does not rely on trust to deliver a design project because trust is automatically assigned to an underlying system based on the idea of the DAO (Decentralised Autonomous Organisation). The DAO acts as an entity that sets design problems as a smart contract through the Ethereum blockchain. Through the DAO, any stakeholder can participate in the design optimisation by staking tokens using their own Ethereum address. A collection of Ethereum smart contracts is programmed to perform a set of actions which include the connection of the BIM software with the Ethereum Blockchain, the definition of the design challenge, the collection of the possible solutions and the solving function. Once the solutions meet certain criteria, the loop is terminated, and incentives are awarded to participants. This approach guarantees a complete record of all design attempts, contributing to a more transparent and efficient design based on cryptographic records. A similar role to the DAO was assigned by Mathews, et al (2017) to Oracles. On this occasion, the consensus mechanism was provided by singular entities who possess specialised knowledge to execute smart contracts.

In the planning context, Nawari & Ravindran (2019) developed a complete BIM+Blockchain workflow based on Smart Contracts and automatic code checking techniques to speed up the permission process in post-disaster recovery. It was demonstrated that principles of decentralisation, privacy and transparency were successfully achieved, leading to significant savings in paperwork and time needed to issue planning permission. In this instance, achieving more trust and transparency was an essential deliverable due to the possibility of malicious individuals taking advantage of the emergency's nature and urgency. The author believes that similar conditions, such as timely and transparent building permit grants, could represent a basic need for the Irish planning to develop BIM+blockchain alternatives.

3. Research Methodology

To This research is conducted as a case study and adheres to the case study research approach according to (Yin, 2013). As opposed to multiple case studies, single cases may permit the creation of more complex theories since single case researchers can adapt their theory perfectly to the many characteristics of a given case (Eisenhardt & Graebner, 2007). Due to the scarcity of theory driving BIM and Blockchain application in planning, an inductive case study technique was employed as it is deemed the most suitable methodology for developing insights around a new subject (Eisenhardt, 1989). Generally, qualitative research methodologies, and inductive case studies, start with extensive observations of the reality. These in-depth observations will be used as the initial point for learning more about blockchain technology and BIM capabilities. For the construction of this case study and the collection of published data sources, secondary data is used with a multiple-cases and multiple investigators approach. The data for this study was acquired from public sources, including whitepapers, experts' review reports, blockchain community sites & social media sources and developers' websites. These resources enabled the researcher to triangulate findings from various pieces of information to gain a better knowledge of the subject (Yin, 1994) and enhance the validity of the case study (Yin, 2013). Firstly, a literature review was conducted to offer basic knowledge of the study's conceptual framework and identify existing research gaps. TUD Dublin library, along with Google Scholar, was the primary database utilised to acquire information. The examined literature mainly consisted of peer reviewed papers to avoid material that may not be accurate, trustworthy, or prejudiced.

The second part of this research is an inductive case study. A reference architecture for the planning practice was developed using an approach similar to that described in Grosskurth & Godfrey (2005). Because of the limited adoption of BIM+Blockchain approaches in planning, the proposed conceptual architecture was derived using two reference case studies. The first proposed by Dounas, et al., (2021) presented a public blockchain architecture based on Ethereum platform in order to solve engineering design problems. The second case study, on the contrary, designed a blockchain-based planning system supported in a private blockchain. The analysed case studies were compared to find common traits and differences using observations, logic models and cross-case synthesis (Yin, 2013). Based on the results of the previous phase, an optimal architecture was derived for the planning domain.

4. Proposed Framework

a) Defining the infrastructure – Hyperledger Fabric

To address the issues of SHD planning in building a more democratic system, this paper proposes an integrative BIM+Blockchain approach. This section will first evaluate the appropriate blockchain for storing planning data and introduce the associated platform that will host the blockchain network.

A blockchain network can be of two types: permissioned or permissionless. Anyone can join and start submitting transactions in a permissionless network (or public network) such as Bitcoin and Ethereum. Most of the market's digital currency is currently powered by permissionless blockchain networks (Zhou, et al., 2019). They enable users to generate unique addresses under the form of wallets. Wallets allow users to store their own cryptocurrencies and engage with the network by processing transactions and adding data to the ledger. The transactions are verified with mining protocols either by staking tokens as collateral to validate transactions (Proof of Stake - POS) or by using computational power to solve complicated mathematical problems (Proof of Work - POW). Permissioned blockchain networks (or private blockchains) on the other hand, are distinguished by the fact that they need authorisation protocols to enable users to join the network. They are typically employed by centralised organisations such as public authorities, businesses and consortiums. These blockchains are usually more versatile than permissioned ones by giving the participants a significant degree of customisation and privacy (Castro & Giraldo, 2020). In the construction management framework, while there are arguments (Dounas, et al., 2021) sustaining permission-less blockchain as an instrument to assign trust to the technical system instead to the network members, the tendency is to believe that permissioned types of blockchain are best suited for purpose (Nawari & Ravindran, 2019; Mathews, et al., 2017). A permissioned blockchain is a method of protecting data transfers between members of organizations who share a common purpose but have intellectual property rights that they must safeguard when sharing information between the networks. Also, the high degree of confidentiality in the AEC (Architecture, Engineering and Construction) industry requires that only permissioned members are allowed to join the network and exchange data while a strict number of users with specific technical knowledge can trace back or audit transactions. If a permissionless approach was used in a planning framework, experts and non-experts might give equal contributions to the planning process. This might result in eroding the knowledge and decision-making capacity of the experts. These privacy and control access requirements will suggest a permissioned blockchain to be an optimal solution for the planning system.

Between private blockchains, one of the most adopted architectures is the Hyperledger Fabric (Zhou, et al., 2019), and this will be used for the purpose of this research. In particular, Hyperledger Fabric (HLF) is chosen for its properties of scalability, privacy and access control over the planning data, reducing the time to store and share information, improving trust and lowering the overall costs. Hyperledger is a private blockchain initiative of the Linux Foundation. Since its creation, it has become a popular platform attracting the attention of big corporations such as Microsoft and IBM. Among Hyperledger projects, "Fabric" is the most popular. With the first version launched in 2018, HLF presented a permissioned blockchain structure for running smart contracts. It is particularly suited for a group of identified individuals who have common objectives but lack trust in each other. Unlike the execute-order structure, typical of traditional blockchain platforms, Fabric presents an "execute-order-validate" architecture with a pluggable Byzantine-fault tolerant consensus protocol (Manevich, et al., 2021). Under this scheme, the transaction flow is divided into three steps: firstly, a transaction or smart contract executed and endorsed by a subset of peers; the outputs of the execution are then ordered via a customizable consensus protocol by the ordering nodes who group transactions into blocks and broadcast to the validator nodes; transactions are then validated in the third and last phase against a specific system policy and finally added to the ledger.

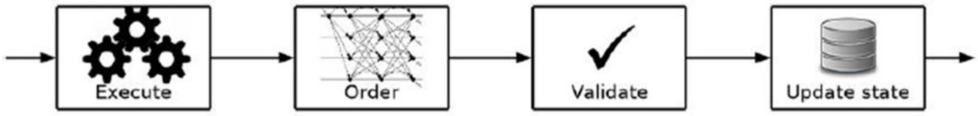


Fig. 2: Execute-order-validate architecture of Fabric (Colyer, 2018)

In the HLF framework, a client is an application which proposes a transaction over the network on behalf of an individual. The roles that run the system are mainly Peers and Ordering Service. Peers, who can be endorsers or committers, keep track of the network status and retain a copy of the ledger. On the other hand, the ordering service receives approved transactions, organizes them into blocks, and distributes the blocks to the committed peers. As mentioned, there are two different roles for peers: endorser peers simulate and endorse transactions while committer peers validate transaction outcomes before committing to the blockchain. Although this difference, there is an overlapping of roles because the system is designed to make a peer always committer. Other main functionalities that distinguish Hyperledger Fabric from traditional blockchains are:

- Smart Contracts (chaincode): In Hyperledger “chaincodes” are the equivalent of Smart Contracts. They are essential for the network’s- routine operations, defining how assets are exchanged or manipulated. As per Smart Contract, chaincodes assume the form of computer programs containing certain logic to perform transactions. They are expressed in Go or eventually in Java language.

- Membership Service Provider (MSP): The MSP is the system that provides the rules for validating and authenticating users’ identities. This component manages users IDs and grants access to the network by giving credentials to customers to request transactions.

- Channels: Channels enable organisations to share the same network while keeping separate blockchains. Transaction details are visible only to the member of the channel where the transaction was initiated. This is possible because each peer belonging to a given channel can retain multiple ledgers.

The next section will focus on the technical aspects of solving the trust problem in the SHD housing. A case study will be presented implementing the high-level framework described in this section. This example is designed not to revolutionise the current SHD process but to modernise the current practice with a BIM+Blockchain approach. Since the objectives are to speed up and bring more transparency to the fast-track planning legislation, the following structure will be proposed: a BIM model-checking module which will substitute the pre-consultation phase with the local’s planning authority and a document management module which will provide proof of trust among the parties in the consultation stage with An Board Pleanála.

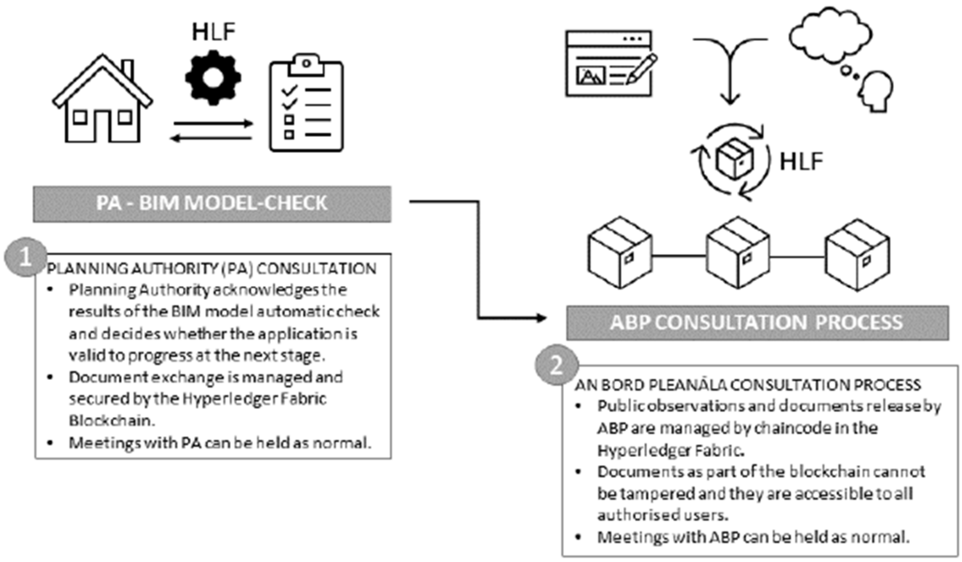


Fig. 3: Model-checking and document management module overview

b) Automatic Model Checking Transaction Flow

As discussed by Nawari & Ravindran (2019) it is possible to achieve a model code-checking compliance by using HLF in a BIM workflow. The idea behind this strategy is to keep both planning code and BIM models "off-chain" and invoke a chaincode capable of acting as a model checker. In order to do this, a smart contract (chaincode) needs to be able to process into computer language the planning rules written as ordinary pieces of legislation. Another study proposed by Nawari (2019) showed that such an approach could be possible by employing a Transformation Reasoning Algorithm (TRA) that transforms standards and regulations into computer language and run code compliance based on BIM models' object extractions via ifcXML. This algorithm can be written as smart contract, or if all the planning legislation terms are not supported, it can be expressed directly in a scripting language and then be invoked by a chaincode. For simplicity, at the time of the model submission, it is assumed that the planning code is accessible as a scripting language and stored in an off-chain database. The structure of the checking mechanism is presented as follows:

1. The first step consists in storing the BIM model data off-chain. This will allow the invoked chaincode to access read/write key-value pairs in the dataset and perform the function of code checking in the following phase. The BIM model is exported into a ifcXML by the client's application and distributed into the authorised peers' side storage via gossip data dissemination protocol. The hash of the file could be retained in the main ledger as non-tampering proof.
2. A model checker in the form of a smart contract is invoked with a transaction in the HLF. The model data are then verified against the translated rules, and

a report is generated with an appended smart contract to notify the client of the results. two models use a similar approach following the Hyperledger Fabric blockchain transaction flow and can be implemented independently from one another based on the exigencies of the planning network or due to technological barriers.

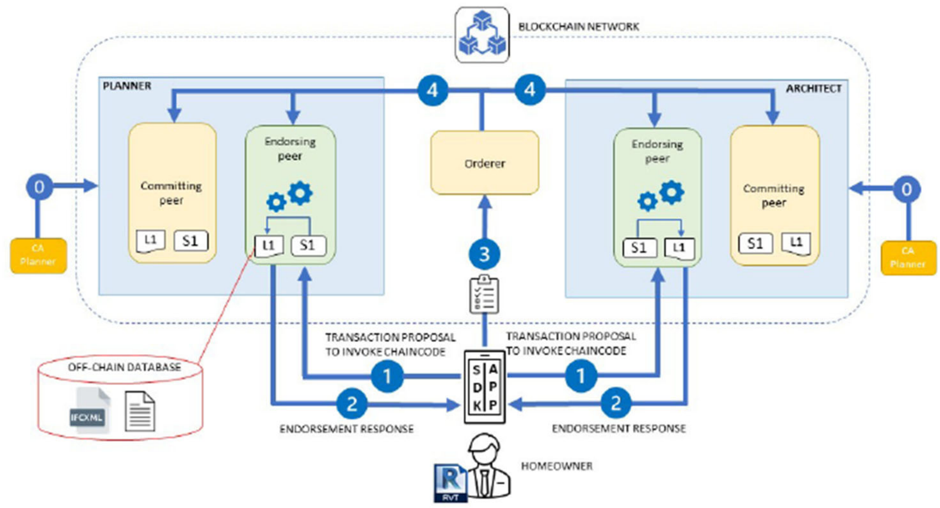


Fig. 4: Model-checking typical transaction flow

In the HLF planning network, such transaction flow will follow this structure:

1. The homeowner or architect is sending a request to the planning authority under the SHD housing scheme. This request includes a BIM model as part of the pre-checking stage previously described. The request is processed by the Software Development Kit and translated in a proper format to create a data exchange proposal. Essentially this proposal consists of a request to invoke a smart contract that will read/write key value pairs in the ledger. A digital signature is generated using the cryptographic credentials of the user. This part corresponds to number (1) in the Figure above.

2. In part (2), the endorsing peers verify that the proposal is well formulated, it was not previously submitted, and that the client's signature is correct by checking the certificate authority (CA) previously released by the MSP. This endorsement policy is triggered automatically in every smart contract. Then the nodes simulate the transaction by running the invoked chaincode, which reads the key-values associated with the BIM model and planning legislation. Note that there are no updates to the ledger at this stage.

3. The peers' response arrives to the application (3). The response includes the data read results and the peers' signature. At this point, a chaincode present in the application, previously encrypted and discretised into blocks, performs the functions of code-checking. Since this program could consist of several chaincodes it is executed by a separate code-checking service application and expressed in C#

or Java. Finally, the model's key-values are checked against the translated planning rules, producing code-compliance results.

4. The checking results are passed to the ordering service that validates transactions, group them into blocks, and (4) transmit blocks to all network peers. The blocks will be appended to all nodes of the planning network, and an event is invoked from the application to notify the client that results are available.

This approach should provide a record of every code-checking transaction that happens in the planning network. Also, the computational mechanism is designed to perform as many operations as possible off-chain, leaving only the transactions metadata stored in the primary ledger. This ensures a fast and reliable code-checking performance with the advantages of discretisation and privacy offered by a blockchain methodology.

c) Automatic code compliance checking (ACCC)

Achieving automatic code compliance checks is a crucial requirement to ensure that the principles of cost-effectiveness and design efficiency are implemented in the planning practice. As previously mentioned, there is an increasing research interest in implementing ACCC processes in the planning practice, yet the proposed solutions are not suitable for a generalised framework using Industry Foundation Classes (IFC) data standard. However, a recent study by Nawari (2019) aims to develop a Generalised Adaptive Framework (GAF) for IFC models that enables effective ACCC techniques. The concept behind this approach is to develop an object-based representation of the building rules (Malsane et al., 2015) obtained from the transformation of the written code into computable, semantic-rich information. Secondly, a design review is processed by invoking algorithms that access and link BIM and regulations using ifcXML format. An overview of the ACCC methodology is proposed in the following figure.

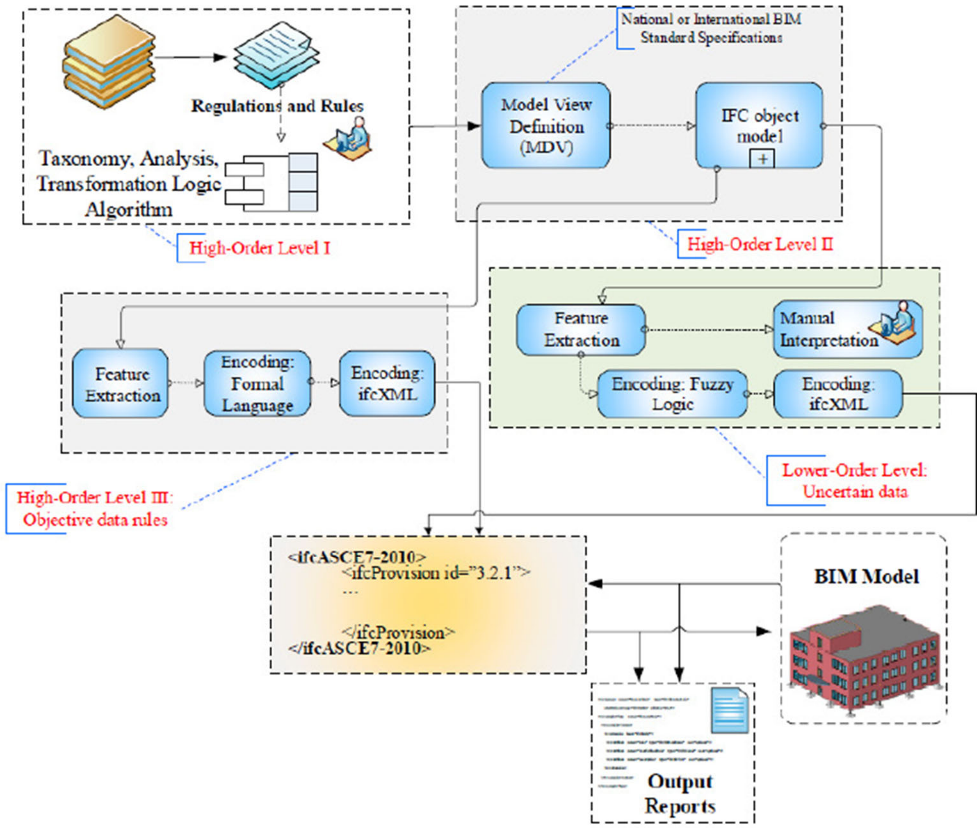


Fig. 5: ACCC Architecture (Nawari, 2019)

The proposed architecture defines initially standardised extraction protocols for the translation of the code requirements from textual rules into computable language. This phase is also known as the “Tranformation Reasoning Algorithm” (TRA) (Zhang & El-Gohary, 2015). Under TRA, the regulation clauses are classified into four categories: contents (descriptions), provisory (explicit rules), dependent (on provisory clauses) and ambiguous (fuzzy logic). These groups are automatically formed using computer code after data analysis, splitting and categorising the regulation language. Subsequently, the produced knowledge is used to develop a Model View Definition (MVD) standard that supports a specific IFC data schema. The following phases employ extraction algorithms intending to build the ifcXML data object model. This is undertaken under a higher-level order (unambiguous data) or lowerlevel order (ambiguous data). The final part of the framework includes a compliance check handled with Language-integrated Query (LINQ) programs. These algorithms can access and confront the information obtained from the BIM model on one side and regulations expressed in ifcXML on the other side. As a result of these checks, reports are produced in 3D or 2D format showing the objects that are not compliant with the current building regulation.

The main advantage of this approach is the adaptability provided by the TRA algorithms to handle different building codes as opposed to “Black Box” or “Grey

Box" techniques (Nawari, 2019). These offer hard coding rules suited for a specific purpose that in many cases are deemed to be costly to maintain and inflexible to change due to the absence of a generic framework for modelling building rules and regulation (Nawari, 2019). GAF could bring considerable benefits to the AEC industry in automatic code compliance checking. However, the degree of complexity of such methods is very high, and the implementation cases are limited to simple buildings spaces assessed with few different building codes (Nawari, 2019). Thus, more research is needed to assess this technology under various designs and regulations properly.

d) Document Management in HLF

This section aims to democratise the SHD planning by building trusted relationships within the Hyperledger Fabric protocol. Immutability is one of the main proprieties of blockchain technology, and this implies that the data in the ledger can never be altered (Dounas, et al., 2021). With this logic, trust among parties could be enforced by building a blockchain-based document database that keeps cryptographic proof of the existence of documents at a given time. This platform could be built on top of an existing project dashboard allowing authorised users to securely access documents and automatise various tasks by employing smart contracts. The main functionalities of such a scheme are explained in figure 6.

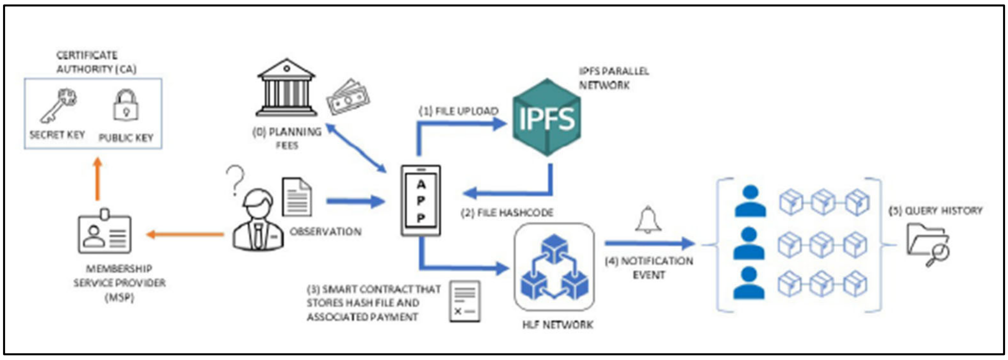


Fig. 6: Document Management in the planning framework

The image shows a typical process of storing planning files in a case of public observation. Any individual who wants to participate in the planning process must firstly prove his identity to the network. Identities are issued by Certificate Authorities which generate a public and private key pair to sign or endorse transactions digitally. The Membership Service Provider (MSP) keeps a record of the peers' public keys that are used to verify the validity of a transaction. In this way the MSP ensures that all identities of the network are trusted without disclosing the peers' private keys.

Once users are verified, a request to submit an observation is made by the client application and a planning fee is processed. Since the capabilities of the Hyperledger Fabric to support token's transactions are under development and there are no built-in cryptocurrencies, custom token solutions can be programmed to be used in conjunction with smart contract (Lee, et al., 2020). Payments using HLF framework are currently the subject of research interest in the electric vehicles charging system (Jamil, et al., 2021; Khan & Byun, 2021). Such solutions employ smart contracts that automatically trigger at the completion of the charging process to generate payment requests and automatically balance the transaction between the parties. Similarly, in the planning context, a chaincode could be initiated by the client requesting the submission of a document to the planning authority. The PA will charge the fees the smart contract that will automatically deduct the tokens from the e-wallet of the owner. After the transaction is made, every participant will get a success notice.

At the payment, the application will initiate the observation upload under the form of a .pdf or .docx file. Since storing large files in the blockchain usually leads to performance issues, storing data in it is necessary to store data in a sideDB or in an offchain database (IBM, 2018). Only the hash of the file is generated and stored in the blockchain along with other transaction details. According to Desai, et al. (2020) and Ye & Park (2021) Interplanetary File System (IPFS) could be used in combination with HLF blockchain to achieve successful off-chain storage of files. The process involves the previous creation of a parallel IPFS network that will store and encrypt the file. In the given example, the client's application is instructed to upload the file in the IPFS database so that the returned hash is inserted in a smart contract that will store it in the blockchain. Note that this smart contract could be triggered from the precedent chaincode at the event of the fees' payment and could be further developed by inserting time-limit conditions for ABP to respond. Usually, chaincodes owning subchaincodes should be preferred for their capability to manage all data in one contract, thus increasing data security (Ye & Park, 2021).

Finally, a new block with the associated transaction details is committed to the ledger, and the SDK (software development kit) executes a peer-based channel event to notify the users. In HLF, an event is a program-detected activity, so when a new block is committed to the peer's ledger, the Fabric client gets informed. This event service can deliver filtered blocks containing a minimal set of information to enhance privacy. Also, further actions could be triggered by the client's application after being notified.

When a transaction is validated and committed to the blockchain ledger, the process is considered complete. The data in any given block cannot be changed retrospectively without affecting all future blocks, which needs the network's majority agreement or the involvement of an Oracle. This characteristic ensures that trust is finally established within the planning network.

In HLF, the block data are arranged as a list of transactions that are packaged and ordered by the ordering service in a well-defined sequence. In a situation where multiple planning applications are processed simultaneously, all transactions referencing different planning permission might be
batched in the same block. This happens because the ordering nodes create blocks based on the received transaction in chronological order. From this arises the necessity to dispose of tools that help stakeholders to query data based on specific criteria such as planning ID or submission date. At present, the development status of Hyperledger Fabric allows viewing all ledger's relevant information such as blocks, transactions,

and network data in a web application. However, none of the existing tools can perform sophisticated queries on transactions and blocks, nor can they monitor the state's database operational history. Zhou, et al. (2019) investigated the possibility to query blocks or transactions effectively by employing a ledger data analysis middleware. The proposed "Ledgerdata Refiner" framework extracts ledger data from a Hyperledger Fabric-based blockchain network and saves the outputs in a third-party database. As long as a client certification is supplied, Ledgerdata Refiner can be connected to any fabric network peer to synchronize ledger data and parse the relationship between them.

This functionality offers an enhanced data view for users by providing schema overview and customizable inquiry on ledger states. Since information is stored in the form of <key,value> in the ledger, in a potential planning framework, anyone could retrieve information about a specific planning application by querying a specific planning ID number (with a given planning ID "00001" the query condition may be like 'PlanningInfo.PlanninngElement.ID="00001").

5. Results & Discussion

The first notable finding of this work suggests a positive synergy between BIM and Blockchain to address construction problems and improve the current planning practice. From one side, the literature review has shown that BIM methodologies enable better decision-making and a better understanding of the project deliverables within the SHD context. From the other side, it was demonstrated that Blockchain technologies could solve the problem of privacy and transparency that represented a fault in the current legislation around Fast Tracking. An inductive case study was developed to validate this theory and demonstrate the compatibility of a BIM+Blockchain approach. The main functionalities of the presented architecture can be summarised as follow:

- Any electronic document (public observations, planners' document release, BIM model files, drawings, etc.) is encrypted, timestamped, and published in the planning blockchain.
- Designers and planners can perform automatic model checks against the current planning legislation using TRA algorithms.
- Users (typically homeowners, architects, and planners) are notified by a smart contract when a new document is released. The same smart contract will enforce a defined timeframe to respond, if relevant.
- At the end of the planning process, a complete history of the application is available to authorised users by using history data retrieval and filtering functions in the Hyperledger Fabric blockchain.

Since Hyperledger Fabric's projects are still in the early stages of implementation or testing, the present research is mostly based on whitepapers and peer reviewed articles, supplied with other high-quality information sources when available. While the examination of secondary data enables a complete understanding of the subject, they only provide preliminary information on the value of BIM and Blockchain applications in SHD planning. Also, due to the current technological capabilities, the employability of such a framework in a real-case scenario might be consistently limited. Future research may need to simplify and condense the proposed methodology to consider standard planning cases.

6. Conclusions

Lack of transparency, poor record-keeping, and irregularities have historically characterised the Irish planning system to date. Transparent planning can generate more inclusive and sustainable economic growth by increasing the accountability of communities. Improved accountability ensures that all urban policies are implemented with all demographic groups. It also fosters trust among people and allows for active engagement. If transparency is taken into account in planning developments, cities would be able to provide services and infrastructure more successfully. Trusted relationships between planners and local governments also allow planners to identify the needs of the citizens and deliver better policies.

Through BIM+Blockchain this research has established a digital trusted relationship in the planning system. The proposed architecture is designed to enhance better transparency in the SHD planning by using specific capabilities in the Hyperledger Fabric. Moreover, by exchanging BIM files within the planning network, users can improve their comprehension around a specific planning application, leading to better decisions and reduced errors due to misinterpretation of the design characteristics.

This framework provides a solid theoretical foundation for developing BIM+Blockchain integrated solutions in the SHD Irish planning framework. The presented case study has shown that all the relevant pieces of technology contribute towards a more transparent SHD planning network. Future research is needed to evaluate the feasibility of the proposed framework in a real-world scenario.

References

Altıntas, Y. D. & Ilal, M. E., 2021. Loose coupling of GIS and BIM data models for automated compliance checking against zoning codes. Automation in Construction, Volume 128.

Andersen, M. P. et al., 2018. Democratizing Authority in the Built Environment. ACM Transactions on Sensor Networks, 14(3-4), pp. 1-26.

Buterin, V., 2014. A next-generation Smart Contract and Decentralized application platform. Ethereum White Paper, pp. 3-37.

Castro, C. I. & Giraldo, O., 2020. Academic Certification using Blockchain: Permissioned versus Permissionless Solutions. The JBBA, 3(2).

Colyer, A., 2018. Hyperledger fabric: a distributed operating system for permissioned blockchains. The Morning Paper.

Cong, L. W., Zheng, J. & Zhiguo, H., 2017. Blockchain Disruption and Smart Contracts. SSRN Electronic Journal.

Desai, S. et al., 2020. Blockchain Based Secure Data Storage And Access Control System Using Ipfs. Journal of Critical Reviews, 7(19).

Dounas, T., Lombardi, D. & Jabi, W., 2021. Framework for decentralised architectural design BIM and Blockchain integration. International Journal of Architectural Computing, 19(2), pp. 157-173.

Eisenhardt, K. M., 1989. Building Theories from Case Study Research. Academy of Management Review, 14(4), pp. 532-550.

Eisenhardt, K. M. & Graebner, M. E., 2007. Theory Building from Cases: Opportunities and Challenges. The Academy of Management Journal, 50(1), pp. 25-32.

Grosskurth, A. & Godfrey, M. W., 2005. A Reference Architecture for Web Browsers. Proceedings of the 21st IEEE International Conference for Web Browsers, pp. 661-664.

Hjelseth, ., 2015. Public BIM-based model checking solutions: lessons learned from Singapore and Norway. Building Information Modelling (BIM) in Design, Construction and Operations, pp. 1743-3509.

IBM, 2018. Why new off-chain storage is required for blockchains, s.l.: s.n. [14] Jamil, F. et al., 2021. PetroBlock: A Blockchain-Based Payment Mechanism for Fuelling Smart Vehicles. Applied Sciences, 11(3055).

Khan, P. W. & Byun, Y.-C., 2021. Blockchain-Based Peer-to-Peer Energy Trading and Charging Payment System for Electric Vehicles. Sustainability, 13(7962). Kim, I., Choi, J., Teo, E. A. L. & Sun, H., 2020. Development of KBIM E-submission Prototypical System for the Open BIM-based

Building Permit Framework. Journal of Civil Engineering and Management, 26(8), pp. 744-756.

Kim, J. I., Kim, J., Fischer, M. & Orr, R., 2015. BIM-based decision-support method for master

planning of sustainable large-scale developments. Automation in Construction,

Volume 58, pp. 95-108. [18] Lee, Y.-T., Lin, J.-J., Hsu, J. Y.-J. & Wu, J.-L., 2020. A Time Bank System Design on the Basis of Hyperledger Fabric Blockchain. Future Internet, 12(5: 84). Lennon, M., 2019. Planning's Position in the 'Hollowing-Out' and 'Filling-In' of Local Government in Ireland. Planning Theory & Practice, 20(4), pp. 612-618.

Lennon, M. & Waldron, R., 2019. Dedemocratising the Irish planning system. European Planning Studies, Volume 27, pp. 1607-1625.

Manevich, Y., Barger, A. & Assa, G., 2021. Redacting Transactions from Execute-Order-Validate Blockchains. s.l., 2021 IEEE International Conference on Blockchain and Cryptocurrency (ICBC).

Mason, J., 2019. BIM Fork: Are Smart Contracts in Construction More Likely to Prosper with or without BIM?. Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 11(4).

Mathews, M., Robles, D. & Bowe, B., 2017. BIM+Blockchain: A Solution to the Trust Problem in Collaboration, Technological University Dublin. [24] McCarthy, G., 2018. The Irish Planning System. Galway, GMIT.

McNally, J., 2019. The potential impact of BIM- on early design stages of Residential Apartment

Construction in Ireland: A computational Design Approach. s.l.: Capstone Report. Technological University Dublin. Mitchell McDermott, 2021. Strategic Housing Development Infocard. [Online] Available at: https://mitchellmcdermott.com/

Monaghan, B., 2015. A Framework for Integration of Building Information Modelling Into the Irish Planning and Building Control System, Dublin: Dublin Institute of Technology

Nawari, N. O., 2019. A Generalized Adaptive Framework (GAF) for Automating Code Compliance Checking. Buildings, 9(4), p. 86.

Nawari, N. O. & Ravindran, S., 2019. Blockchain and Building Information Modelling (BIM): Review and Applications in Post-Disaster Recovery. Journal of Building Engineering, 25(8).

Olsson, P.-O., Axelson, J., Hooper, M. & Harrie, L., 2018. Automation of Building Permission by Integration of BIM and Geospatial Data. International Journal of Geo-Information, Volume 7, p. 307.

Olsson, P.-O., Axelsson, J., Hooper, M. & Harrie, L., 2018. Automation of Building Permission by Integration of BIM and Geospatial Data. International Journal of Geo-Information, 307(7).

Plazza, D., Röck, M., Malacarne, G. & Passer, A., 2019. BIM for public authorities: Basic research for the standardized implementation of BIM in the building permit process. IOP Conference Series: Earth and Environmental Science, Volume 323. Pradeep, A. S. E., Amor, R. & Yiu, K. T. W., 2020. Blockchain Improving Trust in BIM Data Exchange: A Case Study on BIMCHAIN. Construction Research Congress 2020, pp. 1174-1183.

Reddy, T., 2004. Planning inconsistency 'pushing up costs'. [Online] Available at: https://www.irishtimes.com/news/planninginconsistency-pushing-up-costs-1.988766

Safa, M., Baeza, S. & Weeks, K., 2019. Incorporating Blockchain technology in construction management. Strategic Direction, 35(10), pp. 1-3. [36] Turk, Ž. & Klinc, R., 2017. Potentials of

Blockchain Technology for Construction Management. Procedia Engineering, Volume196, pp. 638-645.

Ullah, K., Raitviir, C., Lill, I. & Witt, E., 2020. BIM Adoption in the AEC/FM Industry – The case for issuing building permits. International Journal of Strategic Property Management, 24(6), pp. 400-413.

Van Berlo, L., Stoter, J. & Dijkmans, T., 2013. Experiment for Integrating Dutch 3D Spatial Planning and BIM for Checking Building Permits. ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., Volume II-2/W1, p. 279–284.

Williams, B. & Nedović-Budić, Z., 2020. Transitions of Spatial Planning in Ireland: Moving. Planning Practice & Research. [40] Williams, B. & Varghese, J., 2019. Examining the Impact of EU Cohesion Policies Aiming to Reduce Regional and Social Disparities with Example of Policy Impacts in Ireland. EUROPA XXI, Volume 35, pp. 89-109.

Xu, Y., Chong, H.-Y. & Chi, M., 2021. A Review of Smart Contracts Applications in Various Industries: A Procurement Perspective. Advances in Civil Engineering, p. 25 pages.

Ye, H. & Park, S., 2021. Reliable Vehicle Data Storage Using Blockchain and IPFS. Electronics, Volume 10, 1130.

Ye, X., König, M. & Sigalov, K., 2020. Integrating BIM- and Cost-included Information Container with Blockchain for Construction Automated Payment using Billing Model and Smart Contracts. s.l., s.n.

Yin, R. K., 1994. Discovering the Future of the Case Study Method in Evaluation Research. Evaluation Practice, 15(3), pp. 283-290.

Yin, R. K., 2013. Case Study Research Design and Methods. 5th Edition a cura di Thousand Oaks, CA, USA: Sage Publications.

Zhang, J. & El-Gohary, N., 2015. Automated Information Transformation for Automated Regulatory Compliance Checking in Construction. Journal of Computing in Civil Engineering, Volume 29.

Zhou, E. et al., 2019. Ledgerdata Refiner: A Powerful Ledger Data Query Platform for Hyperledger Fabric. IEEE.

.

THE FUNCTION, DESIGN AND CONSTRUCTION OF THE BRITISH BUNKER AT UNIVERSITI SAINS MALAYSIA

SYED FADZIL, S.F., BAHDAD, A.A.S.
School of Housing, Building and Planning, Universiti Sains Malaysia
Email address: sfsf@usm.my
Email address: alibahaddad@gmail.com

Abstract. Universiti Sains Malaysia is located on a 500-acre site in Penang. The university site was once the location the British Barracks during the occupation in World War II, and during the war with Japan. There are many buildings left by the British on this site and many still stand strong. This bunker, 2 identical ones, however, are often neglected. No one seems to pay much attention to them. These bunkers, presumably a century old already, are now being converted to chemical stores housing organic and inorganic chemical compounds for sale or for use in the university. Careful investigations reveal that there are many interesting things which can be learnt from these bunkers, and amongst them the secret tunnels which surrounds the main space. This paper will dwell on the unique design and construction of the bunker, and the efforts done to do detailed measurements and drawings of them to be archived and kept for the future generation. This paper is hoped to instil awareness of the structures which were left in Malaysia by the British especially in the areas of heritage appreciation and conservation, and the quality construction in the past which is usually forgotten presently

Keywords: Design. Function, Construction, Bunker.

1. Introduction

1.1 BRIEF HISTORY OF THE COLONIZATION OF MALAYSIA

From most history book being used to teach in the Malaysian schools, the Portuguese were the first European colonial powers to establish themselves on the Malay Peninsula and Southeast Asia, capturing Malacca in 1511, and that was followed by the Dutch in 1641. However, after initially establishing bases at Jesselton, Kuching, Penang and Singapore, it was the English who ultimately secured their hegemony across the territory that is now Malaysia. Japanese invasion during World War II ended British rule in Malaysia (at that time Malaya). In the Peninsula also, the Malayan Communist Party took up arms against the British and the tension led to the declaration of emergency rule for more than 10 years. A serious military response to the communist insurgency in 1955 led to the establishment of independence for Malaya on 31 August 1957 (then called Malaysia) through diplomatic negotiation with the British. The term "British Malaya" loosely describes a set of states on the Malay Peninsula that were brought under British control between the late 18th and the mid-20th century, and it was during those times that many buildings were built with their distinct British colonial architecture. A lot has been written about the British architecture in Malaysia (Ahmad, 2004; Chun, 2005; Henderson, 2004). However not much has been written and researched on the bunkers which is another building typology left by the British in Malaya.

1.2 BUNKERS AT USM – DESIGN AND USE

A bunker is a defensive military fortification designed to protect people and valued materials from falling bombs or other attacks. Bunkers are mostly underground, in contrast to blockhouses and barracks which are mostly above ground, and some are used to store ammunition and other chemicals used in war like gunpowder and dynamites. Some bunkers were used as command-and-control centres, and storage facilities. Bunkers can also be used as protection from tornadoes, in countries where there can be a common occurrence of them. However, in Malaysia underground protection spaces like basements and sub basements are not usually in use as tornadoes are not common occurrence and there is not much need for them.

Malaysia is one of the countries located in Southeast Asia along with neighbouring countries like Brunei, Singapore, Indonesia and Thailand (Figure 1). Penang (Figure 2) is one of the 14 states in Malaysia, and it is an island with some part of it being in the Peninsular, connected to the island via 2 bridges. Penang is the location of one of the biggest and oldest public university in Malaysia which is the Universiti Sains Malaysia or USM in short.

Universiti Sains Malaysia is located on a 500-acre site in Penang (Figure 3 and Figure 4). The university site was once the location the British Barracks during the occupation in World War II, and during the war with Japan. There are many buildings left by the British on this site and many still stand strong. Other than the colonial buildings seen in the figures, this paper is a study carried out on an often-neglected structure which is the bunker.

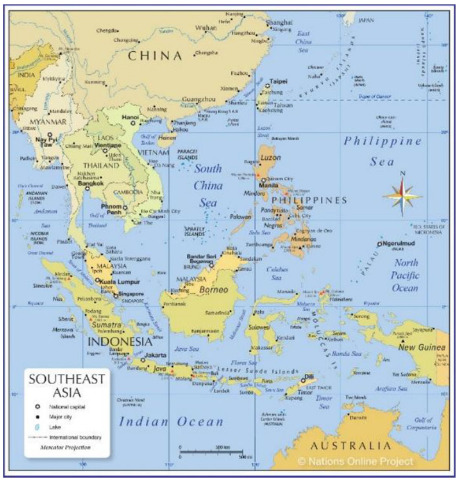


Figure 1. Map of Malaysia (red box) in Southeast Asia (Penang in the red dot)

Figure 2. Map of Penang (Usm in red box)

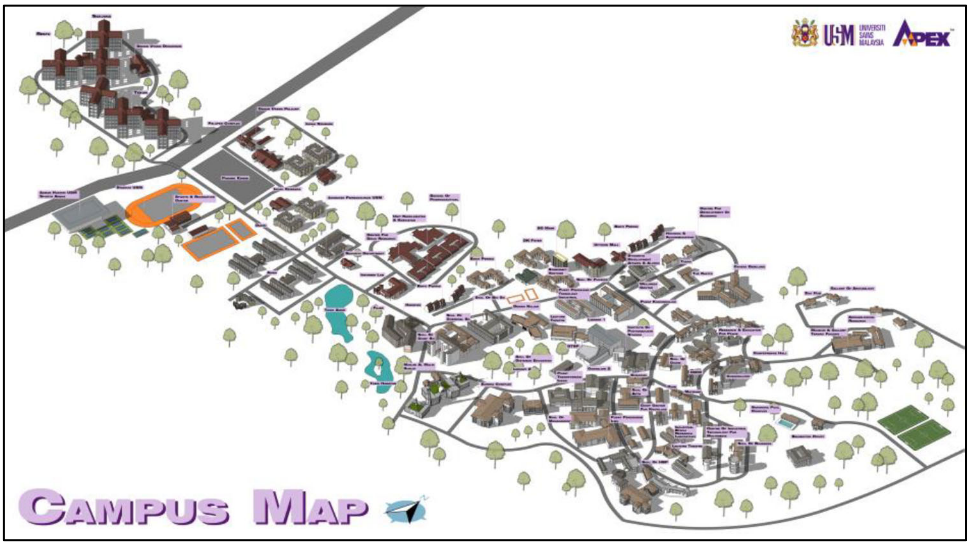


Figure 3. USM Campus map with the bunker location in red box

Figure 4. Images of USM as a British Barrack (source: Google)

On the USM site, this bunker, originated as 2 identical ones, a pair, at a distance of approximately 25m from each other (Figure 5 and Figure 6). No one seems to pay much attention to them. These bunkers, presumably a century old already, are now being converted to chemical stores housing organic and inorganic chemical compounds for sale or for use in the university and nearby industries needing them. Words of mouth from very senior Penangites with parents working as soldiers during WW2 indicated to us that these bunkers at USM were ammunition dumps used to store explosives, gun powder and others

Careful investigations reveal that there are many interesting things which can be learnt from these bunkers, the architecture and construction, the materials, and the secret tunnels which surrounds the main space.

Figure 5. Front view of one of the bunkers at USM

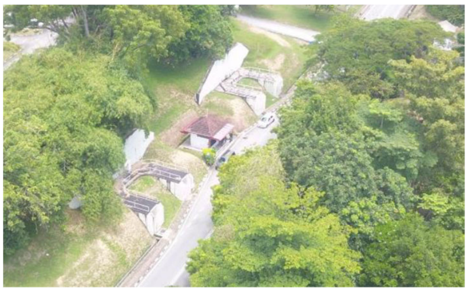


Figure 6. Aerial view capturing the 2 identical bunkers

2. Methodology

This short research is undertaken to measure and draw the bunker in effort to have them safe and carefully archived as they might not to be able to withstand for long. Much of the elements were found to deteriorate and not in its original design anymore. There also has not been any documented drawings of these bunkers but it is understood as military bunkers are designed in secrecy and in highly confidential manner to protect them from the enemies. Usually, architecture students prefer to do measured drawings of bigger colonial buildings above ground with more architectural elements existing which can be learnt from. This research was carried out in the following steps.

First, visual and observation study was carried out on the 2 bunkers and its surrounds. A compilation of photographs was kept. Also, the existing tunnels were explored and videos of them captured. Comparison between the 2 bunkers were also carried out. (Figure 7)

(a) (b)

Figure 7. (a) Examining bunker structure from outside (b) Photo from inside the bunker space.

Second, detailed measurements were done in the conventional way via measuring tape and manual recording of data. It is the intention of the research to do more sophisticated types of measurement using LiDAR and photogrammetry; but for the

initial research all were using the traditional methods as access to site and to the bunker was easy and the building scale was small, tolerable and practical (Figure 8).
Third, detailed drawings of the bunkers using CAD were done based on the measurements. In the process – some approximations were needed when exact measurements manually cannot be achieved like the thickness of the structures and the depth of the soil on top.

(a) (b)

Figure 8. (a) Floor measurements for bunker space (b) Height measurements

3. Results

3.1 OBSERVATIONS

From the observations, we found the bunker being constructed with heavy duty thick concrete and masonry walls which varied from 600 mm to 1000 mm in thickness. The roof or the construction for the bunkers top was made from heavy duty steel and wrought iron beams arranged closely together spanning 7.3m across the shorter bunker dimension. The original double doors of the bunker were made from wrought iron as well, and they are of the most unique design with special locks and ventilation slots at the bottom (Figure 9(a)) And there is also a secret tunnel which exits to the immediate surrounds outside if the main entrance were inoperable (Figure 9(b)).
Another interesting observation was a small but long narrow tunnel which surrounds the main bunker space. This tunnel is 600mm wide and 1700mm high and its total length of around 56m after several sharp turns (Figure 9(c)). Surprisingly, after going through the long tunnel which takes about 1 minute of brisk walk, it was found that the entry and the exit was actually very near, just around 4m of a distance.

(a) (b) (c)

Figure 9. (a) Wrought iron double doors as main entrance, (b) Wrought iron double doors as main entrance, (c) The tunnel surrounding the bunker space

3.2. RESULTS FROM DRAWINGS (PLAN, ELEVATIONS, SECTIONS AND DETAILS)

The drawings below are the outcome from this small research. Major measurements took 6 hours (from 9am to 3pm) with several re-visits to the site for re-confirmations.

These series of drawings shown below in Figure 10 are the resulted drawings from the measurements. The first, is the floor plan of the bunker. The 2 pairs of main doors are oriented South, and the main bunker space is indicated by the light yellow lines measures 7.32m by 20.1m which is approximately an area of 147m2. The tunnel surrounding the bunker is shown in light orange and the transitional space from the outside before reaching the bunkers double doors made of wrought iron is given in light brown. The massive heavy duty load bearing wall structures drawn to scale is given in brown. The darker brown are the drains to rid of excess water especially from heavy down pours.

On top of the main bunker space is the 22 closely spaced steel/iron beams installed with hundreds of bolts and nuts and although it cannot be seen it is assumed that concrete is poured above it to hold the weight of the soil and to give strength to the bunker space in times of war.

Below in Figure 10 also, there are drawings which represent the elevations and sections which can be referred back to the floor plan where they are taken from. The interesting door detail was drawn to scale as we find the design is very interesting and unique, therefore the drawings of them need to be safely kept and archived.

From the 4 double doors in the 2 bunkers which open up to the main bunker space, only one was found to still be in the original condition. Finally, in Figure 10 a drawing which gives a 3-dimensional image of the whole bunker is also drawn to scale.

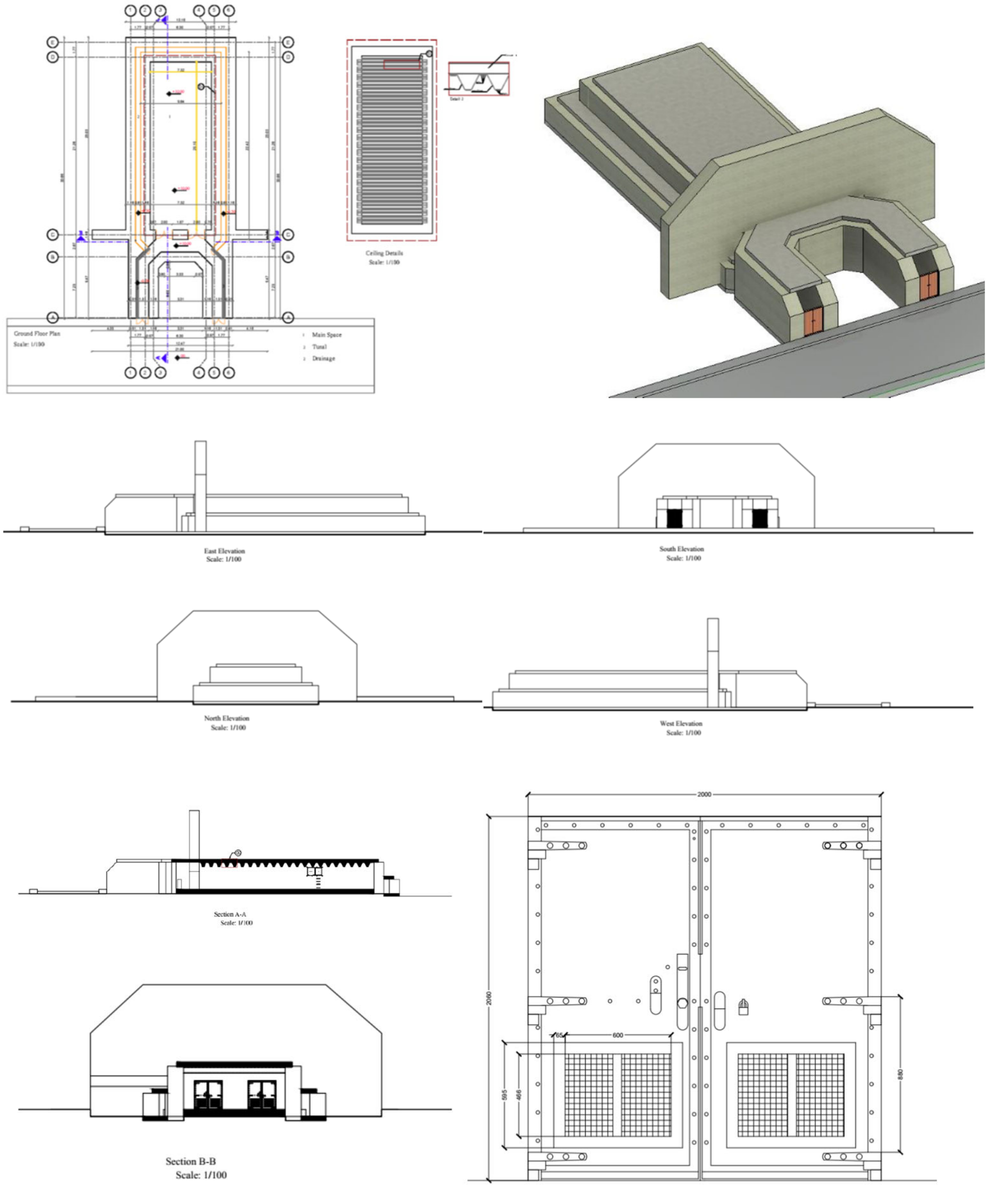


Figure 10. Some measured drawings which resulted from this research

4. Conclusions - Discussions and insights

This bunker is most probably more than a century old – and it is amazing how it still standing strong. These bunkers are unlike modern structure construction typical of the present day which are more prone to defects at earlier stages (Bagdiya et al 2015) (Pop, 2018). Pachta et al 2022 also indicated how historical buildings fare a lot better compared to modern buildings in terms of life cycle assessments and fossil fuel consumption. The technology was quite advanced then (1900s) despite the lack of modern equipment and instruments found today.

From extensive literature review, we have found that there are reasons behind the tunnel construction which surrounds the bunker. It tells us that even in 1900s the construction did not fail to consider safety aspects in the bunkers, especially those storing ammunition. According to Zhou (2011) and Opsvik (2019) care must be taken in the design of underground ammunition bunkers especially when they are prone to targeted attacks by enemies. The blast that would occur if an ammunition dump got hit by a missile, for example, is a horrible disaster affecting a huge area and probably the people living nearby. Therefore, the construction of a tunnel as seen in the USM bunker is a safety precaution, what is termed as ‘adit debris’. The tunnel would help controlling and soften the spread of the hazardous debris if explosion occurs.

There is at present no documented evidence found of the drawings of the bunkers. It is understood that being a highly secretive and confidential in nature, and in storing valuable ammunition; that any drawings and even locations of the bunkers were top security information. This is especially in times of war. Therefore, this research aims to document the structure for careful archiving before it is destroyed by those unaware of its significance and value.

This research also helps in creating awareness especially amongst the newer generation on the importance of conservation and heritage. The awareness of history and the lives of their forefathers should be instilled to appreciate the architecture and to bring down to future generation. At the bunkers presently, only one of the wrought iron double doors is still intact. The 3 others, due to dilapidation, were already changed to the normal laboratory doors to house chemical compounds. Detailed drawings which were done are very essential to show exactly how doors were like a century ago. It is hoped that the government and university will take efforts to take care of these invaluable relics of architecture which made history in Malaysia.
There will be future works in the pipeline for the bunker, namely, to utilize more sophisticated technologies to model and measure the building and to do energy and thermal simulations of the underground bunker in local tropical context similar to researches by Brecani and Dervishi (2018), (2019).

Acknowledgements

Researchers would like to thank and acknowledge the cooperation given by Universiti Sains Malaysia and GeoID Sdn Bhd for the research. Special thanks given to intern Phongsatorn Madsaman for helping in the measurements.

References

HENDERSON, J.C., 2004. Tourism and British colonial heritage in Malaysia and Singapore. Tourism and postcolonialism: Contested discourses, identities, and representations, 3, p.113.

CHUN, H.K., HASAN, A.S. NOORDIN, N.M., 2005, September. An influence of colonial architecture to building styles and motifs in colonial cities in Malaysia. In 8th International Conference of the Asian Planning Schools Association.

AHMAD, A., 1994. Conservation of British colonial buildings built between 1800 and 1930 in Malaysia (Doctoral dissertation, University of Sheffield).

BREÇANI, R., DERVISHI, S., 2019. Thermal and energy performance evaluation of underground bunkers: An adaptive reuse approach. Sustainable Cities and Society, 46, p.101444.

BREÇANI, R., DERVISHI, S., 2018. Computational Evaluation of the Thermal Performance of Underground Bunkers: The Case of Albania.

ZHOU, Y., KUMMER, P., 2011. Design of tunnel features for adit debris hazards mitigation in underground ammunition storage. Tunnelling and underground space technology, 26(1), pp.62-70.

OPSVIK, F., HOLM, K.B., ROLLVIK, S., 1996. Adit debris projection due to an explosion in an underground ammunition storage magazine. NORWEGIAN DEFENCE RESEARCH ESTABLISHMENT KJELLER.

MCCAMLEY, N., 2013. Cold War secret nuclear bunkers: the passive defence of the Western world during the Cold War (Vol. 80). Pen and Sword.

YUN, J., 2021. Bunkers as difficult heritage: imagining future for underground spaces in Seoul. Journal of Asian Architecture and Building Engineering, pp.1-12.

BELL, DAVID F. "Bunker busting and bunker mentalities, or is it safe to be underground?" South Atlantic Quarterly 107, no. 2 (2008): 213-229.

MARTIN, A.J., 2017. The Evolution Underground. Simon and Schuster.

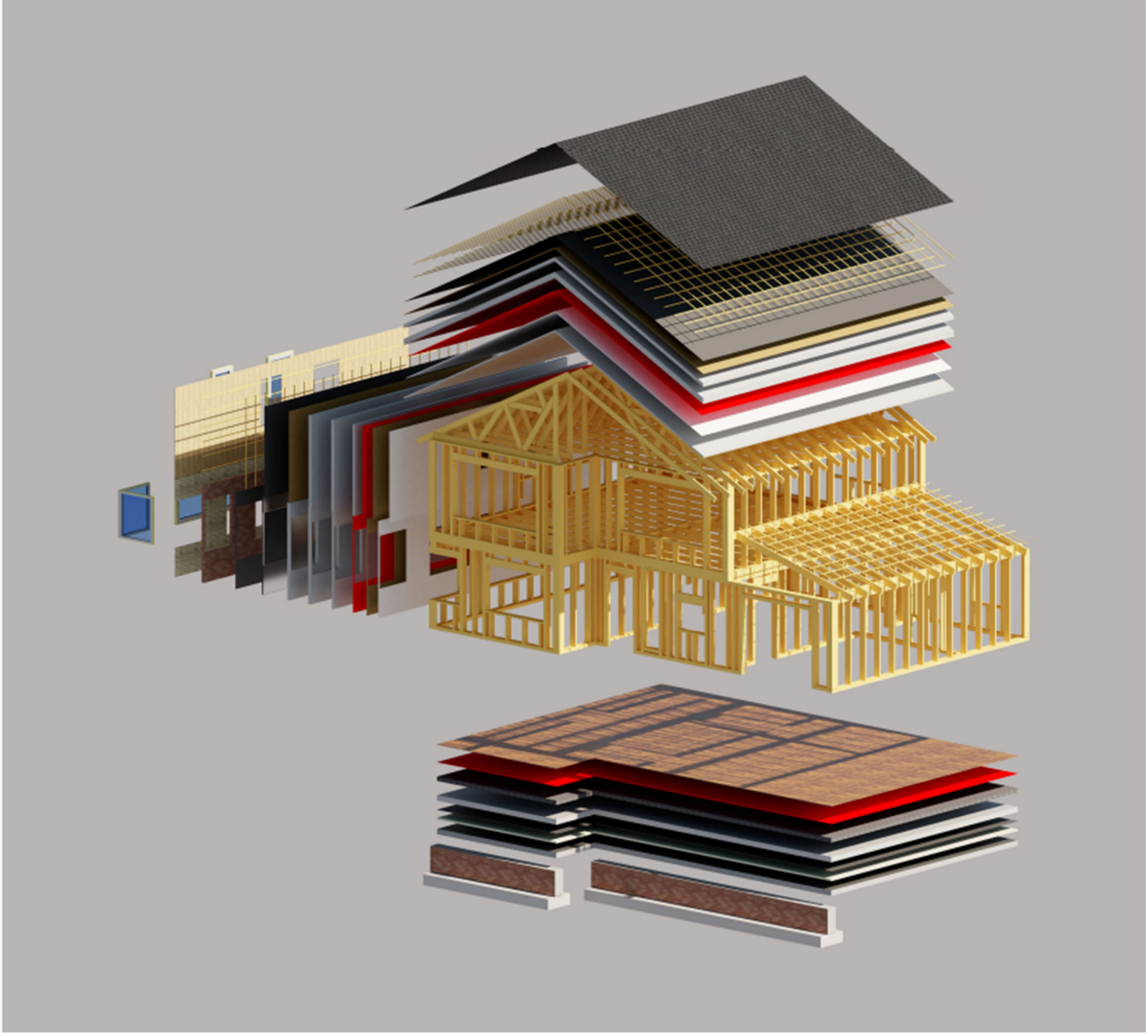
MASCO, J., 2009. Life underground: Building the bunker society. anthropology now, 1(2), pp.13-29.

GARRETT, B., 2021. Doomsday preppers and the architecture of dread. Geoforum, 127, pp.401-411.

ALEXANDER, D., 2002. From civil defence to civil protection–and back again. Disaster Prevention and Management: An International Journal.

JUMEAU, J., WOLF, D., GUTHMANN, L., GORLERO, N., BUREL, F. AND HANDRICH, Y., 2018. The use of military bunkers by the European badger and red fox in Western Europe. Urban ecosystems, 21(2), pp.395-403. POP, T., 2018. Surveying modern façades and common defects. Journal of Building Survey, Appraisal & Valuation, 7(1), pp.19-27. BAGDIYA, N.V. AND WADALKAR, S., 2015. Review paper on construction defects. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), pp.88-91.

PACHTA, V. AND GIOUROU, V., 2022. Comparative Life Cycle Assessment of a Historic and a Modern School Building, Located in the City of Naoussa, Greece. Sustainability, 14(7), p.4216.



ICAT

978-1-907349-22-5