YRSB22

iiSBE Forum of Young Researchers in Sustainable Building

Prague | 2022 July 4

Conference Proceedings

CTU CZECH TECHNICAL UNIVERSITY IN PRAGUE

iiSBE

Scientific Committee

Scientific Committee board

Petr Hájek
Jan Tywoniak
Antonín Lupíšek
Julie Železná
Kristina Fořtová
Marie Nehasilová
Magdalena Novotná
Jakub Veselka

Full papers peer review

The blind peer review process has been carried out by authors themselves, while each of them reviewed one article.

Organizing Committee

Julie Železná
Alena Bílková
Jakub Diviš
Petr Hejtmánek
Martina Liberská
Antonín Lupíšek
Magdalena Novotná
Tereza Pavlů
Kateřina Sojková
Martin Volf

YRSB22 – iiSBE Forum of Young Researchers in Sustainable Building 2022

4th July 2022, Prague, Czech Republic

Editors: Kateřina Sojková, Julie Železná, Petr Hájek, Jan Tywoniak, Antonín Lupíšek

Cover: Petr Hejtmánek

Published by Czech Technical University in Prague

Processed at Czech Technical University in Prague, Faculty of Civil Engineering, Dept. of Building Structures, Thákurova 7, 166 29 Prague 6

1st edition, Prague, December 2022, 128 pages

ISBN 978-80-01-07107-6

Foreword

The agenda of the EU Green Deal (GD) comprises actions to mitigate climate change whilst providing to EU citizens a high-quality of living. One of the key sectors with a significant potential to contribute to the GD goals are buildings, which account for 40 % of primary energy consumption and 36 % of related greenhouse gas EU emissions (GHG). The construction industry consumes a significant amount of raw materials, construction and demolition waste makes one third of the waste generated in the EU annually. EU citizens spend about 80 % of time in buildings. Therefore, improving sustainability of buildings is one of the key measures that are available to significantly support the achievement of the GD objectives.

Sustainable development has many different definitions. One of them defines it as:

„Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Agenda 21, 2001)

Due to the need to promote sustainable development because of our concerns about the environment, two major areas are at the centre of our interests: the construction industry and built environment. These two areas are the main measures of socio-economic development of each country. At the same time, however, they undeniably and significantly affect the human environment. Both positively, for example by improving the standard of living and quality of buildings, as well as negatively, in the form of various environmental aspects and impacts, such as the consumption of energy and material resources, emissions production and land occupation.

YRSB22 – Young Research Forum on Sustainable Building is organized for the fourth time together with CESB22 conference. The idea to organize Young Research SB conference as a satellite event has been initiated and developed in iiSBE – International Initiative on Sustainable Built Environment.

We appreciate that doctoral students, as well as young researchers, who already finished their doctoral studies, can present their scientific achievements and discuss their approaches with colleagues from other teams and universities from different countries. The interaction will help to improve their research and create new cooperation, networks and friendships across the borders.

The proceedings consist of 13 papers from 8 countries presented on YRSB22 conference held July 4th 2022 at the Faculty of Civil Engineering, Czech Technical University in Prague.

We would like to thank all the authors of the papers presenting results of their work in the field of sustainability. We also want to thank to Czech Technical University in Prague, University Centre for Energy Efficient buildings and Faculty of Civil Engineering for the support. A special thank is addressed to all members of the organizing committee. All above mentioned help and support were necessary for successful organization of the conference and publishing of the proceedings. We hope that it will help in dissemination of sustainable building techniques into everyday construction practice and will thus contribute to solution of SDG targets specified in 2030 Agenda for Sustainable Development.

We hope that conference YRSB22 will contribute to enhancement of knowledge in the field of sustainable buildings and built environment.

In Prague in July 2022

Petr Hájek
Julie Železná

Contents

Forum Papers

The Potential of Vertical Extensions: A Case Study Analysis

Charles GILLOTT[a], Danielle DENSLEY TINGLEY, Buick DAVISON

[a] *Department of Civil and Structural Engineering, The University of Sheffield, Mappin Street, Sheffield, England, cgillott1@sheffield.ac.uk*

Abstract

There is a global imperative to reduce greenhouse gas emissions as a means of mitigating climate change. Buildings are responsible for almost 40% of carbon emissions, exemplifying the importance of decarbonising the built environment to limit global temperature increase. As a result of the increasing awareness of the importance of embodied carbon, transition towards a circular economy within the construction sector is key in its decarbonisation The adaptive re-use of existing buildings has a significant role to play through reduced material consumption and waste generation and prolonged building lifespans. One adaptive reuse strategy, the vertical extension of existing buildings, serves to achieve this whilst meeting growing demand for space within already dense cities. This paper reviews seven instances of vertical extension in the UK and Ireland, exploring the specific motivations for, and technical details of, each. These are compared to reveal the suitability of vertical extension to a range of building archetypes, and the case-by-case variability with which both structural appraisal and remediation are required.

Keywords: *adaptation, reuse, circular economy, embodied, whole-life, carbon, vertical extension*

1 Introduction

1.1 Decarbonisation of the Construction Sector

In 2015, attendees of the United Nations Framework Convention on Climate Change signed the Paris agreement. This outlines “aims to strengthen the global response to the threat of climate change”, including “holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C” [1]. In 2020 the UK responded to this in their Nationally Determined Contribution by “committing to reduce economy-wide greenhouse gas emissions by at least 68% by 2030, compared to 1990 levels” [2].

With buildings alone being responsible for 38% of global carbon emissions [3], decarbonisation of the built environment represents a significant challenge that must be addressed. In the UK this is recognised by numerous declarations of climate emergency from within the sector, including those by architects, designers, engineers, project managers, surveyors, developers, contractors, suppliers, students and academics [4]. The importance of decarbonising the built environment is also noted by the UK government’s “Ten Point Plan for a Green Industrial Revolution” [5].

1.2 Embodied Carbon and the Circular Economy

Although historically overlooked in prioritisation of operational carbon emissions, considering the carbon embodied within the built environment is becoming increasingly important. This refers to emissions during the extraction of materials and manufacture of components; transportation and construction processes; and end of life phases. Embodied carbon is known to contribute 11% of the whole-life carbon of buildings [6], with this value expected to increase with time in line with improvements in operational performance and decarbonisation of the electricity grid. Reductions in embodied carbon also allow significant *upfront* savings to be made before a building's occupation (whereas operational benefits must be accrued over a building's lifespan), consistent with the urgency with which the sector must decarbonise.

As embodied carbon depends upon material extraction and waste generation, strategies to reduce this are consistent with those to transition towards a circular economy. This moves away from a linear model of consumption in which resources are extracted, manufactured, used and discarded, to one where focus is placed on retaining materials within the technosphere for as long as possible, and at their highest possible value. As explained by Bocken et al., this includes strategies that: slow resource flows through the design of long-life goods and product life extension; narrow resource flows through more efficient design; and close resource flows through reuse and recycling [7].

As a result of the growing emphasis on transitioning towards a circular economy in the built environment, different strategies to achieve this have been suggested by various organisations. These generally consider adaptability, design for deconstruction, circular material selection and resource efficiency, with building lifespan extension also being prioritised in some cases [8].

1.3 Adaptive Reuse and Vertical Extension

One approach to building lifespan extension is adaptive reuse, which serves to slow resource flows and ensure a maximum amount of material is retained in the built environment at its highest possible level. Adaptive reuse refers to the modification of existing buildings to meet new needs and mitigates sources of embodied carbon by reducing material extraction; component manufacture; transportation and construction processes; and waste generation. The benefits of adaptive reuse in achieving a circular economy and decarbonising the construction sector are increasingly being recognised by industry such as in the Architects Journal's 'RetroFirst' campaign. This aims to "prioritise retrofit over demolition and rebuild" [9] and has been signed by more than 200 organisations.

Whilst specific use requirements of buildings may vary with time (as seen with decreased requirement for office space following the COVID-19 pandemic), net demand for useable floorspace is expected to increase, in line with a growing population. Within cities this increase in demand is expected to be more extreme, with the percentage of the global population living within urban areas predicted to rise from 55% in 2018 to 68% in 2050 [10].

The vertical extension of existing buildings therefore represents an adaptive reuse strategy in which required additional space may be generated simultaneously with decarbonisation of the construction sector. Additional benefits associated with vertical extension include the increase in density this facilitates, and its ability to create mixed-use spaces. Both of these aspects are known to be conducive to a sustainable urban form.

2 Vertical Extension Case Studies

Seven instances of vertical extension in the UK and Ireland have been reviewed, focussing on specific motivations for, and technical details of, each project. This explores the key drivers of vertical extension for a range of design scenarios and building archetypes, as well as the degree of structural appraisal and remediation required in each instance. A summary of each of the case studies, outlining key details, may be seen in Table 1. Unless otherwise stated, all information contained within each case study is derived from the corresponding source in Table 1, or through informal exchanges with relevant parties.

Tab. 1 *Overview of considered case studies, showing key details of each.*

Building Name	Location	Original No. of Storeys	Storeys Added	Original Use	New Use	Existing Form	Extended Form
Southbank Tower [11]	Southwark, London	31	11	Office	Residential	Concrete frame	Steel frame & concrete core
Crown House [12]	Sheffield	6	3	Office	Residential	Steel frame	Steel frame
Lister Mill [13]	Bradford	5	1	Mill	Residential	Masonry, cast iron & concrete	Prefabricated timber & steel
Arnold House [14]	Shoreditch, London	4	3	Office	Office, retail	Concrete frame	Steel frame
The Department Store [15]	Brixton, London	3	1	Retail	Office, retail	Masonry	Oak frame
1 Triton Square [16]	Camden, London	5	3	Office	Office, retail, gym	Concrete frame	Steel frame
Clerys Department Store [17]	Dublin	4	3	Retail	Retail, office, restaurant	Concrete frame	Steel frame

2.1 Southbank Tower

As part of a wider refurbishment and office-to-residential conversion, 11 storeys were added to this 1970's reinforced concrete (RC) tower. Utilising reserve capacity in the existing concrete core, this has been extended, and a steel frame cantilevered from this using steel tension hangers (Fig. 1). As a result of consolidation of the founding clay, loads experienced by the structure's piled foundations were permissibly increased by up to 25%, negating the requirement for their strengthening.

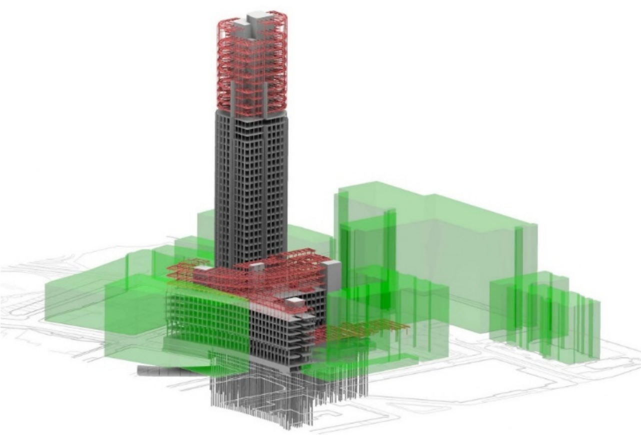


Fig. 1 *3D model of the Southbank Tower extension, showing the original structure (grey), additional steelwork (red) and surrounding buildings (green). (© AKT II)*

To ensure occupant comfort despite the 1/3 increase in height, Computational Fluid Dynamic (CFD) analysis of the extend structure was carried out. This resulted in the linkage of the tower and surrounding podium structures (Fig. 1) as a means of resisting increased wind loads. Three additional storeys were added to these structures themselves, generating additional office and roof garden space [18].

2.2 Crown House

As part of an office-to-residential conversion and wider redevelopment, this steel framed building has been extended by three storeys to generate 181 student properties. A further 172 beds have been contributed by two new build blocks of eight and nine storeys (Fig. 2).

To allow for this, reserve capacity resulting from the less onerous design load associated with the change of use was utilised. This supplemented by removal of the existing upper floor and inefficiencies in the original design. Renovation and refurbishment of the existing structure was also required, including the steel frame and internal fit out [19]. The existing steel frame was extended vertically, following the same grid as the existing building [20].

Owing to time constraints associated with the annual rental period for student properties [19], and the sites proximity to a major transport route [20] (Fig. 2), the scheme was required to move from planning to construction stages in just 13 weeks.

Fig. 2 *Rendered image of the completed office-to-residential conversion, lateral (rear) and vertical (front) extension of Crown House, Sheffield. (© RG Group)*

2.3 Lister Mills

Lister Mills in Bradford was built in 1873 using a cast iron frame with an ornate stonework façade. This supports brick-lined concrete floors and brickwork internal walls. Following the closure of the mill in 1992, the building became derelict before being refurbished and extended in 2001 for residential use. As a result of low land values in Bradford, cost was a major constraint on this project, as was the roof width of just 19m.

Rather than a single structure, as with other case studies, individual units were created at roof level (Fig. 3) to be accessed by a shared staircase. Owing to the limited budget, constrained site and requirement for a lightweight solution, prefabricated timber cassettes wrapped around a lightweight steel frame were selected for use. These were prefabricated off-site and craned to roof level for assembly, negating the need for temporary works. For further financial savings and ease of construction, each of the ten cassettes are identical, comprising eight curved plywood I-beams joined by OSB noggins and braced with an OSB outer skin. The rooftop units are supported by a new concrete slab, transferring loads to a set of steel universal beams. These replace the original cast iron roof trusses in being slotted into existing notches within the stone piers. Construction of the new roof was completed first to allow for the separation of the extension works and refurbishment of the existing building.

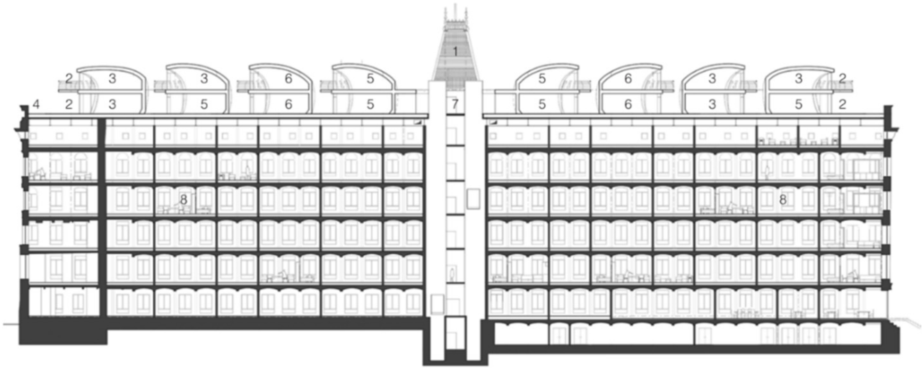


Fig. 3 *Section drawing of the refurbished Lister Mills building, showing the completed rooftop development. (© David Morley Architects)*

2.4 Arnold House

Originally built as a concrete framed warehouse in the 1960s and converted into office space in the 1990s [21], Arnold House struggled to attract tenants in the mid-to-late-2010s despite its desirable location in Shoreditch. This was because of its dated interior and the fact it only had one elevator, as well as its poor operational performance as a result of single glazing and lack of air conditioning.

The building therefore underwent extensive renovation and vertical extension in order to increase its lettable value in line with that of the surrounding area. As a result of its original use as a warehouse, Arnold House was particularly suitable for this, because of reserve structural capacity and the large floor-to-ceiling height desired in modern offices.

Three steel-framed storeys were added to the existing structure, and a rear extension constructed to result in a 50% increase in floor area to 75,000 ft^2. New cores and additional lifts were also added to improve circulation and provide access to the extended portion [21]. Further improvements included new glazing, re-cladding of existing facades [21] (Fig. 4), the installation of an air conditioning system, construction of a landscaped roof terrace, and inclusion of cycle storage and changing facilities. In addition to office space, the ground floor level now hosts cafés, restaurants and retail units [21].

Fig. 4 *Image of the extended and upgraded form of Arnold House showing continuity between new and existing structures. (© Allsop)*

2.5 The Department Store

Built in 1906 as one of England's first steel-framed buildings, this Edwardian department store has previous uses including office and retail. When acquired in 2015, it was in a state of disrepair following numerous conversions and the degradation of the structure with time. Now, as part of a wider refurbishment and retrofit, a fifth storey, set back from the building's roofline, has been constructed.

This uses an oak frame (Fig. 5), with 450 mm diameter oak columns resting on the original steel columns at 5375 x 7300 mm centres. Each of these are hewn from a single 'green' oak trunk, with these being cored to allow for the insertion of an adjustable 75mm stainless steel tension rod. These are then connected to 350 mm deep oak beams to form the roof structure (Fig. 5).

In order to construct the extension, a crawler crane was dismantled and reconstructed on the existing roof. This was then used to lift components from street level and arrange these as required on the rooftop. At present, the refurbished department store is used as office space, with retail units at the ground floor. The new extension itself is used as a rooftop bar and restaurant.

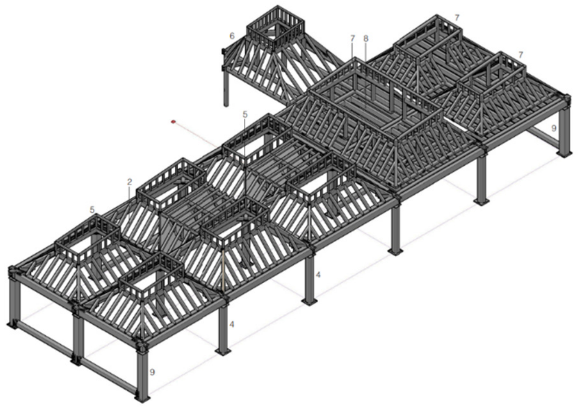


Fig. 5 *3D model of the oak-framed rooftop extension to The Department Store, Brixton. (© Carpenter Oak)*

2.6 1 Triton Square

Built in the 1990s, this building originally took the form of a 6-storey, 72m x 72m, office building, following a 9m x 9m structural grid. This comprised an RC frame, with braced, steel-frame cores placed at each corner for lateral stability. As a result of the over-conservativity of the initially assumed design actions and oversized stair cores, this was particularly suitable for vertical extension.

To streamline the structural appraisal process, the capacity of elements experiencing no increase in design load were not considered, with all other elements being re-analysed using modern codes of practice. This allowed the reduction of assumed imposed loads from 5 kN/m^2 to 4 kN/m^2. The stability offered by the concrete frame was also considered in the re-appraisal, where neglected in original calculations.

Despite these measures, a number of existing concrete columns required strengthening using a 125-150 mm thick RC encasement or fibre reinforced plastic (FRP) wrapping. Depending upon their anticipated failure mode, existing steel columns were either encased in concrete or strengthened using steel plates, with the original diagonal braces being replaced to enhance overall stability. Supplementary piles were added within the basement and tied to existing piles using a new concrete raft. Within the extended portion of the building, lightweight composite steel/concrete floors are supported on a traditional steel frame.

The above remediation measures result in an embodied carbon over the new floor area of 390 kgCO2e/m2, which is higher than the targeted benchmark value of 350 kgCO2e/m2. Through reusing the existing building however, 1,900 t of steel and 35,000 t of concrete were saved. When the embodied carbon of new material is considered over the entire building’s floor area, the revised value is 136 kgCO2e/m2.

2.7 Clerys Department Store

Originally constructed in the 1920s, this concrete framed building housed a department store until its closure in 2015. In this time, it saw numerous adaptations, including the infilling of an atrium in the 1940s, and an initial rooftop extension in the 1970s. In 2020, work began to refurbish the building as part of a wider regeneration initiative. This includes the deconstruction of previous adaptations, and the addition of three new storeys.

Because of a lack of reserve capacity, the extended portion of the building was required to be structurally independent. This has resulted in the insertion of additional columns following the existing 6m x 7m grid. These fabricated I-section columns are split at each floor level and joined using stiffened splice plates to straddle the existing concrete beams. Micro-piles and raft foundations are used to support these columns at ground level. A steel frame construction is used for the new storeys, with these deviating from the existing structural grid through the use of cellular beams up to 14m in length (Fig. 6). This allows them to be used as adaptable office space and a rooftop restaurant, whilst existing storeys are used for retail.

Fig. 6 *Rendered cross-section of the refurbished Clerys Department Store showing the increased structural grid of the upper storeys and terraced extension. (© Visual Lab)*

3 Discussion

3.1 Motivations for Vertical Extension

Though present in all cases, the environmental benefits discussed in Section 1 are most prevalent as a motivation for 1 Triton Square (Section 2.6), for which they are explicitly stated as the primary driver. Beyond this, financial incentives for adaptive reuse and vertical extension are also reported, as with the desired increase in lettable value for both Crown House (Section 2.2) and Arnold House (Section 2.4) and.

Opting for vertical extension because of a tight project timeline is explicitly stated in the case of Crown House (Section 2.2), with programme benefits being cited in a number of additional instances. This exemplifies the ability of vertical to reduce project programme in comparison with the alternative of demolition and reconstruction. The less intensive construction process also makes vertical extension more suitable for constrained sites, as suggested for Crown House (Section 2.2), Lister Mills (Section 2.3) and The Department Store (Section 2.5). This enables the increase in value of an asset to which access is temporally or spatially limited, with the craning of materials and components to roof level commonly being employed to facilitate this.

In the case of more historically and architecturally significant structures, such as Lister Mills (Section 2.3) and Clerys Department Store (Section 2.7), vertical extension is also revealed to be a useful tool in the conservation of heritage. This is because it allows space provision in key locations to be brought in line with current requirements, without the need for demolition. Linked to this is the ability of vertical extension to act as a catalyst for wider regeneration, as is observed to be the case for Southbank Tower (Section 2.1), Lister Mills (Section 2.3) and Clerys Department Store (Section 2.7).

3.2 Existing and Extended Building Archetypes

The applicability of vertical extension to a range of building archetypes is illustrated by the above case studies. Although examples of the extension of former retail (Sections 2.5 and 2.7), and industrial buildings (Section 2.3) are discussed, cases of vertical extension are shown to primarily take place on existing offices

(Tab. 1). This may be because of increasing vacancy rates in such buildings, or because of the inherent adaptability of offices as a result of their open structural grids and large imposed design loads.

Cases of both across- and within- use extension are discussed, further demonstrating the applicability of vertical extension to a wide range of scenarios. Office-to-residential conversions are revealed to be particularly common, potentially resulting from the ability to deliver such schemes under permitted development rights [22]. The ability of vertical extension to deliver high-density mixed-use spaces (Section 1) is also reiterated, with a number of instances of office- or residential- over-retail extensions being discussed (Tab. 1). Opportunity to integrate leisure offerings such as bars and restaurants is also shown in a number of case studies, utilising the inherent ability of vertical extensions to provide architecturally interesting forms and reveal previously unseen rooftop views.

As well as various use-types, different existing and extension materials and forms are utilised in the above case studies. Existing concrete frames are shown to be most commonly extended (Tab. 1), potentially resulting from the fact these make up a large portion of the current building stock and represent typical 'engineered' structures for which reserve capacity may be identified. This may also be because these structural forms are most often used for office buildings, which are noted above to be most commonly extended. In addition to concrete framed structures, extensions are shown to be suitable for steel frames (Section 2.2), and buildings with various load bearing masonry elements (Sections 2.3, and 2.5), reiterating the flexibility of this construction type.

The extended storeys of the above case studies are dominated by steel frame constructions (Tab. 1), but also include instances of prefabricated (Section 2.3) and 'heavy' (Section 2.5) timber structures. This is likely to result from the fact that these materials are more lightweight than concrete or masonry alternatives, which is of great importance when attempting to utilise scarce reserve capacity. Steel and timber structures also offer additional benefits in that they can be designed to use purely mechanical fixings, which require no 'wet' trades and are particularly suited to adaptation and prefabrication [23].

The projects discussed in Section 2 also show a range of different approaches to the addition of new storeys. This includes projects in which a similar aesthetic is employed within the original and extended portions (e.g. Crown House and Arnold House) as well as those in which effort is made to differentiate between the new and existing portions (e.g. Lister Mills). The former of these approaches is revealed to typically be used in the extension of more recent and utilitarian buildings, whilst the latter is employed on those of greater architectural significance.

3.3 Structural Assessment and Remediation

The level of structural appraisal carried out for each of the projects in Section 2 is shown to vary on a case-by-case basis. This ranges from the full assessment of the building's extended form using finite element analysis (e.g. Southbank Tower), to more simplistic checks based on comparisons of existing and extended loads. Between these extremes are examples such as 1 Triton Square (Section 2.6), where individual elements experiencing an increase in load are checked, whilst all others are assumed to offer sufficient resistance.

Following these assessments, different degrees of structural remediation are shown to be required by the above case studies. This includes instances of simplistic (e.g. Crown House etc.) and complex (e.g. Triton Square) elemental strengthening, as well as more novel support systems (e.g. Southbank Tower and Clerys Department Store). The required degree of structural intervention is shown to result both from the ability to identify reserve capacity within the structure, and its condition. For example, Crown House only required minimal localised strengthening as a result of its decrease in assumed imposed loads and good structural health, whereas more intense interventions were required for derelict structures such as Clerys Department Store.

In most instances, the capacity of existing foundations is deemed to be insufficient, requiring the strengthening of these or the construction of supplementary piles (e.g. 1 Triton Square and Clerys Department Store). In some cases, however (e.g. Southbank Tower), consolidation of founding soils from the weight of the original building is used to justify an increase in soil strength and thus the resistance offered by existing piles.

As a result of the increase in building height associated with a vertical extension, the increased lateral loads compared with the original building need to be considered, particularly where a large number of storeys are added. In the case of Southbank Tower, where the buildings height was increased by 1/3, this required CFD analysis to accurately determine the wind loading for use in structural appraisal. The requirement for remediation in this case was the linkage of the tower and surrounding podium structures (Section 2.1), though other lateral stability increases have been achieved through the replacement of steel bracing and consideration of hitherto ignored stiffness (e.g. 1 Triton Square), as well as the construction of new cores (e.g. Arnold House).

The nature of vertical extensions, in that they increase loads experienced at the existing roof level, dictate that strengthening or replacement of this element is often required. This is shown to be true in the case of Lister Mills, for which new load transfer structures were introduced to transmit loads to existing members. In some cases however, such as Crown House, the loads associated with the existing structure may be transferred directly to existing column ends, with imposed floor loads being supported by the original roof structure.

4 Conclusions

The above case studies reveal vertical extension to be a versatile construction method capable of adding new useable floorspace to a variety of existing building archetypes. This includes traditional load bearing masonry structures, as well as more recent 'engineered' structures such as steel and concrete frames. Although most commonly carried out on existing offices, extensions are also shown to be applicable to residential, retail, and industrial building. Both within- and across- use adaptations are included, with the generation of mixed-use spaces being common.

As well as the embodied carbon and circular economic benefits discussed in Section 1, additional motivations for vertical extension are revealed to include: the ability to increase asset value at a reduced project cost; reductions in project programme; suitability for constrained sites; and the preservation of heritage.

Depending upon the form and condition of the existing building, different degrees of structural appraisal and remediation are required. This ranges from full finite element and CFD analysis, to element-wise capacity checks. Superstructure remediation is shown to vary from localised strengthening (where single elements are insufficient), to the construction of complex load transfer structures (where the extended portion is required to be structurally independent). The requirement for substructure strengthening also varies on a case-by-case basis, dependent upon capacity of the existing foundations and the anticipated increase in load.

References

[1] UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE. *The Paris Agreement*. 2015.

[2] DEPARTMENT FOR BUSINESS ENERGY AND INDUSTRIAL STRATEGY. United Kingdom of Great Britain and Northern Ireland's Nationally Determined Contribution. *Comparative Politics* [online]. 2019. P. 68–134.

[3] UNITED NATIONS ENVIRONMENT PROGRAMME. *2020 Global Status Report for Buildings and Construction*. 2020.

[4] BUILT ENVIRONMENT DECLARES. Built Environment Declares Climate and Biodiversity Emergency. [online]. [Accessed 11 October 2021]. Available from: https://builtenvironmentdeclares.com/

[5] HM GOVERNMENT. *The Ten Point Plan for a Green Industrial Revolution*. 2020.

[6] 6WORLD GREEN BUILDING COUNCIL. *Bringing embodied carbon upfront*. London, 2019.

[7] BOCKEN, Nancy M. P., PAUW, Ingrid de, BAKKER, Conny and GRINTEN, Bram van der. Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering* [online]. 3 July 2016. Vol. 33, no. 5, p. 308–320. [Accessed 12 October 2021]. DOI 10.1080/21681015.2016.1172124. Available from: https://www.tandfonline.com/doi/abs/10.1080/21681015.2016.1172124

[8] GILLOTT, Charles, MIHKELSON, William, LANAU, Maud, CHESHIRE, David and DENSLEY TINGLEY, Danielle. *Developing a circular economy engagement tool for the assessment of new and existing buildings*. 2021.

[9] THE ARCHITECTS JOURNAL. RetroFirst – A campaign by The Architects' Journal. [online]. [Accessed 12 October 2021]. Available from: https://www.architectsjournal.co.uk/news/retrofirst

[10] UNITED NATIONS DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS. *World Urbanization Prospects 2018 (Highlights)* [online]. New York, 2019. Available from: https://population.un.org/wup/

[11] AKT II. South Bank Tower. [online]. 2016. [Accessed 15 October 2021]. Available from: https://www.akt-uk.com/projects/south-bank-tower/

[12] WORDSWORTH CONSTRUCTION SERVICES. Crown House, Sheffield. [online]. 2017. [Accessed 15 October 2021]. Available from: https://www.wordsworthconstruction.services/experience/33/crown-house-sheffield

[13] TRADA. *Velvet Mill, Lister Mills, Bradford*. 2020.

[14] ALLSOP. Transformation complete! How ARNOLD became the new hot property in Shoreditch. [online]. 2019. [Accessed 15 October 2021]. Available from: https://www.allsop.co.uk/media/transformation-complete-how-arnold-became-the-new-hot-property-in-shoreditch/

[15] TRADA. The Department Store, Brixton, London. . 2019. P. 1–8.

[16] ROBERTSON, Andrew and STUREL, Eric. 1 Triton Square, London – Low- carbon development through reuse of an existing building. *Structural Engineer*. 2021. Vol. 99, no. 3, p. 30–35.

[17] STEELCONSTRUCTION.INFO. Steel serves up store refurbishment. *New Steel Constuction*. 2021.

[18] MACE. South Bank Tower: A once derelict tower brought back to life. [online]. [Accessed 15 October 2021]. Available from: https://www.macegroup.com/projects/south-bank-tower

[19] CUNNIFF DESIGN. Crown House - Student accommodation scheme delivered by Cunniff Design. [online]. 2018. [Accessed 15 October 2021]. Available from: https://www.cunniffdesign.com/portfolio/crown-house

[20] RG GROUP. London and Scottish. Crown House, Sheffield. [online]. 2018. [Accessed 15 October 2021]. Available from: https://rg-group.co.uk/portfolio-item/london-scottish-crown-house-sheffield/

[21] E-ARCHITECT. Arnold House in Shoreditch. [online]. 2015. [Accessed 15 October 2021]. Available from: https://www.e-architect.com/london/arnold-house-in-shoreditch

[22] HM GOVERNMENT. *Town and Country Planning (General Permitted Development) (England) Order 2015* [online]. 2015. Available from: http://www.legislation.gov.uk/uksi/2015/596/pdfs/uksi_20150596_en.pdf.

[23] DENSLEY TINGLEY, Danielle. *Design for Deconstruction: An Appraisal The University of Sheffield*. 2012.

Approach to Holistic Energy, Comfort and Health Management in Residential Buildings with Split Air Conditioning Units

Yuanchen WANG[a], Dirk SCHWEDE[a], Konstantinos STERGIAROPOULOS[a]

[a] *Institute for Building Energetics, Thermotechnology and Energy Storage (IGTE) at the University of Stuttgart, Pfaffenwaldring 35, 70569 Stuttgart, Germany, yuanchen.wang@igte.uni-stuttgart.de*

Abstract

Increased temperature, intensification of the urban heat island and rising comfort requirements drive the fast-growing energy demand for space cooling. Due to multiple reasons, there are more people who prefer to use mechanical cooling instead of electric fans or natural ventilation. This will not only lead to a dramatic increase in energy consumption but can also result in poor indoor air quality due to inadequate ventilation during cooling, especially in residential buildings with split air conditioning units. Occupant behaviour in this building type has a significant impact on the building energy performance and the indoor environment, but it is difficult to consider in the design phase due to the lack of accurate predictions. This study introduces a holistic approach to analyse the energy, comfort and health-related issues as well as the human-building interactions during building operation. Its outcomes will provide a sufficient basis for the development of sustainable solutions for existing and new buildings.

Keywords: *energy efficiency strategy, indoor environmental quality, occupant behaviour, split air conditioner, residential building*

1 Introduction

1.1 Background

Since the 2015 Paris Climate Change Agreement set out a global framework to limit global warming, many countries have developed their own climate action plans, such as Germany aims to be climate-neutral by 2045, and China aims to hit peak emissions before 2030. The building sectors are responsible for over one-third of global final energy consumption and nearly 40 % of total CO_2 emissions [1]. Improving energy efficiency in buildings, therefore, is a key to achieving climate and energy targets. Nowadays, about 75 % of the EU building stock is not energy-efficient [2]. Energy-related CO_2 emissions from buildings can be reduced by improving existing buildings and by adopting energy-efficient solutions when constructing new buildings. Although many countries are actively promoting energy-efficient buildings, global CO_2 emissions from buildings still reached an all-time high in 2019 [1]. There are many factors that contributed to this growth, including increasing energy demand for heating and cooling with rising air conditioning (AC) unit ownership. Energy demand for space cooling has more than tripled since 1990, and AC usage has emerged as one of the key drivers of global electricity demand growth. Furthermore, 35% of the world's population lives in countries with an average daily temperature above 25°C, but only 10% of them have AC units [3] yet. With rising living standards, population growth, and more frequent heatwaves, the number of AC units installed is estimated to increase by another two-thirds by 2030 [3]. According to the report of JRAIA [4], the growth is expected to occur mainly in the residential AC sector, especially in residential buildings with mini-split AC units in Asia. It is necessary to review and adapt the current building design standards and methodologies to address the unprecedented cooling demands in the residential building sector of the next decade.

1.2 Residential buildings with mini-split AC units

According to the equipped building technical systems and their operation modes, buildings can be divided into three types: 1) occupant-controlled naturally ventilated and conditioned buildings (NV-buildings); 2) mechanically ventilated and conditioned buildings (AC-buildings); 3) Mixed-mode buildings (MM-buildings). The thermal conditions in NV-buildings are regulated primarily by the occupants through opening and closing of fenestration in the envelope, and the occupants' thermal responses depend in part on the outdoor climate and may differ from thermal responses in AC-buildings with centralized HVAC systems, primarily because of the different thermal experiences, changes in clothing, availability of control, and shifts in occupant expectations [5]. Residential buildings with mini-split AC units belong to the MM-buildings, which is a combination of NV-buildings and AC-buildings. During the cooling season, the occupants in MM-buildings can use AC or other adaptive opportunities such as altering clothing, activity, diet, ventilation (windows) and air movement (electric fans) [6]. Another characteristic of cooling behaviour in residential buildings with mini-split AC units is that the occupants usually only cool their rooms for a few hours while they are occupied, which is referred to as "part time" and "part space" behaviour. The result of this cooling behaviour is that AC units in MM-buildings are used less intensively than in AC-buildings with larger centralized cooling systems [7].

1.3 Impact of occupant behaviour

Occupant behaviour is a major factor contributing to gaps between simulated and actual measured building performance [8–12]. The building performance simulation for MM-buildings is particularly challenging due to the diverse operating characteristics, such as the operation of AC, windows and electric fans, as well as occupant schedules. Cuerda et al. [9] compared the impact of occupancy patterns on energy demand in residential buildings with results showing that the heating and cooling energy demand may differ by up to 15% depending on whether actual or standard presence profiles are used. In their study, only the occupancy pattern was varied, while other variables in the building simulation were kept constant. If the actual air conditioning behaviour is introduced in the simulation, the difference in the simulation results will become more obvious. Yao [13] modelled the stochastics air conditioning behaviour using measured data from a bedroom and found that simulation using settings based on the building standard over-predicted the total cooling energy demand by 5.6 times. Sun and Hong [12] pointed out that the impact of occupant behaviour on the performance of energy efficiency measures should be quantified, and integrate uncertainties related to occupant behaviour can provide evidence-based decision support. Occupant behaviour has not only a significant impact on energy consumption but is also related to indoor air quality (IAQ). Opening windows or room doors during space cooling will increase energy consumption and affect the cooling effect, while closed rooms result in inadequate ventilation. Adopting appropriate energy efficiency measures will not only reduce the cooling demand but also improve indoor air quality [14]. Occupant-related building operations are dynamic, stochastic and diverse, therefore, occupant behaviour models that reflect the different operating characteristics need to be introduced into the development of building energy efficiency measures to maximize the benefits of the improvements. However, the occupant-related boundary conditions in current building design standards and real projects are often oversimplified due to the cost and complexity of data collection and modelling. Determining occupant cooling behaviour in residential buildings is even more difficult than in office buildings because measurements are limited by privacy concerns, and occupants have more adaptive opportunities. Moreover, different occupant behaviours can be observed in different rooms of the same apartment, so modelling occupant behaviour for the entire apartment requires measurement data with high spatial and temporal resolution.

This study, therefore, aims to discuss and address the following questions related to residential buildings with split ACs: a) How to quantify the impact of occupant behaviour on the benefits of energy efficiency measures? b) How to reduce the cost and complexity of modelling occupant behaviour while ensuring accuracy? A framework for evaluating building performance and quantifying the impact of different occupant behaviour styles on energy efficiency measures is introduced in **Section 2**. The preliminary results of an ongoing pilot study that employs this proposed approach are presented and discussed in **Section 3**. Finally, **Section 4** concludes the paper.

2 Methodology

2.1 Overview of the Framework

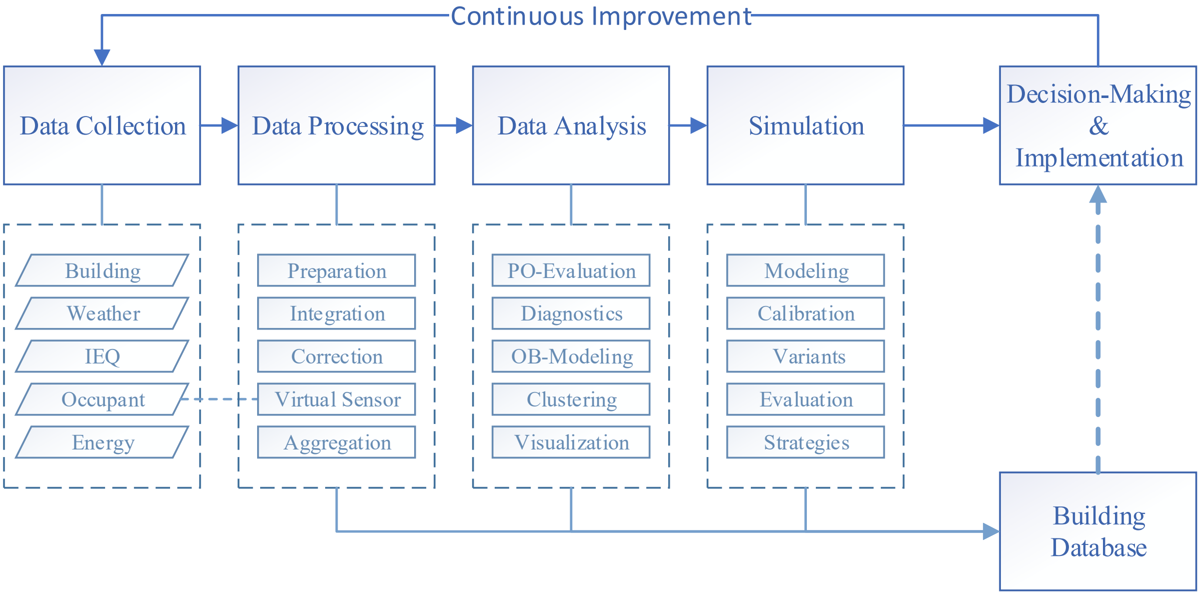


Fig. 1 *A Framework for evaluating building performance and quantifying the impact of occupant behaviour styles on energy efficiency measures*

The proposed framework shown in **Fig. 1** includes five main steps and one optional step:

Step 1: data collection. The first step is to collect the necessary data related to the building, weather, indoor environment quality, occupant behaviour, and energy consumption. The necessary basic data and their collection methods are described in detail in **Section 2.2**.

Step 2: data processing. The long-term monitoring data collected in step 1, such as weather data, indoor climate data, etc., are pre-processed firstly. Data from external sources are then integrated as needed to supplement the data set or fill data gaps. For example, if the weather data is not specifically measured, the available data from nearby weather stations can be integrated into the data set. These pre-processed data also need to be corrected (calibrated) when necessary, as the sensor may drift due to environmental conditions during long-term measurements. In previous studies, occupant presence and AC operation were measured directly to derive occupant schedules and cooling behaviour models. This not only raises the measurement costs but also causes disturbance to the occupants. Therefore, this framework emphasizes the use of virtual sensors that indirectly measure these sensitive data based on available data (e.g. non-intrusive occupancy recognition based on CO_2 measurements). The data obtained through this method will be aggregated with data collected through real measurements, building audits and occupant surveys, etc., and labelled with de-identified building information in preparation for the next step of data analysis. The prepared data set can also be optionally stored in an open-source or commercial building information database to support further research and development.

Step 3: data analysis. Measured data and data collected through occupant surveys are used as important inputs for post-occupancy evaluation to holistically analyse thermal comfort, indoor air quality and energy consumption. The analysis of thermal comfort can be based both on measurements of environmental variables and on subjective feedback from occupants. Since it is not practical to conduct frequent questionnaires to the occupants, it is necessary to link the occupant comfort with the environmental measurements through comfort models. Two comfort models, PMV (Predicted Mean Vote) and adaptive, are specific to AC and NV-buildings, respectively, while MM-buildings include a combination of both comfort model types [5]. Therefore, long-term thermal comfort performance in MM-buildings need to be evaluated with different comfort models depending on the AC state. In addition, many studies [15–17] have pointed out that adaptive comfort temperature varies from region to region, so the applicability of the adopted comfort models needs to be verified by comparing occupant surveys. Thermal comfort, air conditioning usage and occupancy need to be considered when evaluating indoor air quality and energy consumption. Apartments with high energy consumption, low thermal comfort and poor indoor air quality need to be identified for further diagnosis. Occupant behaviour, such as AC usage and window opening behaviour, are then modelled based on research needs. In previous studies, stochastic models were often used to predict different behaviours of occupants. Yao and Zhao [18] established predictive models of the occupants' window opening behaviour in residential buildings based on multivariate linear logistic regression. Ren et al. [19] developed an action-based stochastic model to predict AC usage in residential buildings, where typical patterns affecting AC usage, including those driven by environmental triggers and event triggers, were mathematically described as a series of conditional probabilities. Since occupant AC behaviour in residential buildings is s significantly linked to occupant schedules, the authors suggest that predictive models must more accurately reflect the impact of time variables on AC usage. A new predictive model is currently under development and will not be described in detail in this paper. The clustering and visualization of the occupants' behaviour can facilitate the design of representative scenarios in subsequent simulation studies.

Step 4: simulation. In this step, the typical apartment is first modelled according to the previous analysis. Since both natural ventilation and indoor air quality need to be considered in the simulation, it is recommended to use building simulation software that supports multi-zone airflow models, such as TRNSYS [20]. To reduce the impact of uncertainty of models on prediction accuracy, it is recommended to calibrate the simulation model using actual measurement data. After optimization of the simulation model, the performance of different energy efficiency measures under various representative occupant behaviours will be analysed. Improvement strategies are then developed based on specific objectives.

Step 5: decision-making & implementation. In this step, stakeholders perform a risk analysis and decide on an improvement strategy based on the uncertainty of the energy efficiency measures. The process described above can be continued after the implementation of measures to evaluate the actual performance of the adopted measures for the purpose of continuous improvement.

Step 6: building a database is an optional step. The outcomes from steps 2 to 4 can be stored in this building database for further studies. If the sample data in the database is sufficient, then decisions on improvement measures for similar regions can be performed directly based on the information provided in the database. Individual solutions can also be developed based on actual data in the database.

2.2 Data Collection

2.2.1 Building- and apartment related data

Geometric data, such as layout and orientation of the apartment, dimensions of walls, windows and doors, can be obtained from construction plans provided by the real estate company or measured on-site. Information on solar shading devices can be obtained through an occupant survey. **Material data,** such as wall constructions and their thermophysical properties (conductivity, density, specific heat, thermal diffusivity, etc.), the solar factor of glazing can be obtained from construction plans and building design standards. **Air permeability** can be estimated based on empirical data, building design standards or determined through blower door test [21] or simplified CO_2-decay method [22]. Quantity and location of **household appliances**, such as AC, fan, lighting, water heater, fridge, cooker, TV and PC, can be obtained through survey or field-investigation. Their specifications can be retrieved from datasheets.

2.2.2 Weather data

Meteorological parameters, such as air temperature, relative humidity, solar irradiance, wind speed and direction, ambient pressure, precipitation, can be measured with an own weather station or obtained from an open-source or commercial databank. The measurement interval should be 15 min or shorter.

2.2.3 Indoor Environmental Quality (IEQ) parameter

- **Basic measurement:** typical indoor climate data such as air temperature, relative humidity, ambient pressure, and air quality indicator such as CO_2, PM and VOC (optional) can be measured through integrated data loggers. The logger should have internal storage, and the measurement data should be remotely accessible. The measuring device should be placed in rooms where the occupants are often present, such as bedrooms and living rooms, away from direct sunlight and openings. The measurement interval should be 15 min or shorter.
- **Enhanced measurement:** if the PMV model is used to evaluate thermal comfort, it is necessary to measure the mean radiant temperature (MRT) and air movement (VEL) in addition to basic measurements. Clothing insulation (CLO) and metabolic rate (MET) are also required in the calculation. These parameters are rarely or can't be measured long-term during the occupancy phase. They are usually only considered in field-investigations. Furthermore, the environment may affect the accuracy of measuring devices, and the impact on the IEQ-evaluation needs to be determined through field-investigations. In this framework, it is proposed to conduct enhanced measurement, globe temperature, surface temperature, air temperature, and airflow speed at different heights, as well as CO_2 concentration at different locations, should be measured for representative apartments to determine the deviation between different measurement methods and devices.

2.2.4 Occupant-related data

- **Occupancy data:** total number of occupants in the apartment and the number of occupants in each bedroom, as well as the typical schedule of each occupant, can be collected through occupant survey. However, the schedules obtained in this way are only a general summary of the occupants based on their long-term experience. Deviations in actual occupancy can have an impact on analyses that require high time resolution, such as the evaluation of thermal comfort, modelling of air conditioning behaviour, etc. Occupancy data needs to be measured more accurately. In recent studies, cameras, passive infrared (PIR) sensors, Wi-Fi, CO_2-sensors, and smart meters are often used to determine occupancy [23]. Since IEQ-Monitoring includes CO_2 measurement, the non-intrusive occupancy determination using low-cost CO_2-sensors is more practicable. Occupancy determination methods based on CO_2-sensors can be divided into two main categories, mass balance equation-based physical models and data-based statistical models. In previous studies [24, 25], these methods have been used not only to recognize the presence but also to estimate the number of occupants. However, the accuracy of the physical model is affected by the air change rate, which is difficult to estimate accurately in a naturally ventilated building, while the statistical model requires a sufficient data set for training, which requires additional measurements. Because the number of occupants in an apartment is usually fixed, this paper proposed a simple approach only for the purpose of occupancy state recognition **(see Section 2.3)**.
- **AC operating data:** Typical usage patterns and usage frequency during the cooling season, temperature setpoints, AC fan speed, operating mode, cooling preferences can be collected through online-surveys during the cooling season. However, the occupant AC behaviour is dynamic and stochastic due to the influence of environmental conditions and adaptive behaviour. As with occupancy data, AC operating data needs to be collected with high temporal and spatial resolution, i.e. turn on/off at which time in which room. In previous studies, there are direct and indirect methods to measure AC operation. Mun et.al. [26] analysed the AC operation by using infrared receivers to obtain signals from the AC remote controller. Ren et al. [19] measured the real-time power of ACs using power meters. Zhang et al. [27] determined the operating state and set point of the AC by directly observing the room temperature measurement data. Song et al. [28]

placed a temperature logger at the supply air vent of the AC and identified the AC events by manual screening the entire dataset. All of the above methods, except for the direct observation of indoor air temperature, require additional measurements and intensive data processing, such as the analysis of remote-control signals. The method of recognizing AC events by manually observing temperature changes is inefficient in practice and not suitable for analysing large amounts of data. Therefore, a simplified approach is proposed to recognize AC events based on room temperature and is described briefly in **Section 2.3**.

- **Other occupant-related data**, such as the operation of fans and sun shading devices, including typical usage patterns and settings, as well as the operation of windows and doors, including typical opening time, opening area and their operation when using AC, sleeping or leaving, can be collected through occupant survey. Although these data can be quantitatively measured by contact sensors and power meters, because there may be many operable windows, doors and fans in an apartment, measuring all of them increases not only the cost but also disturbs the occupants. These occupant behaviours are relatively regular and foreseeable during the cooling season, and their main uncertain factor is caused by AC usage. Therefore, the measurement of them is set as optional in this framework. The setting of these occupant behaviours in simulation studies can be determined based on occupant surveys, AC predictive models and occupant schedules.

2.2.5 Energy consumption

Electric energy consumption data (monthly or with higher temporal resolution) can be measured with a smart meter or obtained from energy bills. The AC-related energy consumption can be directly measured with power meters or estimated as follows: if the occupant survey reveals that ACs or other electric heaters are rarely used for space heating, a baseline of electric energy consumption for the apartment can be established based on the power and typical running time of household appliances, and energy consumption during the non-cooling season. The AC-related energy consumption during the cooling season can be then estimated based on its deviation from the baseline.

2.3 Virtual sensors

A virtual sensor is a software sensor that autonomously produces signals by combining and aggregating signals that it receives from physical or other virtual sensors [29]. In order to determine occupancy and AC events through CO_2 sensors and temperature & humidity sensors, this study proposed a dispersion and gradient-based recognition algorithm. First, the time-series data (indoor air temperature or CO_2-concentration) is scanned along the time axis. When the deviation of a new data point from a dynamic reference line exceeds a given threshold, this data point is labelled with the corresponding event. Moving average of daily minimum CO_2-concentration and moving average of daily maximum indoor air temperature can be used for occupancy recognition and AC event recognition, respectively. Second, all recognized events will be individually checked to determine the exact event start and end time points based on the change rate of the environmental variables. The threshold for each room is determined individually by statistical analysis of the entire time-series data. This approach is robust and efficient because it considers the dynamics and diversity of event recognition criteria. Depending on the actual situation, the recognition accuracy can be further improved by adding rule-based filters. Finally, occupancy profiles and AC event statistics are generated for each room and compared with occupant surveys to validate. This approach will be described in detail by the authors in a separate paper.

2.4 Data analysis and simulation

Detailed workflow for the analysis of the collected data and subsequent simulation studies are illustrated in **Fig. 2**. Data that are not covered in the long-term measurements but are necessary to evaluate the indoor thermal environment such as CLO, MET, VEL and MRT need to be estimated based on field-investigations and surveys. Occupancy and AC operation data can be derived using the algorithm described in **Section 2.3**. These data are the basis for a comprehensive thermal environment evaluation considering different operating conditions. Since the accuracy of the comfort model is critical to the simulation study, it needs to be validated against the subjective responses obtained from the occupant survey. Targeted improvements will be developed based on the post-occupancy evaluation. Typical occupant behaviour will be clustered and modelled to analyse the impact of the uncertainty of occupant behaviour on the performance of improvement measures to provide evidence-based decision support.

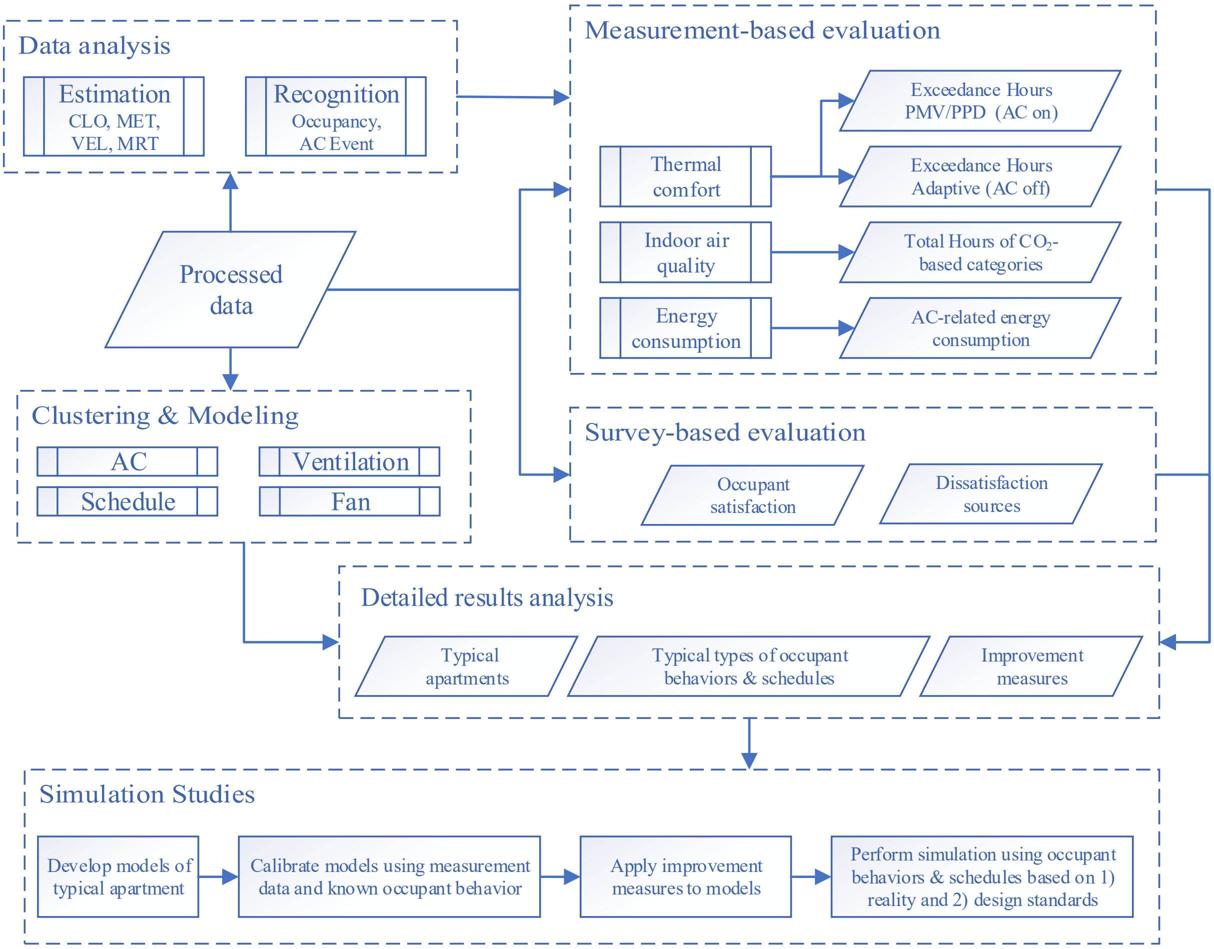


Fig. 2 *Detailed workflow for data analysis and simulation*

3 Pilot study

As part of a research project CAMaRSEC [30], a pilot study was performed in 49 apartment units in 15 modern residential buildings in Hanoi, Vietnam, using the proposed approach to evaluate the actual building performance, analyse the occupant behaviour and quantify their impact on energy efficiency measures. The necessary data have been collected through field-investigations, occupant surveys, and long-term measurements lasted from June 2020 to May 2021. More information about the survey and monitoring protocol can be found in Wang et al. [31]. Because data analysis and simulation studies are still in progress, this section presents only partial preliminary findings.

Fig. 3 shows two types of occupant schedules. On the left are normalized schedules based on three representative design standards [32–34]. It can be noted that only the ASHRAE schedule [34] considers the variation of occupancy with time. The occupancy rate of the entire apartment decreases from 1 to 0.25 during the day. The normalized occupant schedule is not able to reflect the realistic occupancy time and spatial distribution within the apartment, which decreases the prediction accuracy of the building performance simulation. On the right is an actual data-based schedule for a typical apartment, which contains the occupancy probability for main rooms. Typical living room occupancy time is from 16:00 to bedtime, while the master bedroom is almost always occupied at night and occasionally during the day. When the occupant works from home, it is more economical for them to cooling the bedroom with the door closed than in the large living room. Occupant schedules and their AC behaviour are closely linked to each other. The introduction of schedules with occupancy probabilities in stochastic simulations contributes to overcome the uncertain issues related to occupants.

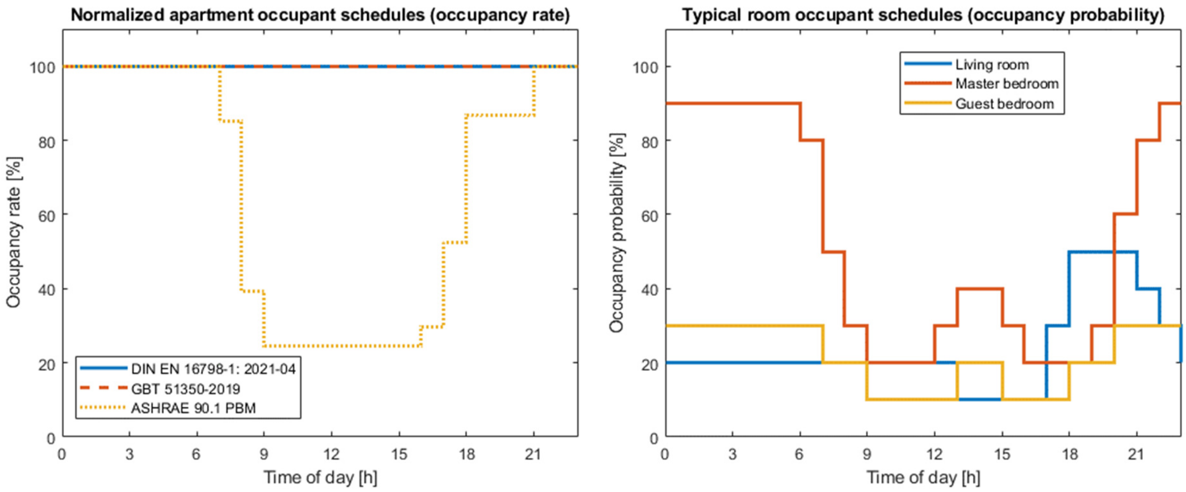


Fig. 3 *Occupancy schedule based on design standards (left) and measurements (right), data source: measurements in 49 apartment units in Hanoi in the CAMaRSEC project*

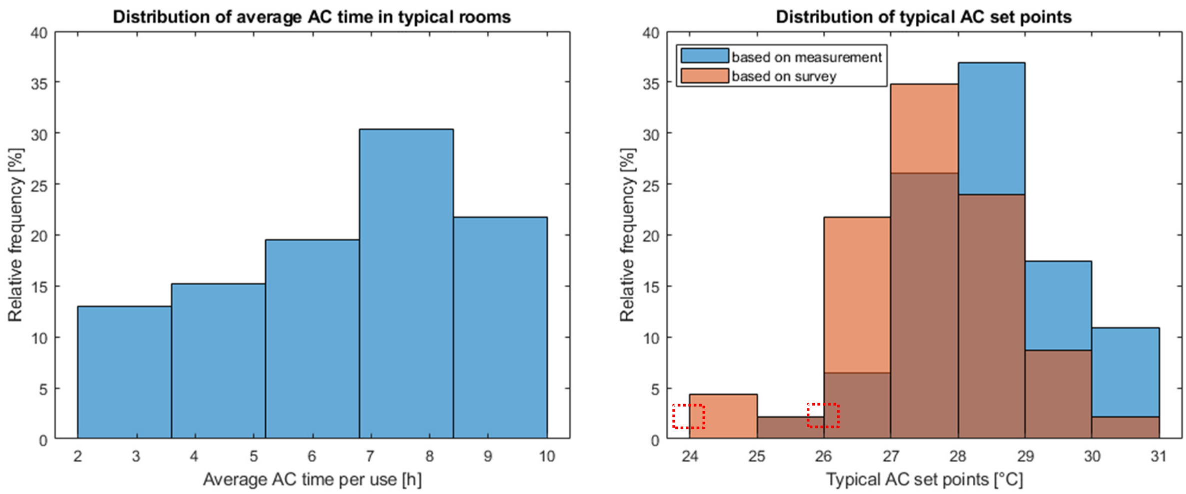


Fig. 4 *Distribution of average AC time (left) and cooling setpoints (right) in typical rooms, data source: measurements in 49 apartment units in Hanoi in the CAMaRSEC project*

Regarding air conditioning patterns in mixed-mode buildings, there is still a gap in current building energy-efficient standards. "Full time" and "whole space" cooling behaviour with a relatively low design indoor air temperature is introduced in most standards. This deviates significantly from the behaviour based on actual data, as shown in **Fig. 4**. The measurements show that continuous cooling for more than 10 hours is very rare in typical rooms where split ACs are frequently used. More than half of these rooms have an average AC time of between 5 and 8 hours. Typical cooling setpoints are determined using two different methods, with measurement-based results shown in orange and survey-based results shown in blue. The distributions based on these two methods are similar, but the distribution based on measurements is shifted to the left by 1 °C compared to the occupant feedback. The field-investigation revealed that the temperature measured with wall-mounted sensors is closer to the operative temperature, which deviates from the return air temperature used to control the ACs. This deviation must be considered in post-occupancy evaluation and simulation studies. Typical cooling setpoints obtained by both methods are higher than those given in GBT [32] and DIN [33] (≤26 °C), and in ASHRAE (≤ 24 °C) [34]. The new version of Vietnam Standard TCVN 306: 2018 (not yet published) [35] defines the design indoor air temperature of category A as between 25 and 27.2 °C, which is still higher than the actual data. Most occupants usually set the AC temperature between 27 and 29 °C, and some even set it above 29 °C for individual health reasons. These results show that occupants in MM-buildings, especially those living in hot and humid climate zones, have a higher tolerance to the thermal environment. Therefore, building design standards should be based on local conditions, and the implementation of energy efficiency measures should consider the occupant-related uncertainties.

4 Conclusion

This paper presented a holistic post-occupancy evaluation approach to support evidence-based design and improve the comprehensive performance of residential buildings with split AC units. The impact of occupant-related uncertainty on the accuracy of building performance prediction was summarized. Data collection methods for evaluating the actual building performance and modelling occupant behaviour styles in this building type were described in detail. A simplified algorithm to determine the occupant schedules and AC usage patterns with low effort and costs using basic IEQ-sensors were proposed to evaluate building performance with high temporal-spatial resolution and quantify the impact of occupant behaviour on energy efficiency measures. The preliminary finding of a pilot study reveals that normalized occupant schedules and cooling behaviour based on design standards deviate significantly from the actual measurements, which can lead to overestimation of cooling demand and overdesign of energy efficiency measures. The occupant behaviour models will be further applied to simulation studies to improve the thermal building environment while providing economic and health benefits.

Acknowledgement

The study is funded by the CAMaRSEC project within the funding initiative "CLIENT II – International Partnerships for Sustainable Innovations" by the German Ministry of Education and Research (BMBF) (No. 01LZ1804).

References

[1] IEA. Tracking Buildings 2020. IEA, Paris. https://www.iea.org/reports/tracking-buildings-2020.

[2] EUROPEAN COMMISSION. In focus: Energy efficiency in buildings. 2020. EC, Brussels.

[3] IEA. Cooling. 2020. IEA, Paris. https://www.iea.org/reports/cooling.

[4] JRAIA. World air conditioner demand by region. 2019. JRAIA, Japan.

[5] ANSI/ASHRAE 55-2020, *Thermal Environmental Conditions for Human Occupancy*.

[6] ASHRAE. *2017 ASHRAE handbook: Fundamentals (SI).* Atlanta, GA: ASHRAE, 2017.

[7] IEA. *The Future of Cooling in China:* OECD, 2019. ISBN: 9789264505247.

[8] Paone, A., and Bacher, J.-P. The Impact of Building Occupant Behavior on Energy Efficiency and Methods to Influence It: A Review of the State of the Art. *Energies.* 2018, **11**(4), 953.

[9] Cuerda, E., Guerra-Santin, O., Sendra, J.J., and Neila González, F.J. Comparing the impact of presence patterns on energy demand in residential buildings using measured data and simulation models. *Build Simul.* 2019, **12**(6), 985-998.

[10] Zhang, Y., Bai, X., Mills, F.P., and Pezzey, J.C. Rethinking the role of occupant behavior in building energy performance: A review. *Energy Build.* 2018, **172**, 279-294.

[11] Wang, X., Feng, W., Cai, W., Ren, H., Ding, C., and Zhou, N. Do residential building energy efficiency standards reduce energy consumption in China? – A data-driven method to validate the actual performance of building energy efficiency standards. *Energy Policy.* 2019, **131**, 82-98.

[12] Sun, K., and Hong, T. A framework for quantifying the impact of occupant behavior on energy savings of energy conservation measures. *Energy Build.* 2017, **146**, 383-396.

[13] Yao, J. Modelling and simulating occupant behaviour on air conditioning in residential buildings. *Energy Build.* 2018, **175**, 1-10.

[14] Hu, S., Da, Y., and Qian, M. Using bottom-up model to analyze cooling energy consumption in China's urban residential building. *Energy Build.* 2019, **202**, 109352.

[15] Nicol, F. Adaptive thermal comfort standards in the hot–humid tropics. *Energy Build.* 2004, **36**(7), 628-637.

[16] Nguyen, A.T., Singh, M.K., and Reiter, S. An adaptive thermal comfort model for hot humid South-East Asia. *Build Environ.* 2012, **56**, 291-300.

[17] Zhang, Y., Wang, J., Chen, H., Zhang, J., and Meng, Q. Thermal comfort in naturally ventilated buildings in hot-humid area of China. *Build Environ.* 2010, **45**(11), 2562-2570.

[18] Yao, M., and Zhao, B. Window opening behavior of occupants in residential buildings in Beijing. *Build Environ.* 2017, **124**, 441-449.

[19] Ren, X., Yan, D., and Wang, C. Air-conditioning usage conditional probability model for residential buildings [online]. *Build Environ.* 2014, **81**, 172-182.

[20] Weber, A., Koschenz, M., Dorer, V., Hiller, M., and Holst, S. TRNFLOW, a new tool for the modelling of heat, air and pollutant transport in buildings within TRNSYS. *8th International IBPSA Conference,* pp. 1363-1367.

[21] DIN EN ISO 9972:2018-12, *Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method (ISO 9972:2015)*

[22] Cui, S., Cohen, M., Stabat, P., and Marchio, D. CO2 tracer gas concentration decay method for measuring air change rate. *Build Environ.* 2015, **84**, 162-169.

[23] Sun, K., Zhao, Q., and Zou, J. A review of building occupancy measurement systems. *Energy Build.* 2020, **216**, 109965.

[24] Calì, D., Matthes, P., Huchtemann, K., Streblow, R., and Müller, D. CO 2 based occupancy detection algorithm: Experimental analysis and validation for office and residential buildings. *Build Environ.* 2015, **86**, 39-49.

[25] Jiang, C., Masood, M.K., Soh, Y.C., and Li, H. Indoor occupancy estimation from carbon dioxide concentration. https://arxiv.org/pdf/1607.05962.pdf

[26] Mun, S.-H., Kwak, Y., and Huh, J.-H. A case-centered behavior analysis and operation prediction of AC use in residential buildings. *Energy Build.* 2019, **188-189**, 137-148.

[27] Zhang, Y., Chen, H., and Meng, Q. Thermal comfort in buildings with split air-conditioners in hot-humid area of China. *Build Environ.* 2013, **64**, 213-224.

[28] Song, Y., Sun, Y., Luo, S., Tian, Z., Hou, J., Kim, J., Parkinson, T., and Dear, R. de. Residential adaptive comfort in a humid continental climate – Tianjin China. *Energy Build.* 2018, **170**, 115-121.

[29] Martin, D., Kühl, N., and Satzger, G. Virtual Sensors. *Business & Information Systems Engineering.* 2021, **63**(3), 315-323.

[30] Schwede, D., and Wang, Y. Introduction to research project: CAMaRSEC: Climate-Adapted Material Research for the Socio-Economic Context of Vietnam. *Pacific Geographies.* 2019, (52)

[31] Wang, Y., Schwede, D., and Stergiaropoulos, K. Survey of Indoor Environmental Conditions in Residential Buildings in Vietnam. *15th ROOMVENT Virtual Conference*.

[32] GB/T51350-2019, *Technical standard for nearly zero energy buildings*.

[33] DIN EN 16798-1:2021-04, *Energy performance of buildings - Ventilation for buildings - Part 1*

[34] PNNL. ANSI/ASHRAE/IES Standard 90.1 Prototype Building Models

[35] TCVN 306: 2018, *Dwelling and public buildings-Parameters for micro-climates in the room.*

Assessment of Thermal and Urban Micro-Climate of Gelemic, a Traditional Settlement in Turkey

Nurcihan BEKTAS[a], Haniyeh MOHAMMADPOURKARBASI[a], Stephen SHARPLES[a]

[a] *The University of Liverpool, Liverpool, United Kingdom, n.bektas@liverpool.ac.uk, Haniyeh.MPK@liverpool.ac.uk, Steve.Sharples@liverpool.ac.uk*

Abstract

In the built environment, the thermal characteristics of outdoor spaces and the street networks linking them are determinants of people's comfort and the sustainability of that environment. Gelemic is a historic village, as an earthen architectural heritage site in Turkey, located in Bursa city. Low-rise clustered wooden framed earth block structures, narrow streets with old stone pavements, and small backyards shape the authentic urban morphology. The village experiences a Mediterranean climate. This research investigates the outdoor and indoor thermal environments of Gelemic's architecture to identify and quantify the urban forms that create the best comfort conditions. The study considered indoor and outdoor temperature and humidity values of the present traditional and modern urban configurations. The inhabitants' comfort levels were assessed by undertaking a questionnaire survey. Mean radiant and air temperatures, wind speed and relative humidity were measured and modelled in ENVI-met software to evaluate the existing urban design's thermal performance.

Keywords: *microclimate, thermal comfort, earthen architecture, urban heat island, Envi-MET*

1 Introduction

Thermal comfort is both a personal and conditional phenomenon. It depends on how people clothe, how hard their physical activity is, the environmental conditions, and how much people's evolution has made them resistant to heat or cold [1]. Among these parameters, environmental conditions are still not as easy to adapt to as clothing and physical activity, especially against the expected more extreme weather circumstances caused by climate change and global warming. With the motivation to increase adaptability, various built environment studies have examined thermal conditions in different contexts. However, most of these studies were restricted to only indoor thermal comfort and neglect the comfort of pedestrians as they move in the spaces between buildings.

Although climate change is having a growing impact on built and natural environments, there is still limited literature on climate impacts and adaptation measures for buildings [2]. At this point, future weather data projections have a crucial role in maintaining a comfortable built environment. According to a United Nations report [3], an escalation of over 3°C is expected in global temperatures due to excessive greenhouse gases (GHG) density in the atmosphere by 2030. The GHG emission is required to fall by 30 gigatonnes per year to limit this global temperature rise by 1.5°C. GHG emissions for Turkey in 2015 were high, at 510 million tonnes, according to the UN report. The impact of global warming is being experienced in Turkey. Abi [4] examined the average air temperatures within the 32-year observation period between 1975 and 2006 in Bursa, one of Turkey's central industrial cities, and found out that there was an increasing trend in air temperatures. Hence, architectural research in Turkey that contribute to a better understanding of thermal comfort in the context of the built environment and global warming is relevant and important.

Any material configuration of buildings in a defined zone creates a unique climate that differs from the general prevailing weather condition in a larger area. Architectural elements, such as flooring, windows, and walls, affect indoor climate due to their material properties. Each material has a different physical characteristic in response to changes in, for example, temperature and relative humidity. Likewise, urban furniture, building facades, outdoor space layouts, street orientations, and surface materials create different climatic conditions, called microclimates for outdoor spaces. Urban microclimatic conditions matter as they affect how many hours people can spend outside daily. According to studies, mental and physical well-being is closely related to this time period [5]. This research sort to investigate the current urban thermal comfort situation for residents in Gelemic, a traditional heritage village in the Bursa region. The study involved interviewing people, making physical measurements of the thermal environment, and dynamic thermal simulation computer modelling.

2 Literature Review

2.1 Urban Microclimate Studies and Outside Thermal Comfort

Pedestrian thermal comfort is affected by many elements, such as net radiant exchange, air temperature, relative humidity, and the degree of exposure to wind [6]. In urban climatology literature, the factors related to street geometry are less researched than meteorological factors, although they have noticeable influences on urban street microclimates. Shafaghat et al. [7] analysed 27 urban climatology types of research content and found that air temperature and wind speed were the most studied factors, followed by relative humidity, street height-to-width (H/W) ratios, surface temperatures and street orientation.

2.1.1 Urban patterns and microclimate

Urban Heat Island (UHI) is a microclimatic phenomenon that was first recognized by Howard [8] after his study of meteorological conditions in urban and rural parts of London, UK. UHI is partly due to the urban fabric storing solar radiation during the day and releasing it at night [9]. UHI effects can be observed in winter as well as summer, and UHI is directly linked with how much of an area is urbanised and the density of the population [10]. According to United Nations population projections [11], the world's population is expected to be 9.7 billion in 2050, while in Turkey, the proportion of the population in urban areas is anticipated to be 86% for the same year. Therefore, it becomes more critical to tackle the UHI effect when global population growth and urbanisation are both increasing.

Yahia et al. [12] examined various urban morphologies involving low, medium, and high rise structures by developing microclimate simulations in the software ENVI-met [13]. Different thermal maps were created to illustrate the pros and cons of the current urban design of Dar-es Salam (Tanzania) as part of the study. The study concluded that low rise structures had higher mean radiant temperatures than high-rise ones. Research in Singapore by Jin et al. [14] studied the impact on air temperatures of key urban morphology parameters, like sky view factor (SVF), building plot ratio (BPR), percentage of pavement and distance to water, for daytime periods. The researchers concluded that BPR and SVF were the most important parameters influencing diurnal air temperature. Hamdan and de Oliveira [15] found that creating openings in urban patterns for the prevailing wind direction improved the ventilation of outdoor spaces which, combined with shading effects, brought outdoor temperatures within the comfort range. In conclusion, the impact of urban morphology on urban microclimate is contextual and needs to be investigated locally for each case.

3 Methodology

ENVI-met is a 3D microclimatic model based on computational fluid dynamics (CFD) and is designed to simulate surface-air interactions in urban environments. It was used in this study to calculate mean radiant temperature, wind speed, air temperature and relative humidity, and to obtain microclimatic maps of the present urban configurations in the village of Gelemic. The indoor and outdoor thermal performances of the village's vernacular architecture were examined. A thermal comfort survey with 40 residents of Gelemic was undertaken, and field measurements and dynamic thermal computer modelling were also carried out. Urban airflows, temperatures and relative humidities were measured and modelled to evaluate the existing built environment and user thermal comfort. The real-time weather data recordings from three outdoor and four indoor locations were used to validate the simulation results and investigate the village's actual urban microclimatic conditions. Kestrel 5500 and Rotronic HL-1D/TL-1D data loggers were used for the outdoor and indoor environmental measurement, respectively.

4 Case Study

4.1 Climate type and geographical features in Gelemic

According to the Köppen climate classification, Bursa has a Mediterranean climate, with hot arid summers and temperate winters. However, the Gelemic region of Bursa city can also be classified as Mediterranean mountainous climate, with slightly cooler summers and colder winters. According to Givoni [16], concrete structures are not suitable for a Mediterranean mountainous climate as the structure requires 500 mm wall thickness to adapt itself to cold winter days. Givoni underlined that the thermal resistance of 250–300 mm thick concrete walls is insufficient for comfort standards. In this context, the thermal performances of Gelemic's local adobe buildings and some new modern concrete structures were investigated.

4.2 Life in Gelemic

Gelemic's population in 2020 was 405 people, according to the Turkish Statistical Institute [17]. The most important economic activities of the people of Gelemic are fruit growing, animal husbandry and agriculture. The fruit growing, which cannot be done in the village due to the rough terrain conditions, is carried out in the Pelitören, which is located on the summit of the mountain behind the settlement. Most of the villagers have other small homes on this plateau, as they spend the harvest season there from June to August. However, those who do not raise sheep and commute between the village and the plateau in summer. Also, some villagers work in different sectors and travel to the city on a daily basis. There is also another group of people who come from the city of Bursa to spend summer days in the village, where they are more thermally comfortable than in Bursa.

4.3 The architectural character of Gelemic

Gelemic consists of traditional wooden framed earthen houses, where the sloping topography shapes housing characteristics in the village (Fig. 1). The buildings sit on a slope that falls in a south-north direction; there is almost a one-floor difference between these facades. In other words, a three-storey building is seen as if it is a two-storey from its north façade. The ground floors' walls are masonry and 700 mm in width.

Fig. 1 *A typical traditional earthen house (left) and concrete house (right) in Gelemic*

4.4 Field observations

After two weeks of observations and recording of weather data in the field, a significant temperature difference was found between the outside and inside concrete and earth houses. Four different concrete buildings were visited on-site. The concrete houses had a low air quality, with damp-smelling air inside the buildings and mould problems. On the other hand, the earth houses had very dry but dusty air. The lack of maintenance led to woodworm to infest wooden parts of the buildings and caused mites and dust in the rooms. There were also some fallen pieces in the plaster of the earth walls, resulting in less clean surfaces and a dustier environment. Since most earthen structures are over 70 years old and in need of maintenance, the airtightness of these buildings is very low, which allows dust and air to circulate between the rooms easily. Villagers tend to replace the mud houses with concrete ones due to cleaning and heating problems in addition to the regular maintenance requirements. Furthermore, there is no craftsman in the village to repair these structures. For example, the young villagers have not inherited the skills required to cut earth bricks - they are no longer interested in learning these traditional jobs. In addition, it was observed that the earth wall provided very good soundproofing.

5 Data Analyses and Results

5.1 Survey Data

In August and January 2021, as part of this research, total 40 villagers were asked about their indoor thermal comfort for both winter and summer. Half of these people lived in concrete structures and the other half lived in traditional adobe buildings. Thermal comfort questions in the polls disregarded the weather or environmental circumstances the attendees were exposed to at the time of participation and instead focussed on the inhabitants' more generic feelings and opinions about the buildings they reside in. Participants filled out paper surveys, mostly outside their residences in the settlement. According to these questionnaires, 85% of participants who resided in earth houses felt cool in summer. In terms of winter data, 38% of earth house dwellers felt cold while 24% felt cool and 5% felt slightly cool, which meant that 67% of total contributors think that their traditional earth houses do not fulfil their heating and thermal comfort needs in winter (Fig. 2 and Fig. 3). Nonetheless, immediately after their answer, some participants consciously added that the deterioration in these old buildings due to insufficient maintenance should be taken into account. On the other hand, human activity in these buildings has changed over time. Fireplaces were used for heating in these structures. Occupants later started using stoves instead of fire pits, and the unused chimneys caused heat losses. Therefore, they were either blocked with a plate or entirely removed by the residents. Additionally, the stables on the ground floors were not used in most of these structures, which meant that the animals' contribution to heating these buildings was no longer available.

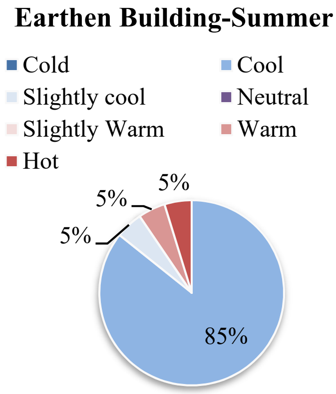


Fig. 2 *How the earthen house dwellers of Gelemic Village thermally feel during the cooling season*

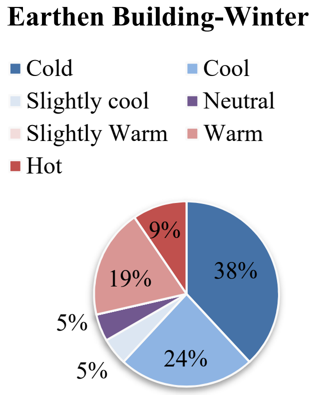


Fig. 3 *How the earthen house dwellers of Gelemic Village thermally feel during the heating season*

As for concrete houses, 30% of those polled said they felt cool inside their homes in summer, while 15% reported they were slightly cool. This indicates that 45% of all attendants considered that these structures provided thermally acceptable living spaces throughout the summer. Out of 20 concrete house users, only one person felt hot, while two others were slightly warm. The number of people feeling neutral was considerable, being 20% of the sample. In winter, a total 60% of people preferred additional heating due to the cold temperature inside. In addition to this, the proportions of those feeling warm and slightly warm in winter were respectively 30% and 10%. (Fig. 4 and Fig. 5) In this context, it is difficult to conclude that the concrete construction in Gelemic adequately contributed to thermal comfort in winter.

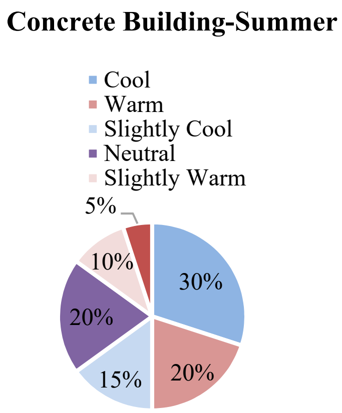


Fig. 4 *How the concrete house dwellers of Gelemic Village thermally feel during the cooling season*

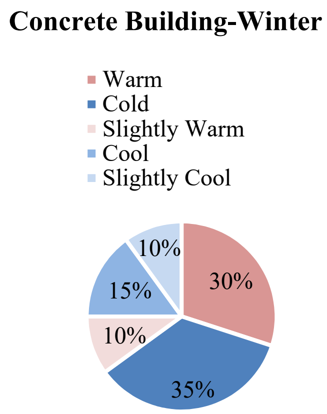


Fig. 5 *How the concrete house dwellers of Gelemic Village thermally feel during the heating season*

5.2 Computer Modelling Data and the Weather Data Obtained from the Field

Fig. 6 displays the data logging points: locations A, B, and C in the village. The architectural material configurations in these zones are also illustrated in this map.

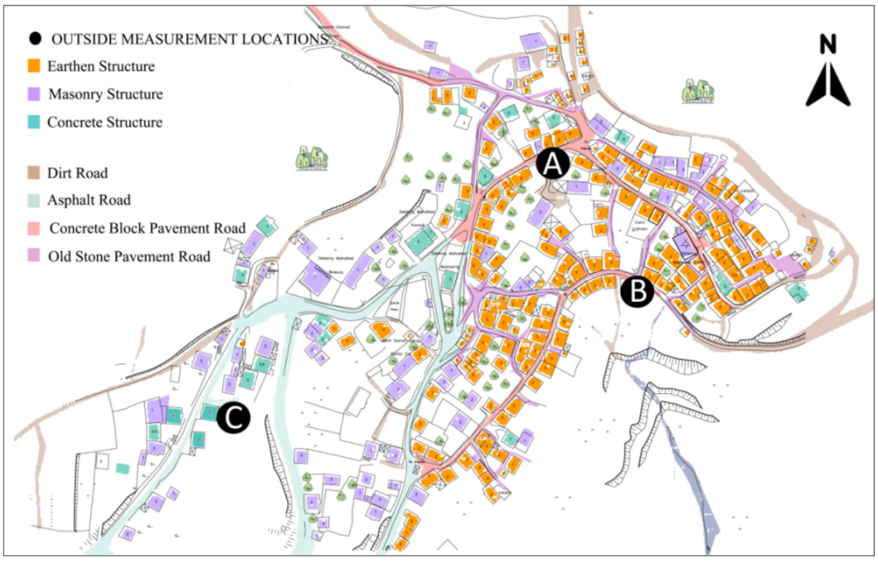


Fig. 6 *The data logging and real-time monitoring points: Locations A and B near the adobe houses and Location C near the concrete houses in the village.*

As can be seen in Fig. 6, locations A and B are predominantly close to the earth structures, whilst Location C is consisting of the concrete buildings. The urban density in Location C is less than Location A. The ENVI-met predicted mean radiant temperatures for Locations C and A are presented in Fig. 7, whilst relative humidity and potential air temperature values around these zones are shown in Fig. 8 and Fig.9 respectively. All the Envi-MET simulation maps in this paper depict the values at 1.4 metres above the terrain. The buildings in which the real-time indoor weather data were logged are marked in the graphs. According to the ENVI-met temperature maps, both radiant and air temperatures near the concrete houses at midday on 15th August were notably higher than in the adobe-built environment. It appears from these graphs that the vegetated open areas have extreme radiant temperatures.

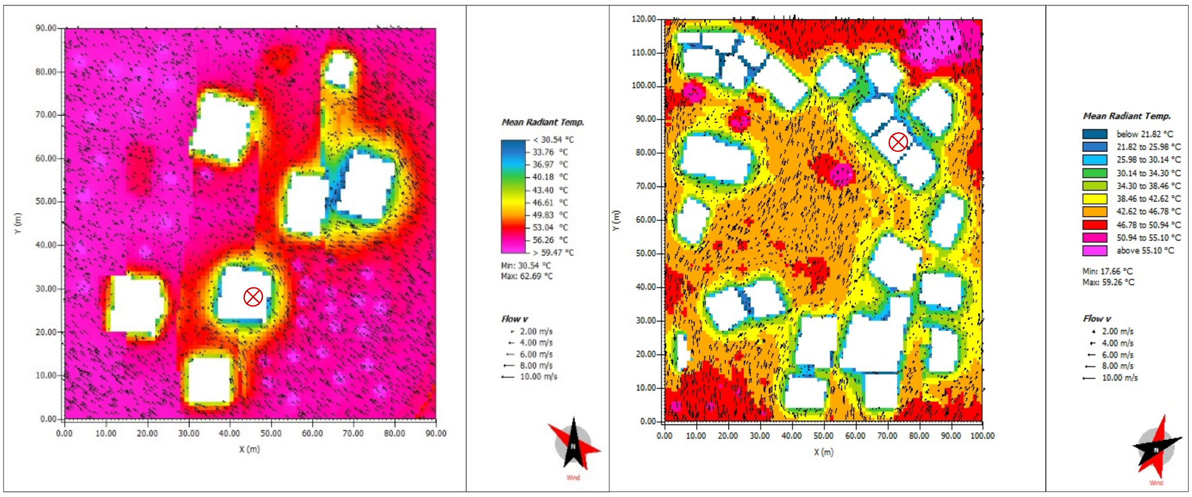


Fig. 7 *Predicted outdoor mean radiant temperature values on Location C (left) and A(right) at 12 am in 15 August 2021*

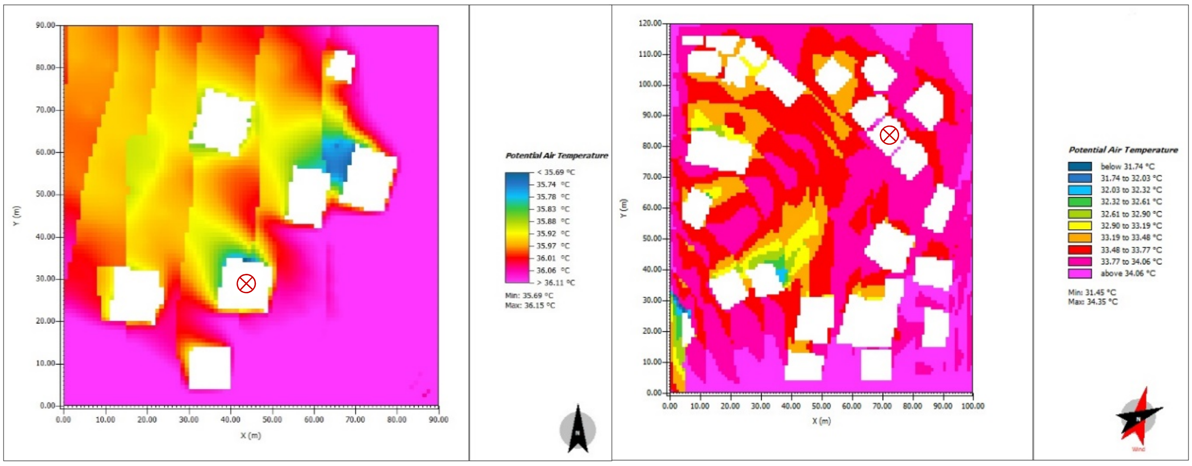


Fig. 8 *Predicted outdoor air temperature values on Location C (left) and A(right) at 12 am in 15 August 2021*

In Fig. 8 it is seen that the temperature variation in the entire zone C is quite minor, with a maximum of 0.42 °C. However, it is obvious that the close perimeters of the buildings were slightly cooler than vegetated south-facing open lands in the area. The right hand map in Fig. 8 above illustrates the air temperature distribution in Location A, where earthen structures had, a more heterogeneous profile regarding thermal environment. Especially in the surrounding area to the earthen building in which the indoor weather data were recorded, the air temperature was about 33.5–34.0 °C, which means roughly 2 °C cooler compared to Location C. To sum up, both regions did not meet the pedestrians' comfort needs with the current urban configurations. For this point, further investigation is needed to determine which parameters cause this 2°C gap primarily and which alterations help to reduce the heat.

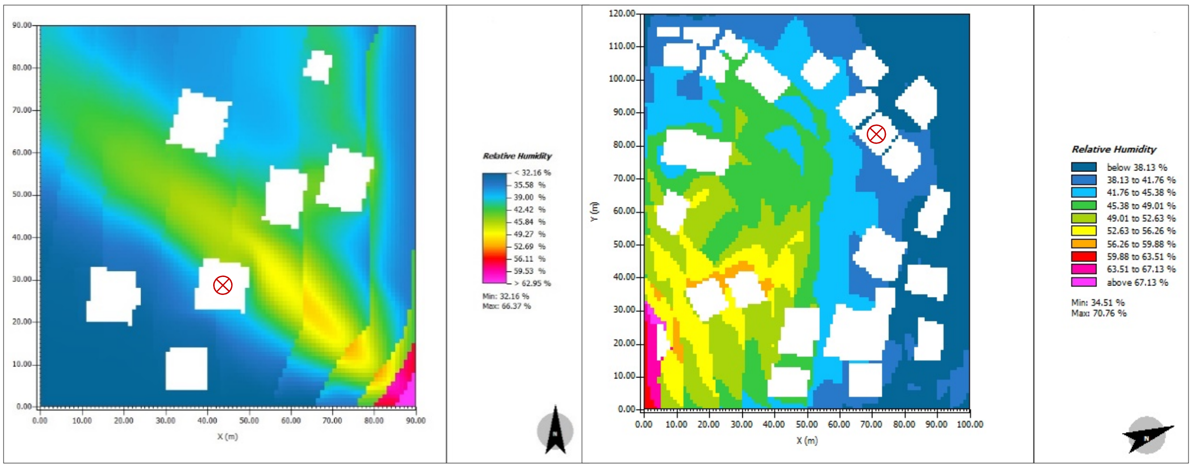


Fig. 9 *Predicted outdoor relative humidity values on Location C (left) and A (right) at 12 am on 15 August 2021*

Based on Fig.9, both built environments include considerable areas where the relative humidity was below the comfort level, although it can be said Location C comparatively performs better since it has a smaller area where the relative humidity doesn't reach to the minimum required percentage which is 40%.

It can be seen from Figure 11 that Location C was different from Location A, with higher indoor relative humidity values. On the other hand, the indoor hourly temperature in Location C was very similar to Location A during the week. Throughout the week, the average hourly air temperature was between approximately 21.0 to 25.0 °C (Fig.10), which is a quite acceptable range. On the simulation day, the real-time outside weather data seemed more or less coherent with the Envi-MET simulation results with respect to air temperature and humidity.

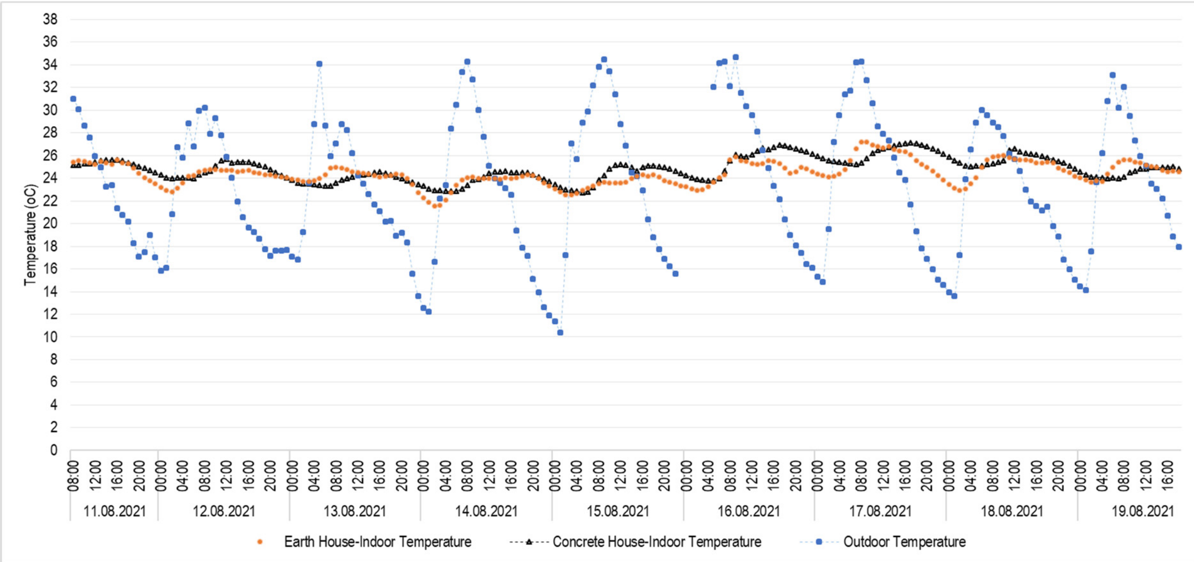


Fig. 10 *Real time monitoring data comparing the indoor air temperature in the earth house and the concrete house with outdoor air temperature.*

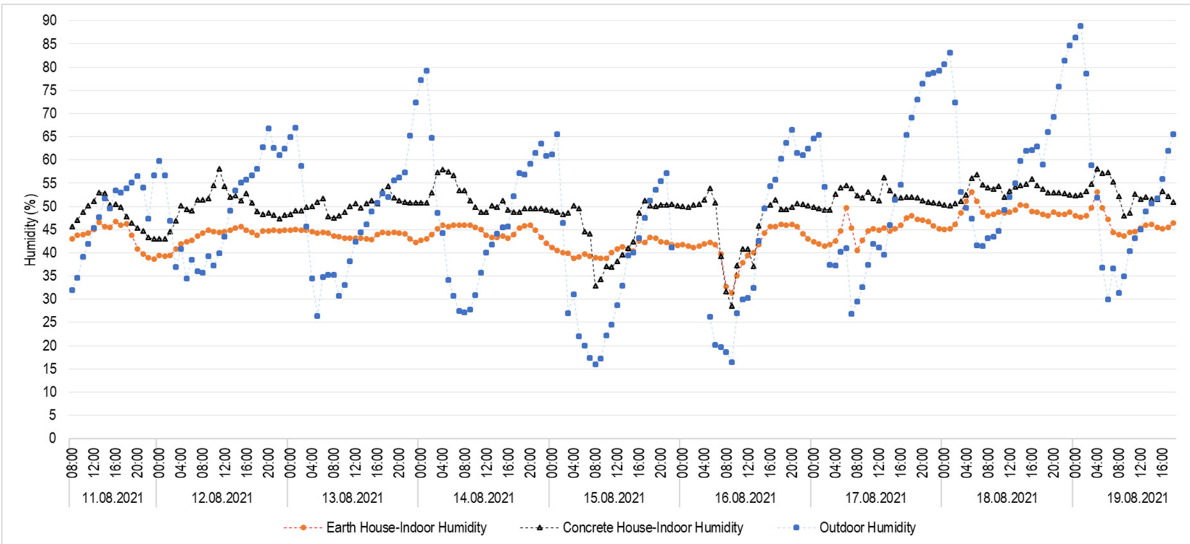


Fig. 11 *Real time monitoring data comparing the indoor relative humidity in the earth house and the concrete house with outdoor relative humidity.*

According to the one-week on-site weather data, the indoor humidity for the earth house in Location A was lower, with the values ranging from 40 to 50% compared to the indoor humidity in Location C, whilst the outdoor relative humidity was fluctuating in a wide range from 15% to 90% (Fig. 11).

6 Conclusion

In this paper, the urban microclimate conditions of Gelemic were investigated in the light of on-site observations, resident surveys and weather data recordings in addition to the computer modelling in ENVI-met software. The main findings of this research are:

- Compared to the concrete house residents, traditional earthen house dwellers in Gelemic feel thermally comfortable during summer periods. However, there is a consensus on the low thermal performance of the earthen buildings in winter periods compared to the concrete structures.
- According to the survey data, the ratio of concrete house inhabitants feeling thermally uncomfortable in winters is 60% whereas the figure for summers is restricted with 35%.
- Hourly indoor relative humidity data recorded in concrete and earth buildings demonstrate that the concrete house have a higher humidity than the earth houses, which was also observed in the field by the researcher. Nevertheless, urban microclimatic simulation results don't validate this clearly.
- The indoor hourly temperature recording presented parallel trends with similar figures for the data of concrete and earthen buildings. This indicates that people find the earth houses cool due to the low humidity in these structures.
- ENVI-met simulation maps for air and radiant temperatures show firstly that vegetated open spaces result in high amount of radiative heat and secondly that adobe structures might contribute more in creating cooler microclimates compared to concrete buildings. Notwithstanding, this prediction is not visible apparently in the on-site data recordings.

Acknowledgement

The Ministry of National Education of the Republic of Turkey, as the primary sponsor of my PhD programme, and The University of Liverpool are both financially supporting this research.

References

[1] Erell, E., Pearlmutter, D. and Williamson, T. J. (2015) *Urban microclimate: designing the spaces between buildings*. Abingdon (Royaume-Uni) [etc]: Earthscan.

[2] Stagrum, A., Andenæs, E., Kvande, T. and Lohne, J., (2020). *Climate Change Adaptation Measures for Buildings*—A Scoping Review. Sustainability, 12(5), p.1721.

[3] UNEP 2021 United Nations Environment Programme (2021). *Making Peace with Nature: A scientific blueprint to tackle the climate, biodiversity and pollution emergencies*. Nairobi. https://www.unep.org/resources/making-peace-nature

[4] Abi, K. (2010) *Effects of Climate Change on Temperature Features of Bursa Province*. Marmara University.

[5] Meredith, G., Rakow, D., Eldermire, E., Madsen, C., Shelley, S. and Sachs, N., (2020). *Minimum Time Dose in Nature to Positively Impact the Mental Health of College-Aged Students, and How to Measure It: A Scoping Review*. Frontiers in Psychology, 10.

[6] Littlefair, P. J. et al. (2000) '*Environmental site layout planning: solar access, microclimate and passive cooling in urban areas*', Building Research Establishment Ltd, 380, p. 151.

[7] Shafaghat, A. et al. (2016). *Street Geometry Factors Influence Urban Microclimate in Tropical Coastal Cities: A Review*, Environment and Climate Technologies, 17(1), pp. 61–75. DOI: https://doi.org/10.1515/rtuect-2016-0006

[8] Howard, L., (1833). *The climate of London: deduced from meteorological observations made in the metropolis and at various places around it*. London: Harvey and Darton.

[9] Mahgoub, M. (2015) '*Assessment of Thermal and Visual Micro-climate of a Traditional Commercial Street in a Hot Arid Climate* Mohamed Mahgoub Bsc , Msc PhD Thesis Title page', (June).

[10] Musco, F., (2016) *Counteracting Urban Heat Island Effects in a Global Climate Change Scenario*. Springer

[11] United Nations, Department of Economic and Social Affairs, *Population Division* (2019). World Population Prospects 2019: Highlights (ST/ESA/SER.A/423).

[12] Yahia, M., Johansson, E., Thorsson, S., Lindberg, F. and Rasmussen, M., (2017). *Effect of urban design on microclimate and thermal comfort outdoors in warm-humid* Dar es Salaam, Tanzania. International Journal of Biometeorology, 62(3), pp.373-385.

[13] ENVI-met (2021) https://www.envi-met.com/

[14] Jin, H., Cui, P., Wong, N. and Ignatius, M., (2018). *Assessing the Effects of Urban Morphology Parameters on Microclimate in Singapore to Control the Urban Heat Island Effect*. Sustainability, 10(1), p.206.

[15] Hamdan, D. and de Oliveira, F., (2019). *The impact of urban design elements on microclimate in hot arid climatic conditions*: Al Ain City, UAE. Energy and Buildings, 200, pp.86-103.

[16] Givoni, B., (1976). *Man, Climate and Architecture* (2nd edition). London: Applied Science Publishers.

[17] 2020. TUIK. *Adrese Dayalı Nüfus Kayıt İstatistikleri*. [online] Available at: <https://biruni.tuik.gov.tr/medas/?kn=95&locale=tr> [Accessed 14 October 2021].

Design of School Buildings and Classrooms as a Prevention of Myopia Development in Children – Review

Martina LIBERSKÁ[a], Lenka MAIEROVÁ[a,b]

[a] *Czech Technical University in Prague, Faculty of Civil Engineering, Thákurova 2077/7, 166 29 Praha 6, Czech Republic*
[b] *Czech Technical University in Prague, University Centre for Energy Efficient Buildings, Třinecká 1024, 273 43 Buštěhrad, Czech Republic*

Abstract

Children aged 6 to 14 spend a large part of their time in school classrooms. The human eye in this age is evolving and is sensitive to the surrounding light conditions. For this reason, it is important to ensure that in the classrooms daylight quantity and quality requirements are fulfilled. The windows and the shading systems need to be designed to limit potential summer overheating and prevent users' discomfort.

Recently, a rapid increase in myopia progression in children has been reported. Possible causes are still unclear, but limited time spent outdoors, insufficient access to daylight and sunlight seem to be important triggers for myopia development. Moreover, data collected during pandemic Covid 19, when people were forced to stay at home, also suggest the irreplaceable role of a quality lighting environment on the healthy development of the eye.

This study assesses the interaction of the classroom design, daylighting, and healthy eyesight.

Keywords: *visual comfort, eye development, window layout*

1 Introduction

People in modern society tend to spend most of their time indoors, where they are exposed only to a fraction of daylight and sunlight in terms of quantity and quality. The design of the buildings must therefore fulfil a variety of visual, thermal, acoustic, and indoor air comfort requirements. Unfortunately, balancing all the requirements is often difficult or almost impossible. Especially if the tools to ensure both thermal and visual comfort are often in conflict.

To provide a healthy environment, indoor spaces must receive as much daylight as possible. To prevent overheating, window openings should be protected from direct sunshine. In some cases, positioning of the windows in certain cardinal direction may limit the overheating, but often it cannot be avoided without further precautions. Exterior shading systems operating during intensive sunlight hours prevent the interior from overheating effectively but also affect the daylight provision indoors. Unfortunately, this problem is globally underestimated.

Natural daylight and sunlight exposure during the day is important for the visual comfort and synchronization of biological rhythms but as well the appropriate development of the human eye. Exposure to daylight and sunlight is crucial for children aged 6 to 14, whose eyesight is still in process of development, and surrounding conditions are dispensable for its healthy development. Recent studies suggest that the lack of daylight could be one of potential risks in developing myopia in children. This literature review investigates actual state of myopia in world population and its potential connection to design of school classrooms.

2 Myopia

Myopia or short-sightedness is an ametropic eye disorder resulting in change of the position of focus in front of the retina. People suffering from myopia cannot see clearly at a longer distance. It can lead to loss of vision caused by retinal detachment [1] or glaucoma [2]. Myopia can be divided into high and low myopia according to the value of a spherical equivalent refractive error [3]. All types of myopia can affect the quality of life (psychologically, cosmetically, practically, and financially). Costs of myopia correction for adults in Asia are estimated at US $328 billion annually. Costs of high myopia care are estimated at US $250 billion annually [4].

Recently, a rapid increase in the number of people suffering from myopia and high myopia has been reported all over the world. It was estimated that there was more than 28 % of the global population suffering from myopia and almost 4 % from high myopia in the year 2010. The prediction for 2050 is more than 60 % of the world population suffering from myopia and 10 % of the world population suffering from high myopia [5]. Rapid increase in the incidence of myopia occurs in the final stage of vision development in children aged 7 to 15 years, after 20 years of age the increase in newly identified cases is minimal [5]. The prevalence of myopia is different in various countries and ethnic groups. In 2020 it reached almost 50 % of population in Asia (China, Japan, etc.), and it is significantly lower in Australia, Europe, and America [6].

In order to prevent this emerging global problem, scientists started researching potential causes of myopia and high myopia in people. The known potential risk factors can be divided into two groups, environmental and genetic. For a period of time, genetic factors were believed to be the main factor causing myopia. Studies suggested that increased severity of parental myopia has led to a greater risk of myopia development in their children [7],[8]. On the contrary, recent findings have proven that only a small proportion of myopia development is driven by genetic factors, while major influences have environmental factors, such as visual activity and lighting [9].

One of the documented environmental risks is near work. Near work is defined as the sum of activities with short working distance, such as reading, studying, writing, doing homework, watching TV, or playing video games [10]. In the study of 12-year-old Australian schoolchildren, near work (close reading distance less than 30 centimeters) and continuous reading (reading longer than 30 minutes) increased the odds of having myopia [11]. This dependence was also observed in a Singapore study [12] where children with a greater current reading exposure were more likely to be myopic.

Further, a lack of outdoor activity or time spent outdoors has been identified as one of the potential risks for myopia development. Several studies [13],[14] confirmed that children who spent more time outdoors are less likely to progress myopia. In the study in North-east China [15], adding a 20-minute recess program outside the classroom prevented myopia onset in children. The increased outdoor activity could become a protective factor in myopia development.

There is only limited evidence suggesting that the amount of daylight in the classroom affects the progression of myopia. However, in 1869 German pathologist Professor Rudolf Virchow [16] identified myopia as the most harmful effect of school attendance. More children became short-sighted as they grew older. An association was found between daylight levels and the observed incidence of myopia.

To summarize, myopia development is affected by a combination of various factors. One of potential factors is availability of sunlight and daylight, which influences healthy development of an eye. Despite a significant role of daylight and sunlight exposition, there is limited knowledge on the daylight and sunlight availability, spectral composition and daylight distribution and myopia development.

3 An average day of a pupil

Light in the natural environment changes its intensity and spectral composition during the day. At noon, there is a high intensity of daylight and sunlight compared to other parts of a day. From the quality point of view, daylight cannot be easily replaced by electric lighting. Daylight and sunlight penetrating the indoor environment are lower in intensity and in spectral composition because of window glazing. Therefore, it is important for children to stay outdoors during this part of the day or at least to stay in excellent lighting and high visual comfort conditions. This is highly relevant in primary school classrooms design because children aged from 7 to 15 spend significant part of a day there.

In 2021, Czech pupils spend 195 days in school during the year. On average, children in OECD countries spend 4,3 hours per day in instructional hours in classrooms [19]. Data from National Kids Survey conducted in 2011 show that more than one third of children (37,7%) spend less than 2 hours per day outside the buildings and almost 5% do not spend time outdoors at all [18].

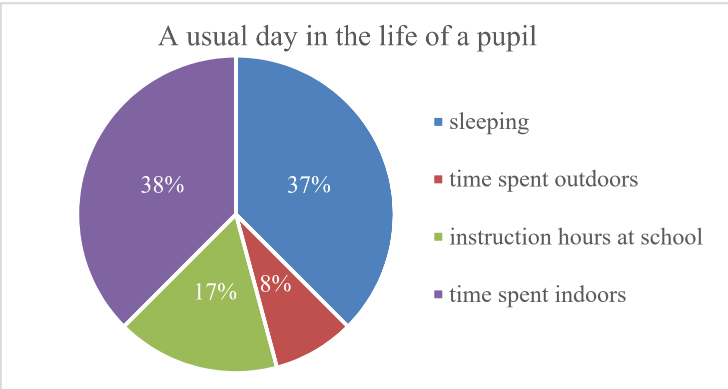


Fig. 1 *A day of an average pupil (hours spend on different activities, based on data from [18,19,27])*

Presented analyses draw attention to the fact that in the age when their eyes are sensitive to quality lighting environment, children spend more than half of a day indoors, largely inside the classrooms. They are exposed only to a fragment of daylight and sunlight in terms of quality and quantity (especially daylight provision and spectral composition). And it differs from outside conditions significantly. Access to daylight and quality of light distribution in primary school classrooms is obviously important for healthy eye development.

4 Daylighting requirements in schools

Visual comfort requirements vary between countries. The first daylighting standard for school classrooms in the Czech Republic has been introduced in 1965 [20]. Over the years, the standards went through a few changes and established a very detailed system with specific requirements for various rooms in school buildings. Depending on the type of visual activity, each space needs a different amount of daylight and different uniformity of daylight [21].

Until recently, the daylight provision has been expressed by daylight factor and calculated under the CIE Overcast sky, without the influence of direct solar radiation. For this condition, the Czech technical standard assumed the global (outdoor) horizontal illuminance of 5000 lux. Inside school classrooms, where writing and reading are dominant, the requirement for daylight provision is set to 1,5 % of the outdoor illuminance, which must be reached in the whole area of the horizontal control plane, i.e. in the whole area of the room. This requirement was very strict and public authorities required its compliance.

In 2019, new European standard has been implemented and replaced the local requirements given by Czech technical standards. Since then, in addition to the daylight provision, technical specialists are recommended to assess also a quality of view and a risk of glare of each user position [22]. The European standard contains recommended values for three different qualitative levels, while at least the minimal level should be fulfilled.

To assess daylight provision, the European standard requires target horizontal illuminance of 300 lux, 500 lux and 750 lux, as a minimum, medium and high level of daylight. The median (outdoor) diffuse horizontal daylight illuminance was established for each capital city among EU countries (Prague - 14900 lx). The requirements define the target values (illuminance expressed in lux) at the respective percentage of floor area. If expressed as daylight factor, minimal requirement is set to reach at least 0,7 % in 95 % of floor plane and 2,0 % in 50 % of floor plane. This basic standard requirement is less strict than the one used in Czech Republic before 2019. For above-standard daylighting quality, higher level of target illumination can be used.

To summarize, the availability of natural light inside the classrooms is significantly lower than outside the building. Even if the highest requirements are met, daylight quantity inside the classroom reaches less than 10 % of the exterior levels and rapidly decreases with the increasing distance from the windows.

4.1 Control of glare risk

Further, the European standard newly implemented methods for evaluating the risk of glare, which was previously not assessed in the Czech Republic. The importance of glare assessment increased due to new visual activities indoors, such as using computers, reading from monitors, or the use of data projectors. To keep visual comfort for these activities, the human eye is more sensitive to the presence of luminance on surfaces within the field of vision. Due to the technical capabilities of display devices, and in order to create a sufficient contrast between the text and its background, the requirements of the lighting environment are stricter in comparison to, for example, reading books. The "newly introduced" glare assessment [22] can be used to predict the visual comfort already in the project phase. Unfortunately, in many projects instead of proposed glare analysis and project optimization, only the statement that a mobile shading system will be installed is included in the project. This approach is sufficient to comply with the administrative requirements, but at the end of the process, there is a classroom with windows covered most of the time with manually controlled, often broken shading elements. The risk of glare and overheating is partially controlled, but together with that, access to daylight is insufficient.

4.2 Orientation of windows in classrooms

Orientation of windows towards the cardinal direction is an important factor for visual and thermal comfort. By adequate design of the orientation of classroom windows, the heat demands can be reduced, overheating can be limited, and visual comfort of the users can be satisfied with no additional precaution. Each orientation towards cardinal directions have benefits and disadvantages.

South-oriented windows: Windows directed to the south with a maximal deviation of 15° to the east or west was the most recommended daylighting strategy in the 20th-century. Constructions practices used in the Czech Republic [23], recommend this orientation of windows, because of its high accessibility of direct solar rays and therefore achieving the highest efficiency in the amount of light penetrating to the classroom. The southern orientation of the windows is suitable for users in terms of quantity. However, the orientation of windows towards the south can lead to a small window design to prevent overheating. This design may ultimately lead to a significant reduction of daylight in deeper parts of classrooms and lowered daylight quality associated. Also, a phenomenal of solar rays as a tool of disinfection is questionable, because of three-layer glazing typically used in new buildings.

North-oriented windows: According to literature, the northern orientation of windows in classrooms is generally unsuitable due to insufficient daylighting, especially in unilaterally illuminated classrooms. When orienting between north and east, it is appropriate to supplement the unilateral lighting with secondary openings oriented between east and south. [24] The northern orientation is according to [23] suitable for art classrooms and laboratories, offices or other rooms with a shorter stay. On the contrary, designing windows to the north can reduce the risk of glare and prevent overheating.

East-oriented windows: According to previous studies [24], positioning of classroom windows towards the east is generally not an ideal choice. The lighting level at the proximity of the window is satisfactory, but with greater the distance from the window, the lighting level at the workplace deteriorates, and is necessary to supplement the daylight with artificial lighting. Especially in the morning hours, there are direct solar rays which can create distracting reflections especially for students sitting near the windows.

West-oriented windows: West-oriented windows have sunlight access during the afternoon. The lectures usually take place in the morning, therefore, there is not a high risk of glare. The daylight provision is similar to the east-oriented windows.

South-east-oriented windows: The orientation of windows to the southeast is suitable in terms of quantity and quality daylight. The level of daylight is suitable for students during the year and there is a lower risk of disturbing glare than in the south-oriented windows. The sun is higher in this orientation than in the east and therefore it is easier to regulate daylight access to classrooms [24]. However, similar problem with shading and daylight provision occurs.

Each orientation of windows has advantages and disadvantages. Different window orientation is suitable for different spaces. For primary school classrooms, it is important to choose the correct orientation of the windows with regard to the lessons that take place in the morning. The orientation of the windows affects the level of daylight in the classroom area, it can help to prevent glare, must allow a view outside during the lessons, and prevent the classroom from overheating. Additionally, the window layout should ensure to limit the amount of energy consumption for cooling or artificial light in the classroom. It is rather difficult to fulfill all the requirements for a healthy and energy-efficient environment with the use of a standard, unilateral fenestration system. A well-designed and optimized complex advanced system, implemented already in the design stage of the project, may provide the balance of these requirements according to today's standards.

4.3 Daylight access to the classroom

Depending on the position of the windows within the room, daylight can access the interior from one or more horizontal directions, vertically from above, or in a combination of several directions.

Unilaterally illuminated classrooms: Unilaterally illuminated classrooms are very common in schools. It is required that the light must come from the left direction because most of the pupils are right-handed. This window layout is traditional and not highly space demanding. Unfortunately, in classrooms with higher depth, the daylight is poorly distributed. Pupils positioned in distance from the window receive significantly lower illuminance than those right next to the window, especially on lower floors of the buildings. This window layout can lead to the overuse of artificial light as an additive light source during the day and a rise in financial energy costs. If the windows are facing the sunny side, during the large exposure to direct solar radiation, it is necessary to shield the entire glazed area with shading systems to protect the classroom from the glare and summer overheating. As a consequence, the penetration of daylight into the room is significantly reduced. The negative impact mainly affects zones further from the windows, where the illuminance may drop below the hygienic minimum.

Bilaterally and multilaterally illuminated classrooms: Classrooms illuminated by windows in a combination of several directions (for example windows situated in opposite walls) are exposed to similar daylight levels in the whole classroom. There is larger availability of view out of the windows for all pupils. This window layout solves the problems with overheating and disturbing glare, by simply shading only a half of windows and leaving another half of windows unshaded for daylight penetration. The solution with windows situated in two adjacent walls provides more space with accurate daylight conditions, but on the other hand, causes a large difference in various places (very low uniformity). Advanced daylighting systems allow daylight to be delivered from multiple sides (opposite walls + skylights), which can lead to homogenous lighting condition in the classroom [25].

In addition to the layout of the windows and the orientation towards cardinal directions, the broader urban concept of the school must be taken into account. Unilaterally and bilaterally illuminated school building concepts differ in the requirement for the building plot size because the spatial layout of bilaterally illuminated classrooms is more complex and therefore more space consuming.

In general, classrooms located it the upper floors of the school building receive a higher level of daylight quantity but also face an increased risk of glare and overheating. A study combining these factors [25] revealed that bilaterally illuminated classrooms situated on lower floors can provide daylight levels and uniformity than unilaterally illuminated classrooms on higher floors. This suggests that advanced layout solutions can provide high lighting quality while keeping desired urban density.

4.4 Other factors

Last, but not least, the interior design can have a significant impact on light distribution and particularly on glare. The color of ceilings and walls should be white or in bright colors. On the other hand, highly glossy surfaces of the furniture and floor should be avoided to avoid potential glare. White and light colors increase the distribution of light deeper in the room and compared to surfaces such as dark wood or concrete, the use of bright surfaces can significantly increase the level of lighting throughout the classroom [24]. Higher reflectivity of large surfaces in classrooms can also be achieved by highly reflective and scattering ceilings. This solution can be used especially in the reconstruction of older buildings. By using highly reflective ceilings, it is possible to increase the level of daylight further from the windows without aggravating the glare of the pupils sitting at the windows with preservation historical and aesthetic values of listed buildings [26].

5 Conclusion

Daylight and sunlight exposure are important factors in human lives. influencing many aspects of it. Therefore, it is necessary to design indoor lighting environment as similar as possible as natural outdoor light with its quantity and quality. Lack of exposure to quality light also causes progression of myopia. Therefore, proper design of indoor environment, where people spend most of their time, is crucial for healthy development of the eye. Vision development is not completed until early adulthood, which causes the eye to be sensitive to sufficient quality lighting. Since children aged 7 to 15 years spend more than half of a day inside the classrooms, it is necessary to ensure good visual comfort there. Despite the physiological, psychological, financial and practical consequences of myopia, this problem is still widely neglected and the understanding of potential risk factors is limited. A few potential risks of myopia are described in the research (such as near work or a length of stay outdoors during the day), apart from it the scientists suggest a potential link between myopia and daylight and sunlight provision in indoor environment.

It is particularly important because the daylight and sunlight penetration into the room is affected by many aspects that must be taken into consideration already in the early stage of the design process. For instance, the orientation of windows of the classroom towards cardinal directions, the distribution of windows in the classroom, or reflection coefficients of designed materials, all these significantly affect the quality of the lighting environment. Apart from architectural factors, there are also requirements of visual and thermal comfort, which can collide in terms of overheating precautions and daylight provision requirements. Understanding the interaction between light in the room, its particular properties, and the processes of the developing eye can help architects to optimize schools and classrooms design. A well-balanced design can improve daylighting significantly and may help to protect healthy eye development in the sensitive population of children.

References

[1] POLKINGHORNE, Philip J a Jennifer P CRAIG. Northern New Zealand Rhegmatogenous Retinal Detachment Study: epidemiology and risk factors. *Clinical and Experimental Ophthalmology* [online]. 2004, **32**(2), 159-163 [cit. 2021-11-07]. ISSN 1442-6404. Available on: doi:10.1111/j.1442-9071.2004.00003.x

[2] MITCHELL, Paul, Fleur HOURIHAN, Jen SANDBACH a Jie JIN WANG. The relationship between glaucoma and myopia. *Ophthalmology* [online]. 1999, **106**(10), 2010-2015 [cit. 2021-11-07]. ISSN 01616420. Available on: doi:10.1016/S0161-6420(99)90416-5

[3] FLITCROFT, Daniel Ian, Mingguang HE, Jost B. JONAS, et al. IMI – Defining and Classifying Myopia: A Proposed Set of Standards for Clinical and Epidemiologic Studies. *Investigative Opthalmology & Visual Science* [online]. 2019, **60**(3) [cit. 2021-11-09]. ISSN 1552-5783. Available on: doi:10.1167/iovs.18-25957

[4] CHUA, Sharon Yu Lin a Paul J. FOSTER. The Economic and Societal Impact of Myopia and High Myopia. ANG, Marcus a Tien Y. WONG, ed. *Updates on Myopia* [online]. Singapore: Springer Singapore, 2020, 2020-10-10, s. 53-63 [cit. 2021-11-07]. ISBN 978-981-13-8490-5. Available on:: doi:10.1007/978-981-13-8491-2_3

[5] Brien A. Holden, Timothy R. Fricke, David A. Wilson, Monica Jong, Kovin S. Naidoo, Padmaja Sankaridurg, Tien Y. Wong, Thomas J. Naduvilath, Serge Resnikoff, Global Prevalence of Myopia and High Myopia and Temporal Trends from 2000 through 2050, Ophthalmology, Volume 123, Issue 5, 2016, Pages 1036-1042, ISSN 0161-6420, https://doi.org/10.1016/j.ophtha.2016.01.006.

[6] PAN, Chen-Wei, Dharani RAMAMURTHY a Seang-Mei SAW. Worldwide prevalence and risk factors for myopia. *Ophthalmic and Physiological Optics* [online]. 2012, **32**(1), 3-16 [cit. 2021-11-09]. ISSN 02755408. Available on: doi:10.1111/j.1475-1313.2011.00884.x

[7] LI, Weiran, Pengcheng XUN, Chang CUI a Jibo ZHOU. The Impact of Parental Myopia on Myopia in University Students: A Cross-Sectional Study from Shanghai, China [online]. , 1-19[cit. 2020-12-21]. Available on: doi: https://doi.org/10.21203/rs.3.rs-29156/v1

[8] LIM, Lik Tahi, Yanhong GONG, Elliott Y. AH-KEE, Gexin XIAO, Xiulan ZHANG a Shicheng YU. Impact of Parental History of Myopia on the Development of Myopia in Mainland China School-Aged Children. Ophtalmology and Eye Diseases [online]. 2014, 6 [cit. 2020-12-21]. ISSN 1179-1721. Available on: doi:https://doi.org/10.4137/OED.S16031

[9] GRZYBOWSKI, A., P. KANCLERZ, K. TSUBOTA, C. LANCA a Seang-Mei SAW. A review on the epidemiology of myopia in school children worldwide. BMC Ophthalmol. 2020. Available on: doi: https://doi.org/10.1186/s12886-019-1220-0

[10] HUANG, Hsiu-Mei, Dolly Shuo-Teh CHANG, Pei-Chang WU a Vishal JHANJI. The Association between Near Work Activities and Myopia in Children—A Systematic Review and Meta-Analysis. *PLOS ONE* [online]. 2015, **10**(10) [cit. 2022-03-11]. ISSN 1932-6203. Available on: doi:10.1371/journal.pone.0140419

[11] IP, Jenny M., Seang-Mei SAW, Kathryn A. ROSE, Ian G. MORGAN, Annette KIFLEY, Jie Jin WANG a Paul MITCHELL. Role of Near Work in Myopia: Findings in a Sample of Australian School Children. *Investigative Opthalmology & Visual Science* [online]. 2008, **49**(7) [cit. 2021-11-08]. ISSN 1552-5783. Available on: doi:10.1167/iovs.07-0804

[12] Seang-Mei Saw, Wei-Han Chua, Ching-Ye Hong, Hui-Min Wu, Wai-Ying Chan, Kee-Seng Chia, Richard A. Stone, Donald Tan; Nearwork in Early-Onset Myopia. *Invest. Ophthalmol. Vis. Sci.* 2002;43(2):332-339.

[13] ROSE, Kathryn A., Ian G. MORGAN, Jenny IP, Annette KIFLEY, Son HUYNH, Wayne SMITH a Paul MITCHELL. Outdoor Activity Reduces the Prevalence of Myopia in Children. *Ophthalmology* [online]. 2008, **115**(8), 1279-1285 [cit. 2021-11-07]. ISSN 01616420. Available on: doi:10.1016/j.ophtha.2007.12.019

[14] Dirani M, Tong L, Gazzard G, et al; Outdoor activity and myopia in Singapore teenage children; British Journal of Ophthalmology 2009;93:997-1000.

[15] JIN, Ju-Xiang, Wen-Juan HUA, Xuan JIANG, et al. Effect of outdoor activity on myopia onset and progression in school-aged children in northeast china: the sujiatun eye care study. *BMC Ophthalmology* [online]. 2015, **15**(1) [cit. 2021-11-08]. ISSN 1471-2415. Available on: doi:10.1186/s12886-015-0052-9

[16] HOBDAY, Richard. Myopia and daylight in schools: a neglected aspect of public health? *Perspectives in Public Health* [online]. 23.3.2015, **136**(1), 50-55 [cit. 2020-12-22]. ISSN 1757-9147. Available on: doi:https://doi.org/10.1177/1757913915576679

[17] Paruthi S, Brooks LJ, D'Ambrosio C, Hall WA, Kotagal S, Lloyd RM, et al. Recommended amount of sleep for pediatric populations: a consensus statement of the American Academy of Sleep Medicine. J Clin Sleep Med. 2016;12(6):785–786.

[18] Larson, Lincoln & Green, Gary & Cordell, H.. (2011). Children's time outdoors: Results and implications of the National Kids Survey. Journal of Park and Recreation Administration. 29. 1-20.

[19] OECD (2021), Education at a Glance 2021: OECD Indicators, OECD Publishing, Paris, https://doi.org/10.1787/b35a14e5-en.

[20] Denní osvětlení ve školách dle ČSN EN 17037, Ing. Miroslav Čermák, 27.11.2020

[21] ČSN 73 0580-3: Denní osvětlení ve školch

[22] EN 17037: Daylight in Buildings (2019)

[23] STÝBLO, Zbyšek. Nauka o stavbách: školské stavby. Vyd. 1. V Praze: České vysoké učení technické, 2010. ISBN 978-80-01-04510-7.

[24] THIRY, Jean-Denis Bernard Marie Ghislain. Typologie des écoles primaires en Suisse de 1945 à 2015 et stratégies d'éclairage naturel: Volume I. Lausanne, 2019. Disertační práce. École Polytechnique Fédérale de Lausanne. Vedoucí práce Prof. M. Andersen.

[25] Vliv dispozičního řešení na dostupnost denního světla a zrakový komfort v učebnách základních škol, Martina Liberská, 2021

[26] NOCERA, Francesco, Alessandro LO FARO, Vincenzo COSTANZO a Chiara RACITI. Daylight, Performance of Classrooms in a Mediterranean School Heritage Building. Sustainability [online]. 2018, 10(10) [cit. 2020-12-26]. Available on: https://doi.org/10.3390/su10103705

[27] Paruthi S, Brooks LJ, D'Ambrosio C, Hall WA, Kotagal S, Lloyd RM, et al. Recommended amount of sleep for pediatric populations: a consensus statement of the American Academy of Sleep Medicine. J Clin Sleep Med. 2016;12(6):785–786.

The Role of Origami Technique in Sustainable Building Systems

Hadel SAAD RAZOKI[a], Ahmed A. Rashid KBAH[b]

[a] *Al-MUTHANNA UNIVERSITY – Collage of Engineering – Department of Architecture, hadel.arch@mu.edu.iq*
[b] *Al-MUTHANNA UNIVERSITY – Collage of Engineering – Department of Architecture, ahmed.architect@mu.edu.iq*

Abstract

Nature is the source of inspiration for art and architecture and design principles such as (linear construction of the tree, shell construction in both the egg and shell, the taut construction of cobwebs). Modern use of the word "Origami" as an umbrella term for folding practices regardless of their culture of origin, the goal of which is to transform a flat sheet of paper into its final shape through sculpting and folding techniques. There are also well-known standard foundations that are used in a wide range of models. And additional basic rules (the square rule). Nature reveals the principles of rhythm and harmony, which are the principles adopted by the Origami design through its inspiration from the organic theory. The research explains the concept of Origami and its impact on contemporary design ideas in (Architecture - interior design and other fields) and answers research questions about its relationship to sustainability. To prove this, the research adopted the descriptive analysis method to come out with conclusions, the most important of which is that the Origami design achieves the elements (durability, flexibility, and beauty), which are important indicators of sustainability.

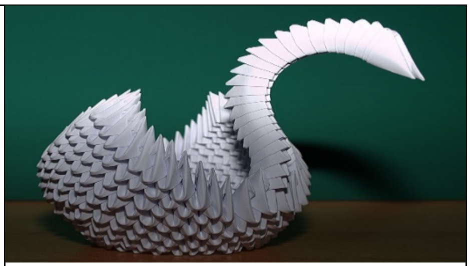
Keywords: *Origami technique, Architecture, Sustainability.*

1 Origami is known as

Origami (Ori) meaning (folding) and (gami-kami meaning paper) is the art of paper folding, which is often associated with Japanese culture through folding paper and transforming it into three-dimensional shapes using folding and sculpting and integrating these techniques with various paper forms, to create complex designs of a degree, they are highly complex and have specific shapes resembling an object or a general state. As Origami stems from two aspects (the biological aspect stems from the organic theory, and the structural aspect stems from engineering Origami thought, which refer to nature). Origami practitioners generally discourage cutting and pasting or making marks on paper. A few basic Origami folds can be combined in different ways to make intricate designs, and the crane is one of the most popular forms of Origami art. Another type of Origami is (Kirigami), which is folding paper using glue or scissors to make the desired shape. The initial models were simple and developed into technical and complex models formed by professionals.

In general, these models start with a square sheet of paper whose sides can be of different colors, shapes, and patterns. Origami, which has been practiced since the Edo period (1603–1867), is less strict in these laws, and sometimes it is used to cut paper or start with paper that is not square. The principles of Origami are also used in packaging and some other engineering applications and also in space, where NASA uses them to make spacecraft as in fig.1. (Louis, Bruce and Francis, 1996; Hor, 2005)

Movable spring, designed by Jeff Bennon, from one rectangular piece of paper



Origami paper crane that represents peace and long life in Japan

Fig. 1 *https://upload.wikimedia.org/wikipedia/en/2/2c/Origami_crane_cropped.jpg*

Many Origami books begin by describing the basic techniques used to build models. They include simple schemes of basic folds such as valley folds, mountains (folds, reverse folds, and depressions). There are also well-known calibration bases that are used in a wide range of models. For example, the base of the bird, which is an intermediate stage in the construction of the flapping bird. And additional basic bases (square base) fish base, and frog base.

2 General features of Origami design

- Unity
- Simplicity
- Abstraction
- Pliancy
- Modularity

3 The Origami thought was inspired by the surrounding nature sources

3.1 Inspiration from nature

Nature is the mother of the sources from which design is inspired. The traditional Origami has been influenced by the elements of vital nature through the following models as fig.2:

Fig. 2 *Origami inspiration from nature (architecture design.com)*

3.1.1 General Organic Style in Folding

It is one of the patterns of forming and showing models inspired by shapes in nature by simulating shapes directly or indirectly from the simplest patterns, to assemble and produce its units together to build the final shape. The unit is characterized by two main elements, namely the pocket and the tip flap, and the two elements of the pocket and the tip are the factor that connects the units together to achieve the desired shape.(Bellamy, Boustani, Brehm, & Soto, 2019)

3.1.2 Bio Kinetic Pattern

It is inspired by the movement of living organisms (mechanics: this doctrine is that the movements of the universe arise from mechanical force, where inspiration is from nature through the expression of forces that move within nature to transfer matter from one point to another, since energy in nature occurs with less energy through four models of movement Including: (explosion, snail, zigzag, branching) as fig.3.

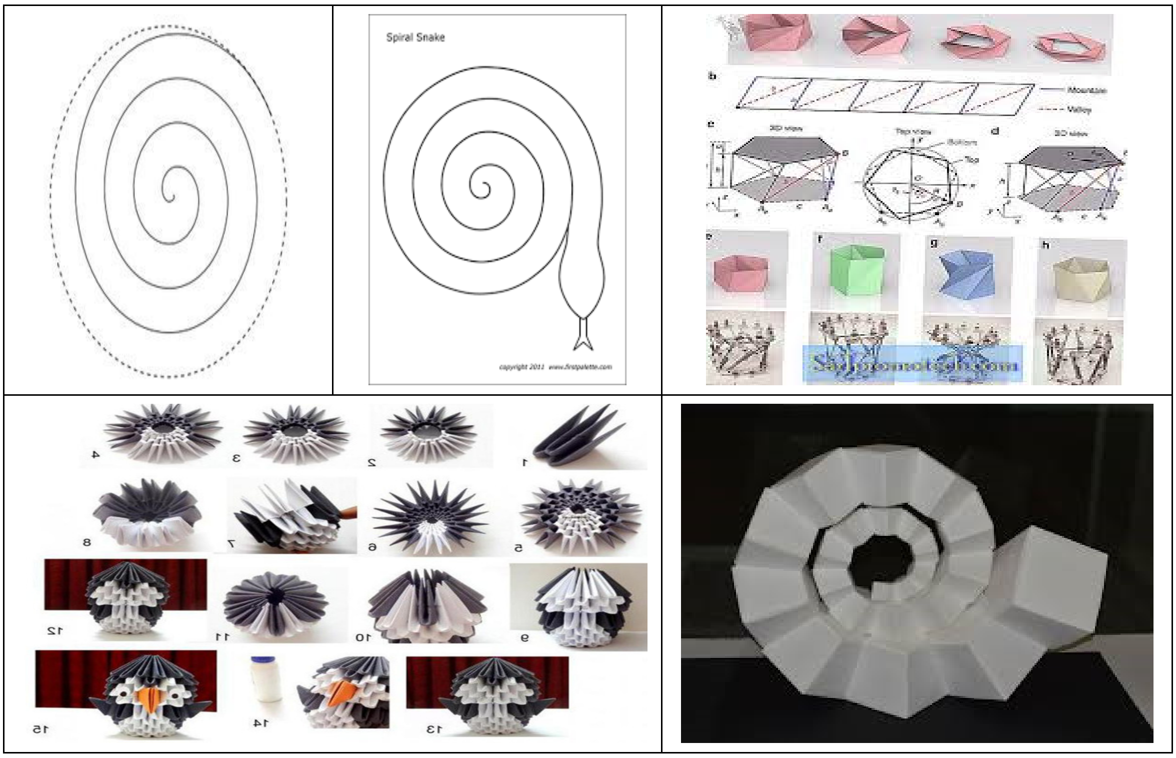


Fig. 3 *Bio kinetic pattern snail https://www.google.iq/url?sa=i&url*

3.1.3 Pattern from Polarity to Space

This pattern of vitality and growth is inspired by the fact that the organic world is mobile and subject to change in its form, and that the transformation of forms is necessary for its continuity in the space of time (Pavón et al., 2022). Because time is the fourth dimension, and the continuity that appears in the forms is the materiality of the forces. This transformation is explained by (expansion and contraction, concavity and convexity, spiral growth, central radiation) as fig.4.

Fig. 4 *central radiation https://www.nippon.com/ar/currents/*

3.1.4 Producing shapes in design

The organic composition represents the spatial space that is determined by a group of levels to represent the first structural unit of the formation by the point, which represents the basic vocabulary for the formation of the line, the plane and the void, that is, the point is the first episodes from which the processes of transformation and generation of shapes begin, so that the line consists of the movement of the point in multiple directions, and the movement of the line, In multiple directions generate surface. And the organic architectural composition consists of the movement of the surface in multiple directions.

That is, the process of growing the organic forms of Origami is represented by the patterns (linear, central, and free).

4 Global interest and the multiplicity of areas of Origami

Since the 1990s has been the emergence of "computer Origami", which has been supported by the emergence of software applications to aid design and simulation. In 2012, the US National Science Foundation presented a research project on Origami technology. Innovative studies are progressing, as shown in making self-flexing robots with smart plastic chips [1].

While self-opening structures encountered in nature such as oysters, insect wings, and sunflower seeds, they offer subjects of study in the fields of space science and mechanical engineering [2]. There are many future studies that lead to applications in areas ranging from the mechanisms of opening the solar battery panels for satellites to everyday tools such as umbrellas and foldable hand fans. Also, using Origami art to design beautiful pieces of furniture that can come from anywhere, and some things provide inspiration for more than just one piece. For example, there are many pieces of furniture inspired by the art of Origami as fig.5 (Sapienza & Rodonò, 2016).

Fig. 5 *Origami used modular in interior design (Origami Chair Stool Combo – Vurni)*

Origami chair and designed by Jan Brouwer & Chris Karthaus. The chair is made of 3mm recycled aluminum sheet. They're laser cut, folded and bolted together. The structures feature sculptural designs and use the triangle as the core concept.

5 Origami in the sustainability of architecture

The concept of sustainability is through creating environments in which emissions and outputs from buildings are reduced in terms of materials used, construction method and operation, to maintain their users by providing healthy environments and improving the quality of life. It is also concerned with recognizing the spiritual importance of the building's design, construction, location and harmony with

[1] Published by a research group whose members include Professor Eric Damien, professor of computer science and engineering at MIT, Science magazine, August 18, 2014

[2] The Proceedings of the National Academy of Sciences published an article by Professor Saito Kazuya of the University of Tokyo with others entitled "Asymmetric folding of wings in the swaying beetle 2014."

the surrounding environment, by creating forms inspired by nature with a strategy of nature conservation and building a sustainable society. (Lester Brown1980)

The sustainability of architecture has emerged using the Origami technique to distinguish its structures (Light weight, static and dynamic stability, longevity, ease of construction, low costs, and environmentally friendly materials) to represent the essential features in achieving sustainable architecture.

Origami technique and its pattern inspired from nature represent a tool for the development of engineering designs in terms of finding the shape or model for architectural applications and has inspired many types of architecture, including:

- **Responsive architecture** / is represented by responsive structures that rely on Origami units rather than surfaces, consisting of small units arranged around a central point.
- **Recycled Architecture** / The foldable building is one of the most suitable buildings for reuse and re-occupation and the least damage to the environment.
- **Transforming architecture** / is represented by temporary buildings that can be installed and dismantled.
- **Biological architecture** / Nature represents the main source of Origami models and shapes, as it provides the ability to expand and fold in the formation of structural relationships between the different components. (megahed, 2017, p69)

From the above, the Origami technique provides the construction of different engineering designs, and the Origami structures have a strong and deep connection to the building, with additional rigidity and appropriate to meet the building requirements of lighting and ventilation and equipped with self-supporting properties, and provide an interface to gain knowledge experience of structural transformations and achieve the sustainability of the building and architecture in terms of the impact of several types from architecture with Origami technology, including architecture (biological – mobile – fixed – responsive – and recycled).

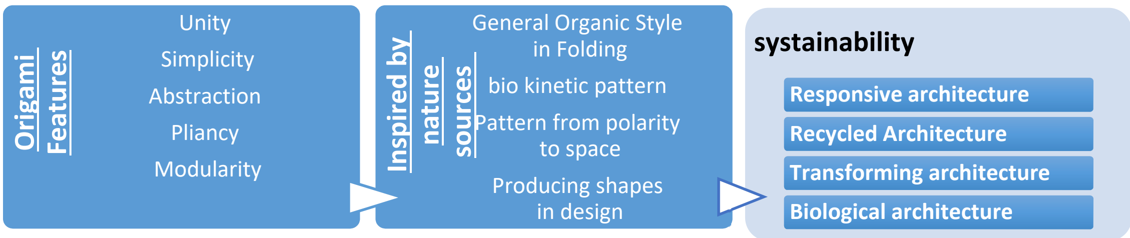


Fig. 6 *Origami (features-inspired- sustainability) by authors*

6 Applications for projects inspired by the concept of folding the art of Origami from nature:

First / Mount Fuji Heritage Center (Shigeru Ban)

Mount Fuji is the highest peak in Japan. The mountain can be seen in clear weather from the Japanese capital, Tokyo, and is located 100 kilometers southwest of the capital, Tokyo, and its height reaches 3776 meters, and its southern slopes reach the sea in Suruga Bay. With its recessed, often snow-capped volcanic conical shape above tree-walled towns, seas and lakes, the mountain's gigantic size and intermittent volcanic activity dictate the beautiful conical shape of Mount Fuji that inspired artists at the beginning of the nineteenth century, whose paintings transcend cultures so the project represent Biological architecture (www.designboom.com).

The inverted pyramid that makes up the Mt. Fuji Heritage Center is covered with an inverted pyramid-shaped intricate lattice of wood from Mt. Fuji's last volcanic eruption, the Edo-era Great Air Eruption (1707), said to have lasted for two weeks. Inspired by the explosive branching pattern of the nature-inspired Origami art of the mountain so the project represent Biological architecture as showed in fig.7.

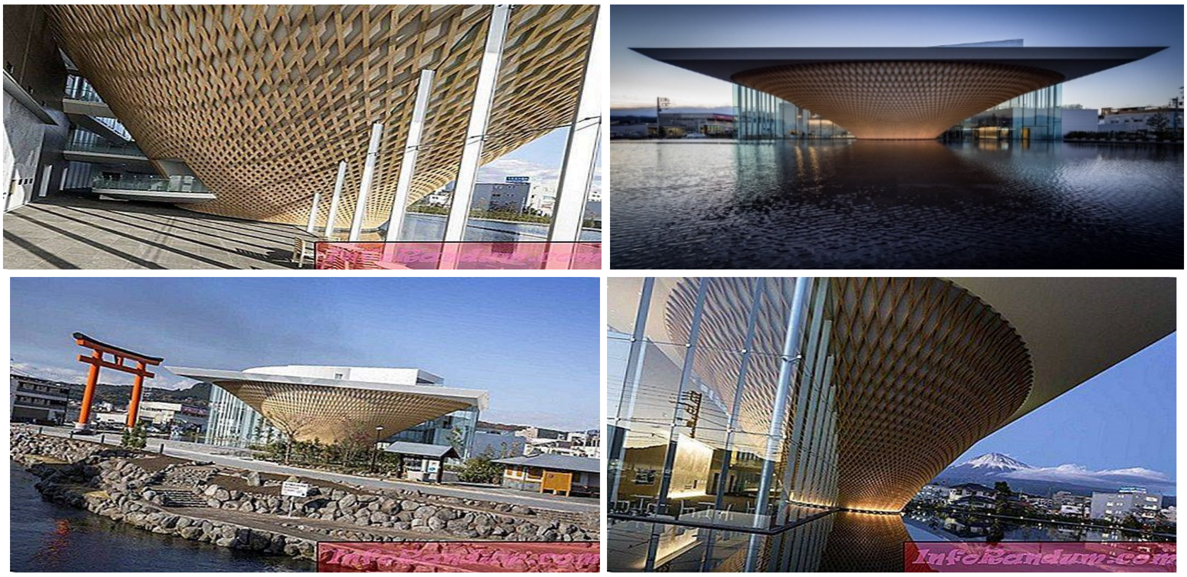


Fig. 7 *Mount Fuji Héritage Center http://www.designcurial.com/news/lighttech-more-yet-subtly*

Second / Serpentine Pavilion 2016

Danish architect Bjarke Ingels (designed by Bjarke Ingels) has a key role in the architecture of this London building, the brick wall. His team at Bjarke Ingels Group (-BIG) sought to "decompress" the wall to create a "serpentine wall" with occupying space (eferrit.com).

The 2016 Suite is one of the largest buildings designed for London summer with 1,798 square feet (167 square metres) of internal usable area, 2,939 square feet of total interior space (273 square metres), within an area of 5,823 square feet (541 square metres). . The design consists of a 'ribbed wall' in which a straight line of tubular glass bricks at the top of the wall is divided into two undulating sides that are fiberglass squares. The cave is lit by fiberglass frames and the gaps between shifted boxes, as well as by a translucent fiberglass covering. This simple manipulation of the garden wall to define the original space creates a presence in the park that changes as you move around it as you move through it so the absence of orthogonal presence becomes curved, the structure becomes A gesture, so we find the design inspired by the culminating movement of the art of Origami and its connection to the organic theory and inspiration from nature so the project represent Responsive architecture fig.8.

Fig. 8 *Serpentine Pavillon https://archello.com/project/serpentine-pavilion-2016*

Third / Heydar Aliyev Center

Designed by Zaha Hadid is the last thing she's done, summarizing the experience of 30 years of research that has resulted in a building that interacts with the city and gives people a place to connect. To create public spaces that people can use freely, and allow the city to flow in a smooth and easy way, because investing in public spaces, whether spaces or buildings, is a vital component of a rich urban life. In the city of Baku, the outdoor space flows around itself to define a series of public spaces within, bringing the urban fabric of the capital into every part or corner of the center. You can consider the building as a landscape, or rather, an engineering landscape that touches the ground and extends from it without anything standing in its face inside, where there are interconnected places without anything interfering with it. so the project represents Recycled Architecture fig.9 (www.architectmagazine.com).

Fig. 9 *Heydar Aliyev Center http://arch.photography/portfolio-item/heydar-aliyev-center*

7 Conclusion

- The art of Origami has developed throughout history from just the art of paper folding and the formation of simple models, to the modern concept of folding that appeared in the projects of folding architecture and had an impact on many fields of art, engineering and theories.
- The paper models reference is important for Origami designers because of the changes that must be achieved equally, represented by random, fixed and divided shapes.
- Origami was directly related to engineering and its most important modern theories, and it appeared clearly in the group of projects covered by the study.
- Origami returns to nature by drawing inspiration from its forms in both its vital aspects stemming from the organic theory and the structural engineering aspect.
- Inspiration from social structure and historical symbols as important variables and references from within architecture.
- The Origami building achieves (flexibility, durability and beauty), which represent important indicators of sustainability according to the indicators of 2030.
- The sustainability of architecture is achieved through the use of the Origami technique that represents nature and the reference to its principles and the use of folding and abstraction mechanisms from the basic references in sustainable Origami architecture.

- The contemporary trend of architecture in its correct sense is based on change and multiplicity of design sources by going to the arts and the environment (natural - urban), including Origami with the thought of modern folding.

References

[1] Mostafa Mahmoud Shehata Mahmoud, *The Impact of Origami Art on the Teaching and Practice of Industrial Design*, MA, Helwan University, Faculty of Applied Arts, 2014.

[2] Ibrahim, Ashraf Hussein, (*The influence of Origami thought towards modern organic theory*), Journal of Architecture and Arts, Eleventh Issue, 2016.

[3] Bellamy, A., Boustani, J., Brehm, C., & Soto, M. G. (2019). (2019*). Towards resilient adaptive origami-inspired diagrid building envelope.* Paper presented at the Active and Passive Smart Structures and Integrated Systems XIII, , 10967 288-298.

[4] Pavón, R. M., Bazán, Á M., Cepa, J. J., Arcos Álvarez, A. A., Trigueros, J. M. A., Alberti, M. G., & Tellaeche, J. R. (2022). *New use of BIM-origami-based techniques for energy optimisation of buildings.* Applied Sciences, 12(3), 1496.

[5] Sapienza, V., & Rodonò, G. (2016). *Kinetic architecture and foldable surface*. Athens J.Archit, 2, 223-235.

[6] "*Paper architecture by Ingrid Siliakus*". Papierarchitectuur.com. Retrieved 2012-08-15. (Bellamy et al., 2019).

[7] http://www.japandesign.ne.jp/IAA/chatani/about.html (Japanese only).

[8] Jump up to: a b c d Chatani, Masahiro. *Pop-Up Origamic Architecture.* Tokyo: Ondorisha Publishers, 1985.

[9] Jump up to: a b *"Origamic Architecture, pop-up cards and other kirigami"*. Origami-resource-center.com. 2007-06-03. Retrieved 2012-08-15.

[10] Jump up to: a b http://baudandbui.free.fr/plier/chatani/chatani.html.

[11] http://www.japandesign.ne.jp/IAA/chatani/about.html; http://www.neo-di.com/KAI/NY/NLE.html.

[12] https://www.designboom.com/architecture/shigeru-ban-mt-fuji-world-heritage-centre-opens-japan-shizuoka-12-22-2017/.

[13] https://eferrit.com/*the-serpentine-gallery-pavilions-of-london*/.

[14] https://www.architectmagazine.com/design/buildings/heydar-aliyev-cultural-center-designed-by-zaha-hadid-architects o.

Where is the Balance Between Optimized and Adaptable Structures?

William MIHKELSON[a], Danielle DENSLEY TINGLEY[b]

[a] *University of Sheffield, Mappin Street, Sheffield City Centre, Sheffield, S1 3JD, United Kingdom, wmihkelson1@sheffield.ac.uk*
[b] *University of Sheffield, Mappin Street, Sheffield City Centre, Sheffield, S1 3JD, United Kingdom d.densleytingley@sheffield.ac.uk*

Abstract

Circular economy and material efficiency strategies for building design have gained increasing attention in recent years, with aims to decrease resource production and consumption whilst increasing the sustainability of cities and communities. However, the relationship between, and conflicting design approaches of, shorter- and longer-term material efficiency has yet to be comprehensively understood. To address the lack of design-based approaches in this space, the presented methodology evaluates building optimization and adaptability strategies for a composite floor design by conducting cradle-to-gate embodied carbon analysis for residential and office loading criteria. Results show that decisions made regarding floor configurations have a significant impact on the material efficiency and therefore trade-offs between increased structural capacity and floor area provision must be balanced with consequent increases in material mass. This study highlights the importance of exploring conflicting material efficiency approaches to inform sustainable material consumption, offering practical insight for structural design practitioners to work towards material efficiency.

Keywords: *Material efficiency, circular economy, adaptability, optimization, buildings*

1 Introduction

Countries have accumulated a vast stock of materials in the form of civil infrastructure and buildings within cities and neighborhoods. This material stock provides services to society and results in the nexus of carbon emissions and human development, the decoupling of which is central to sustainable development goals. Building related activities are among the greatest contributors to global greenhouse gas emissions. However, as industry continue to address operational energy consumption, the relative proportion of carbon emissions resulting from material manufacture (embodied carbon (EC)) [1] is becoming significant [2]. The manufacture and use of construction materials is now estimated to contribute 11% of global energy use [3]. Steel and cement are key construction materials and their production accounts for 9% and 5-7% of global CO_2 emissions respectively [4, 5]. By 2050, it is expected that global engineering material demand will double from the levels in 2011 [6] and it is generally agreed that realising emissions savings and sustainable development goals cannot be entirely achieved by ignoring embodied carbon [2, 7, 8]. In response, the International Energy Agency (IEA) have outlined material efficiency strategies aiming to tackle material consumption across the value chain in the built environment [3]. At the design stage, the IEA recommend lightweighting, reduced over-design, and designing for first use in order to reduce the volume and mass of initial material use in building design. Contrary to this, the IEA also recommend designing for long life, and reuse at the design stage. The extension to building lifetime may be facilitated through designing for adaptability, the principle of which is to ensure buildings are able to change use over their lifetime requiring, for example, increases to unobstructed floor area and reserve structural capacity. However, principles of sustainability are most effective when implemented at the early design stage highlighting the important role design practitioners play when considering material efficiency. This also highlights possible tensions in opposing design strategies aiming to decrease the whole life carbon of buildings. It may therefore become of significant importance for design professionals to consider the trade-offs of shorter- and longer-term material efficiency strategies to maximise EC savings over the lifetime of buildings.

1.1 Optimization

The structural design process follows design codes which identify minimum limits to design criteria ensuring that structural elements can perform safely. However, there is no upper limit to "overdesign" of structural members and therefore no requirement on designers to optimise material use in designs [9]. Studies addressing material efficiency in buildings recognise lightweighting of structural elements as an opportunity to significantly reduce the environmental impact of designs [3, 7, 10, 11]. Lightweighting of elements focusses on reduced over-design, involving designing for more realistic loading [7, 11], thus reducing the addition of mass that is not required for the use, as well as ensuring high utilisation ratios for elements [4, 7]. The Utilisation Ratio (UR) presents an opportunity to identify excess material, i.e., material that is not required to perform within safe limits. The UR is applied as a safety check for all appropriate failure modes (e.g. bending, shear etc.) and is calculated as in eq. 1. The UR is bound between 0 (none of the mass is utilized to resist loading) and 1 (100% of the mass is utilised to resist loading).

$$UR = \frac{actual\ performance}{design\ capacity} \tag{1}$$

where, $0 \leq UR \leq 1$

Most studies addressing over-design focus on the UR as a measure of the redundancy of material provision for the initial use. The URs of a large sample size of structural elements have been evaluated for steel-framed buildings in the UK highlighting significant excess material for the building's use [4]. The results show an average UR by mass of 0.56 for over 10,000 beams analysed highlighting potential for a saving of 214 million tonnes of CO_2 emissions each year if this were to be increased 0.90 (assuming the UR and material mass are proportional) [4]. Although this assumes that the sample of steel buildings is representative of all those across the globe, it underlines the opportunity of a simple measure to ensure short-term material efficiency in the sector.

Another approach to optimise material use is to ensure appropriate design loading is adopted. Standard loadings are outlined throughout design codes for building uses, however values used by designers are frequently much higher than those outlined [9]. The design load is unequivocally related to the performance of structural members and therefore accurate specification of design loads, whilst providing high UR values for elements, ensures buildings are designed for use. Although using higher loading may limit the material efficiency in the short term, over-designing is recommended to allow for a degree of adaptability within the building. This is agreed through identified limitations of short term material efficiency which suggest that loading in excess of standards may be used to cater for possible change of use [9, 12].

1.2 Adaptability

The effective use of a building over its lifetime is limited by its ability to accommodate change and so the potential obsolescence of buildings is a concern for all building owners [13]. A building designed to accommodate change is better able to reduce environmental impact over its lifetime by reducing the demand for new build projects and preventing the waste of construction material and energy resulting from demolition. Whilst short term emissions savings can be achieved through the lightweighting of structural elements, adaptability has gained increasing attention in material efficiency and circular economy literature. Adaptability is now believed to be one of the most important strategies to conserve materials and reduce the energy consumed within the building sector [14]. Characteristics of adaptability are often related to their frequency of use and relate to the building layers by considering the lifetime of individual layers (e.g. structure, services, façade etc.). Building layering is intrinsic to adaptable design, enabling layers to be replaced, repaired, and upgraded without affecting others. This is crucial as the dynamic processes involved in a building's use [15] lead to a high demand for flexibility to adapt to change [16]. Changes to structural members are expensive and difficult to change once constructed [15] and therefore adaptability is rooted within the building at the design stage [14, 17–19]. Many attempts have been made to further the understanding of adaptable building design through extensive literature analysis and industry facing surveys. Various definitions and characteristics of adaptable building design exist within literature [20, 21]. However, it is generally agreed that building flexibility should be maximised relating to changes to: 1) the use of the space [17, 20–23], the load carried [17, 21, 24], and 3) the flow of people and environmental forces [17]. The change in use of space can be better accommodated by open plan layouts and large internal spaces [20–22]. This involves increasing the span of floor beams and slabs to create open plan layouts enabling configuration of rooms for various uses across the building's lifetime. Generally, the ease of conversion for steel and concrete frames relies on, amongst other factors, the size and height of the building and the internal space layout [23]. Adaptability can be further maximised by considering excess structural capacity which is recommended as a strategy for reducing the whole life EC of designs [24]. This is related to the loading adopted for designs and contrasts with the previously outlined literature aiming to optimize the mass in structural elements for the specific building use.

The optimization of building material within members can therefore be achieved by industry professionals during the design stage using existing methods. The UR provides a method with which to comply with building design codes whilst maximising the utilisation of material within members. The use of realistic loading ensures that sections are not over-specified and material use is optimised for the buildings use. Contrasting this are the strategies of adaptability which generally point towards increases in unobstructed floor space, floor-to-floor heights, and reserve capacity to ensure flexibility in future use. This in turn reduces the demand for future buildings by enabling the conversion of existing building stock whilst reducing whole life carbon. However, these decisions must be made early in the design process by industry professionals and current literature lacks a quantified understanding of the trade-offs between these opposing material efficiency strategies. The study therefore aims to provide insight into the trade-offs of optimization and adaptability, considering the response of a structural engineer when pursuing a reduction in EC. This focuses on 1) lightweighting structural elements by maximising the UR (close to UR = 1), and 2) designing with reserve structural capacity whilst providing various unobstructed floor areas. In each case, structural elements are designed for minimum weight.

2 Method

Floor systems are a key area of study in material efficiency conversations, accounting for 80-85% of the EC of RC buildings [25] and approximately two thirds of the mass in a typical steel frame [26]. A composite steel and concrete floor system is therefore used for the study and is in-keeping with material efficiency recommendations [3]. The applications of composite steel and concrete design are vast but cover both residential and office applications [27], however an initial comparison of composite and non-composite designs is undertaken to validate the strategy proposed. Minimum weight design is adopted for residential, standard office and high-specification office loading to ensure minimal steel consumption. Options for adaptable floor design are achieved by implementing various increases to floor loading corresponding to different uses. Residential and office loadings are considered as these represent significant opportunity for change of use and cover a variety of loading criteria suitable to other uses. Realistic loading is selected following a review of the codes of practise and literature exploring design and measured office loadings. There is variability within literature and industry regarding recommended loading for different building uses [11]. However, design loadings are adopted as outlined in [13, 24, 28, 29] and are shown in Tab. 1.Permanent and variable loads for residential use are taken as 0.5kN/m^2 and 2kN/m^2 respectively. For office loading, a permanent load of 0.75kN/m^2 is adopted with variable loads of 3.0kN/m^2 and 5.0kN/m^2 for standard and high-specification office loading with an additional 1kN/m^2 allowing for removeable partitions in both cases. Construction loading is taken as 1.0kN/m^2 for all building uses.

Tab. 1 *Loading criteria used for the design of office and residential building*

Load type	**Office (kN/m^2)**	**Residential (kN/m^2)**
Construction	1	1
Imposed	3 [12] 5 [28]	2 [24]
Permanent	0.75 [29]	0.5 [29]

Different configurations of primary and secondary beam spans are considered providing varying degrees of unobstructed floor area. The spacing of secondary beams is generally limited to 2.5-3m center-to-center spacing in order to reduce slab thickness and increase fire resistance [24]. This results in one less secondary beam required for the 6m primary beam configurations. Primary beam depths are limited by the depth of the secondary beams to pay attention to the constructability of the floors. Concrete slab depth, reinforcement grade, shear stud numbers and steel decking used remain constant and therefore only beam sections vary. Reinforcing mesh properties as well as shear stud spacing, and number are taken from the Structural Engineers Pocket Book [24]. From here the resulting EC/m^2 of the whole systems is output as well as the total beam weights for each floor configuration. A cradle-togate approach is adopted to evaluate the consequential EC of floor designs. Modules A1-A3 [30, 31] cover raw material extraction and supply, manufacturing, transport, and fabrication. A summary of the material selection and EC is given in Tab. 2. The Oasys compos software is used to complete the preliminary designs and is validated through hand calculations along with the Steel Construction Institutes Composite Beam Tool.

Tab. 2 *Embodied carbon data used for the selected material* [32]

Material	**Embodied carbon (kgCO_2e/kg)**
Steel section (S355)	UK typical 59% recycled – 1.53
Reinforcement	UK typical 59% recycled – 1.4
Concrete, C25/30	0.113
Comflor60 steel deck	2.52
Shear studs	UK typical 59% recycled – 1.53

3 Results

Initially, the results indicate significant savings for increasing floor area when adopting composite floor systems over non-composite. A maximum of almost 40% of the total EC/m^2 can be saved when adopting a composite floor system under standard office loading. Further, the utilisation of steel within the primary and secondary beams generally diverges as the unobstructed floor area increases. The results therefore validate the recommendations made by the IEA [3]. Fig.1 highlights the variability in total beam mass required for all floor configurations across each of the loading criteria. Generally, there is greater variability in the total beam mass when considering floor configurations as opposed to reserve capacity. Thus, decisions made regarding the unobstructed floor area may have greater impacts on the final material efficiency compared to designing for use by considering the appropriate loading criteria.

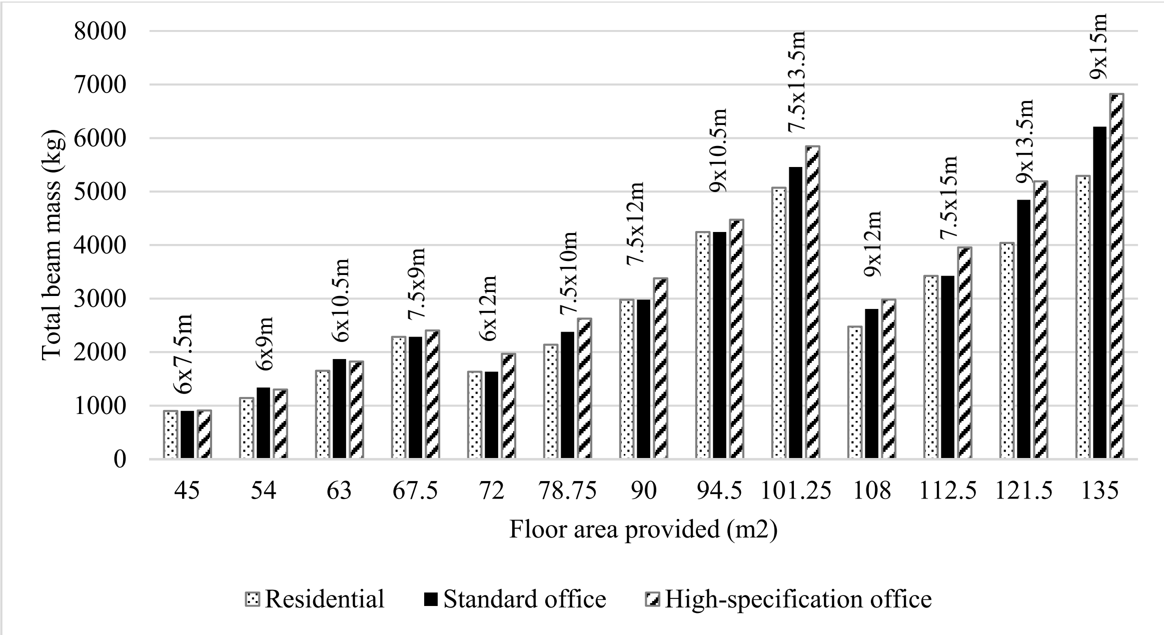


Fig. 1 *Total beam mass for all considered floor systems with indicative primary x secondary beam spans*

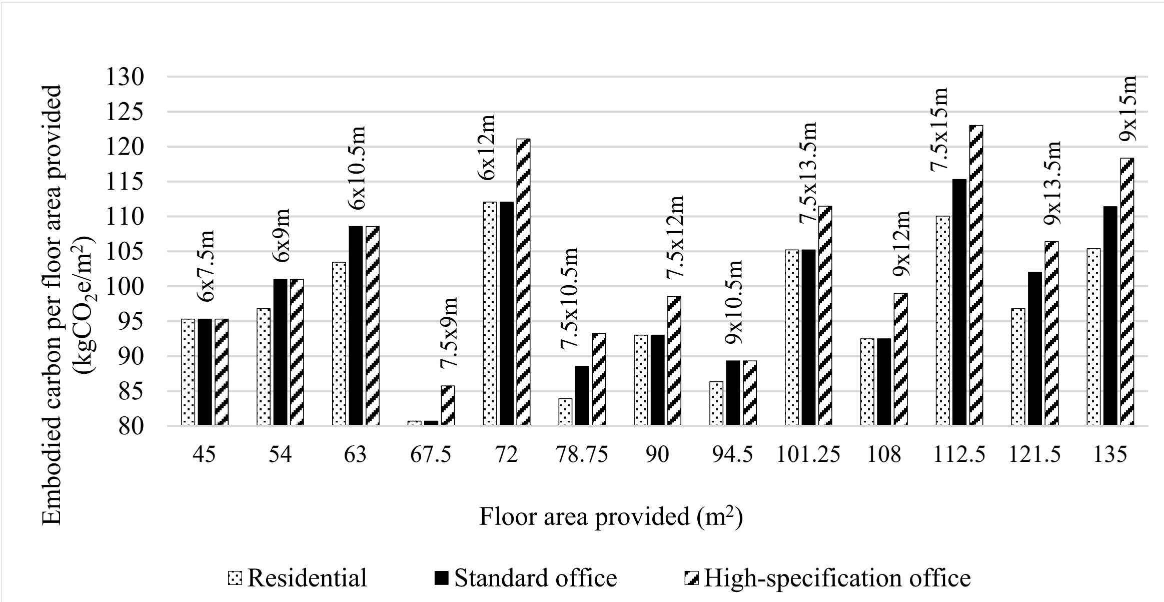


Fig. 2 *Embodied carbon per floor area provided for all considered floor systems with indicative primary x secondary beam spans.*
Note: 67.5m² and 135m² floor configurations discussed in results

Fig. 2 shows the variability in the efficiency of material use between floor configurations and loading by normalizing the EC by floor area provided (EC/m^2). For example, the 7.5x9m configuration requires less EC/m^2 than the 6x10.5m configuration for residential loading, as well as innate reserve capacity to accommodate both residential and standard office loading. Further, the 7.5x9m floor configuration is found to be the most materially efficient solution in the short-term demonstrating the lowest EC/m^2 for all load cases and configurations. If the floor configuration maximising unobstructed floor area and reserve capacity is considered as the most adaptable solution (i.e., the 9x15m configuration designed for high-specification office loading) alongside the 7.5x9m configuration for each load case, insight into the limits of short- and long-term material efficiency can be explored. Fig. 3 shows the total EC/m^2 required for changing building use after construction of the initial use case (e.g., residential to office use after either 1) designing for use, or 2) providing maximum adaptability at first use). Fig. 3 shows that employing maximum adaptability results in a maximum increase in EC/m^2 of 51% (and a maximum increase in EC of 202%) when compared to optimizing for first use. This is a result of the inherent reserve capacity of the 7.5x9m configuration to change from residential to office use, resulting from the availability of section sizes. However, the results highlight that, once demand changes, or the initial use case changes, providing maximum adaptability saves a maximum EC/m^2 of 28%. This is due to the demand for new office space resulting in two optimized new build structures (one for residential and one for high-specification office).

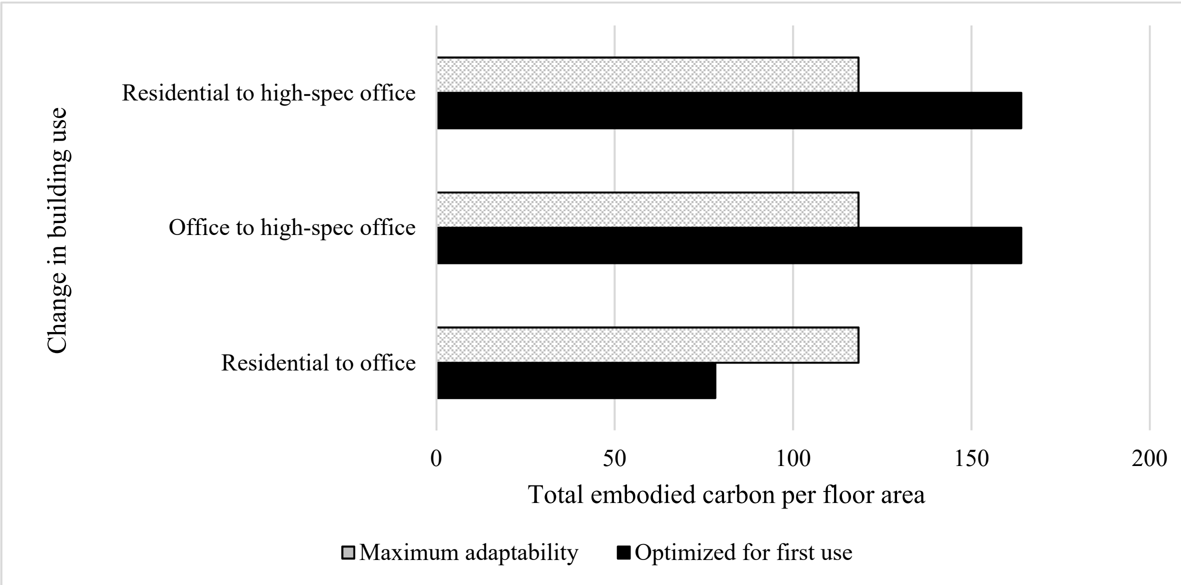


Fig. 3 *Total EC/m^2 required for changing building uses. Maximum adaptability is provided through maximum reserve capacity and unobstructed floor area using the 9x15m floor configuration. Optimization is provided through designing for first use using the 7.5x9m floor configuration.*

The results highlight how, in the early design stage, considering EC separate from the provision of floor space overlooks aspects of material efficiency. This is due to the floor design with the greatest degree of adaptability providing 50% more unobstructed floor area, requiring a greater amount of material mass and thus resulting in a greater total EC. The results suggest that the limit to short- and long-term material efficiency are dependent on accurate prediction of changing building demand which must be balanced alongside the consumer benefits of flexibility in use. The results also suggest that decisions regarding floor provision have a greater impact on lifetime EC than providing reserve capacity for change of use. It is important to note that results assume that change of use is observed during the reference service life of 60 years for domestic and nondomestic buildings [31]. It is also important to note that EC calculations exclude construction and end-of-life stages which may significantly increase savings resulting from adaptable floor design.

The material efficiency of floor systems seems to be a result of the structural form which is shown to have a significant effect when comparing shorter- and longer-term outlooks. Also, some beam sections provide innate reserve capacity and therefore section availability, although to a lesser degree, influences material efficiency in the long-term. The underlying theme of designing for material efficiency therefore considers how floor space is provided. Although reducing overall material mass is preferable, at the early design stage a balance can be found when considering the floor area provided and the material mass required. From here, short- and long-term outlooks can be evaluated. Results therefore demonstrate that systematic consideration of floor area provision and the resulting EC is required at the early design stage for composite floor systems.

3.1 Scalability and further research

The floor systems are designed following the Eurocodes and it is therefore reasonable to assume that the results will broadly mirror those from EU countries adopting Eurocodes for building design. The methodology allows for multiplication of the bay configurations and does not lead to double counting of beams. This means that floor areas can be built up for buildings using the composite designs to begin to evaluate building level optimization and adaptability. Un-propped construction is considered and is not typical within developing countries which therefore limits the scalability of the study. It is important to note that increasing loading criteria will ultimately impact on column sizing. Further research should attempt to evaluate consequent increases in column material mass resulting from adaptable design strategies as well as the cost of such increases to offer systematic insight into industry application.

4 Conclusion

The study approaches material efficiency strategies from the perspective of a structural design practitioner by combining recommendations from the IEA and those found within literature. Results indicate the significance of floor configurations in the assessment of material efficiency for composite floors, offering a shift in perspective of short-term material efficiency from element- wise light-weighting, to a reduction in embodied carbon per floor area provided. From here, increasing structural capacity for future change of use can be balanced with short-term increases in material mass as well as increases to unobstructed floor area for flexibility of use. The study therefore offers insight into decision making at the early design stage. Further research should consider combining optimization of structural elements with EC/m^2 minimization to maximize utilization ratios and minimize steel mass consumption further in composite beams, increasing the material efficiency of both optimized and adaptable floor solutions. Further research should also seek a holistic design approach that includes column and foundation designs coupled with initial cost scheduling to systematically understand the scalability and applicability of material efficiency strategies within industry.

References

[1] MENEGHELLI, Andrea. Whole-building embodied carbon of a North American LEED-certified library: Sensitivity analysis of the environmental impact of buildings materials. *Building and Environment* [online]. 2018. Vol. 134, no. October 2017, p. 230–241. DOI 10.1016/j.buildenv.2018.02.044. Available from: https://doi.org/10.1016/j.buildenv.2018.02.044

[2] IBN-MOHAMMED, T., GREENOUGH, R., TAYLOR, S., OZAWA-MEIDA, L. and ACQUAYE, A. Operational vs. embodied emissions in buildings - A review of current trends. *Energy and Buildings* [online]. 2013. Vol. 66, p. 232–245. DOI 10.1016/j.enbuild.2013.07.026. Available from: http://dx.doi.org/10.1016/j.enbuild.2013.07.026

[3] IEA. Material efficiency in clean energy transitions. *Material efficiency in clean energy transitions*. 2019. DOI 10.1787/aeaaccd8-en.

[4] MOYNIHAN, Muiris C. and ALLWOOD, Julian M. Utilization of structural steel in buildings. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*. 2014. Vol. 470, no. 2168. DOI 10.1098/rspa.2014.0170.

[5] SHANKS, W, DUNANT, C F, DREWNIOK, Michał P, LUPTON, R C, SERRENHO, A and ALLWOOD, Julian M. How much cement can we do without? Lessons from cement material flows in the UK. [online]. 2018. [Accessed 8 October 2021]. DOI 10.1016/j.resconrec.2018.11.002. Available from: https://doi.org/10.1016/j.resconrec.2018.11.002

[6] ALLWOOD, Julian M, ASHBY, Michael F, GUTOWSKI, Timothy G and WORRELL, Ernst. Material efficiency: A white paper. . 2011. Vol. 55, p. 362–381. DOI 10.1016/j.resconrec.2010.11.002.

[7] ORR, John, BRAS, Ana and IBELL, Tim. Effectiveness of design codes for life cycle energy optimisation. *Energy and Buildings* [online]. 2017. Vol. 140, p. 61–67. [Accessed 8 October 2021]. DOI 10.1016/j.enbuild.2017.01.085. Available from: http://dx.doi.org/10.1016/j.enbuild.2017.01.085

[8] YEO, Donghun and GABBAI, Rene D. Sustainable design of reinforced concrete structures through embodied energy optimization. *Energy and Buildings*. 2011. Vol. 43, p. 2028–2033. DOI 10.1016/j.enbuild.2011.04.014.

[9] CARRUTH, Mark A., ALLWOOD, Julian M. and MOYNIHAN, Muiris C. The technical potential for reducing metal requirements through lightweight product design. *Resources, Conservation and Recycling*. 1 December 2011. Vol. 57, p. 48–60. DOI 10.1016/J.RESCONREC.2011.09.018.

[10] ORR, John, DREWNIOK, Michał P, WALKER, Ian, IBELL, Tim, COPPING, Alexander and EMMITT, Stephen. Minimising energy in construction: Practitioners' views on material efficiency. [online]. 2018. [Accessed 8 October 2021]. DOI 10.1016/j.resconrec.2018.09.015. Available from: https://doi.org/10.1016/j.resconrec.2018.09.015

[11] WORRELL, Ernst, ALLWOOD, Julian and GUTOWSKI, Timothy. The Role of Material Efficiency in Environmental Stewardship. [online]. 2016. [Accessed 11 October 2021]. DOI 10.1146/annurev-environ-110615-085737. Available from: www.annualreviews.org

[12] FITZPATRICK, A, JOHNSON, R, MATHYS, J and TAYLOR, A. An Assessment of the imposed loading needs for current commerical office buildings in Great Britain. . 1992. No. March.

[13] SLAUGHTER, E. Sarah. Design strategies to increase building flexibility. *Building Research and Information*. 2001. Vol. 29, no. 3, p. 208–217. DOI 10.1080/09613210010027693.

[14] WEBSTER, Mark D. Structural Design for Adaptability and Deconstruction: A Strategy for Closing the Materials Loop and Increasing Building Value. *New Horizons and Better Practices* [online]. 2007. P. 1–6. [Accessed 11 October 2021]. DOI 10.1061/40946(248)27. Available from: https://ascelibrary-org.sheffield.idm.oclc.org/doi/10.1061/40946%28248%2927

[15] BRAND, Stewart. *How Buildings Learn: What Happens After They're Built*. New York, NY, Viking., 1994. ISBN 0140139966.

[16] ISRAELSSON, Niklas and HANSSON, Bengt. Factors influencing flexibility in buildings. *Structural Survey*. 2009. Vol. 27, no. 2, p. 138–147. DOI 10.1108/02630800910956461.

[17] GOSLING, Jonathan, NAIM, Mohamed, SASSI, Paola, IOSIF, Laura and LARK, Robert. Flexible buildings for an adaptable and sustainable future. *Association of Researchers in Construction Management, ARCOM 2008 - Proceedings of the 24th Annual Conference*. 2008. Vol. 1, no. January, p. 115–124.

[18] GOSLING, Jonathan, SASSI, Paola, NAIM, Mohamed and LARK, Robert. Adaptable buildings: A systems approach. *Sustainable Cities and Society* [online]. 2013. Vol. 7, p. 44–51. DOI 10.1016/j.scs.2012.11.002. Available from: http://dx.doi.org/10.1016/j.scs.2012.11.002

[19] KAMARA, John and DEJACO, Mario Claudio. Taking stock on building adaptability research and practice. *International Journal of Building Pathology and Adaptation*. 2017. Vol. 35, no. 4, p. 282–283. DOI 10.1108/IJBPA-09-2017-0045.

[20] HEIDRICH, Oliver, KAMARA, John, MALTESE, Sebastiano and DEJACO, Mario Claudio. A critical review of the developments in building adaptability. [online]. 2017. [Accessed 11 October 2021]. DOI 10.1108/IJBPA-03-2017-0018. Available from: www.emeraldinsight.com/2398-4708.htm

[21] PINDER, James A, SCHMIDT, Rob, AUSTIN, Simon A, GIBB, Alistair and SAKER, Jim. What is meant by adaptability in buildings? [online]. 2017. [Accessed 11 October 2021]. DOI 10.1108/F-07-2015-0053. Available from: www.adaptablefutures.com

[22] ROSS, Brandon E., CHEN, Diana A., CONEJOS, Sheila and KHADEMI, Amin. Enabling Adaptable Buildings: Results of a Preliminary Expert Survey. *Procedia Engineering* [online]. 2016. Vol. 145, p. 420–427. DOI 10.1016/j.proeng.2016.04.009. Available from: http://dx.doi.org/10.1016/j.proeng.2016.04.009

[23] GANN, David M. and BARLOW, James. Flexibility in building use: The technical feasibility of converting redundant offices into flats. *Construction Management and Economics*. 1996. Vol. 14, no. 1, p. 55–66. DOI 10.1080/014461996000000007.

[24] COBB, Fiona. *Structural Engineer's Pocket Book (Third Edition)*. 2015. ISBN 9781466552081.
[25] ELEFTHERIADIS, S, DUFFOUR, P and MUMOVIC, D. BIM-embedded life cycle carbon assessment of RC buildings using optimised structural design alternatives. *Energy & Buildings* [online]. 2018. Vol. 173, p. 587–600. [Accessed 11 October 2021]. DOI 10.1016/j.enbuild.2018.05.042. Available from: https://doi.org/10.1016/j.enbuild.2018.05.042
[26] DUNANT, Cyrille F, DREWNIOK, Michał P, ELEFTHERIADIS, Stathis, CULLEN, Jonathan M and ALLWOOD, Julian M. Regularity and optimisation practice in steel structural frames in real design cases. [online]. 2018. [Accessed 11 October 2021]. DOI 10.1016/j.resconrec.2018.01.009. Available from: https://doi.org/10.1016/j.resconrec.2018.01.009
[27] RACKHAM, J W, COUCHMAN, G H and HICKS, S J. *Composite Slabs and Beams using Steel Decking : Best Practice for Design and Construction (Revised Edition)*. The Steel Construction Institute and The Metal Cladding & Roofing Manufacturers Association Apart, 2009. ISBN 9781859421840.
[28] GOODCHILD, C. H., WEBSTER, R. M. and ELLIOTT, K. S. Economic concrete frame elements to Eurocode 2 : A pre-scheme handbook for the rapid sizing and selection of reinforced concrete frame elements in multi-storey buildings designed to Eurocode 2. . 2009. P. 182. A Cement and Concrete Industry Publication.
[29] BROOKER, Owen. *Concrete buildings scheme design manual*. 2006. ISBN 1904818447. "A Cement and Concrete Industry publication"--Cover.
[30] EUROPEAN COMMITTEE FOR STANDARDIZATION. Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method (BS-EN 15978:2011). *International Standard*. 2011. No. November.
[31] RICS. Whole life carbon assessment for the built environment. [online]. 2017. P. 41. Available from: http://www.rics.org/Global/Whole_life_carbon_assessment_for_the_BE_ PG_guidance_2017.pdfRICS professional statement, UK. 1st edition, November 2017
[32] HAMMOND, Geoff and JONES, Craig. *Inventory of Carbon & Energy (ICE) Version 2.0*. 2011. Sustainable Energy Research Team (SERT), Department of Mechanical Engineering, University of Bath, UK.

Basic Studies into BIM based Green Building Assessment

Momoko NAKAOKA[a], Tomonari YASHIRO[b]

[a] *The University of Tokyo, 4-6-1 Komaba, Meguro City, Tokyo, Japan, momokonakaoka@outlook.jp*
[b] *The University of Tokyo, 4-6-1 Komaba, Meguro City, Tokyo, Japan, yashiro@iis.u-tokyo.ac.jp*

Abstract

To enhance and clarify the building performance as a total environment, it is necessary to bridge between the BIM based design process and building assessment using Green Building Rating Tools, such as BREEAM, LEED and CASBEE. This paper aims to propose a conceptual framework of their integration and identify possible challenges by information structure analysis of CASBEE.

The analysis is composed of two parts, CASBEE credit classification by the reference information and case studies of BIM use for exemplary CASBEE credits. As a result, the possibility of the framework applying BIM model to scoring CASBEE credits was shown. Moreover, the possible property set for BIM object and the problem that CASBEE has is clarified.

Keywords: *BIM, Green Building Rating Tools, Built, Environment Assessment, CASBEE*

1 Introduction

The establishment of sustainable built environment requires a Green Building Assessment (GBA), an evaluation of whole building performance that promotes discussions among parties, from design stage. Recently, various types of environmental analyses have been conducted in the digitalized design process centered on BIM (Building Information Modeling), however, no systematic knowledge has been established for the data integration between Design and GBA phase.

In many countries, Green Building Rating Tools (GBRTs) such as LEED(U.S.), BREEAM(UK) and CASBEE(JAPAN) have been served for GBA in each life cycle stage of buildings. Although GBRTs contain uniqueness in a way to choose and layer various GBA indicators in accord with social contexts, the key indicators are generally shared by prominent GBRTs. The demands of measurable, reportable and verifiable assessment in the Environmental assessment are seemingly leading an international momentum to pursue reliable information source of GBA using GBRTs [1].

For those backgrounds, the concept of BIM-based GBA is increasingly gaining attention and research have emerged from 2000. However, few pieces of research are on the systematic GBRT-BIM integration. For instance, there are proposals for system-level BIM-LEED collaboration [2] and cloud-based collaboration [3], but they lack detail observations for GBR indicators. Besides, the rapid development in BIM based tools and recent GBRTs' modifications have significantly changed conditions for BIM-based GBA, and newer research is required.

The theme of this research is to integrate data between GBRTs and BIM models to propose collaborative workflows of design development and GBA. As a preliminary study, this paper aims to clarify the issues related with information linkage of BIM models and GBRTs, using one of GBRTs, "CASBEE for Architecture (New Construction)" [4], as a case.

2 BIM-based Built Environment Evaluation

2.1 GBA Data Flow

The previous studies on BIM-CASBEE collaboration identified the potential CASBEE credits (such as daylighting or energy) and developed Revit API for credits' evaluation, but they only focused some credits and there was no clear reason for it [5,6]. Considering this background, the flow shown (Figure. 1) has been established as a framework for BIM-CASBEE collaboration. In this framework, the evaluation targets of CASBEE are divided into unit space and constituent materials. It is also assumed that the information processing process will differ depending on whether attribute information or shape information in BIM is referred to. Therefore, we attempted to extract issues by conducting case studies in which the framework of Fig. 1 was applied to several evaluation items of CASBEE.

2.2 Research Method

CASBEE determines the environmental performance of an entire building through the evaluation of evaluation items arranged in a multi-layered manner in environmental consideration aspects and the integration of evaluation results. These aspects consists of Environmental Quality (Q) and Load Reduction (LR) of the building: Q1.Indoor Environmental, Q2.Quality of Service, Q3.Outdoor Environment on Site, LR1.Environment Quality, LR2.Energy, Resources and Materials, LR3.Offsite Environment[4]. Each evaluation item is scored (generally from 1 to 5) according to the explanations and scoring criteria, and a wide variety of design information is referenced to evaluate the qualitative and quantitative environment of buildings.

In this research, the information to be referred to (reference information) is divided into

- (I) Physical characteristics: concrete information of the design object such as performance and specifications.
- (II) Conceptual characteristics: abstract information of the designer such as concept and approach. In this research, I assume that the BIM model will be used for the (I) physical characteristics.

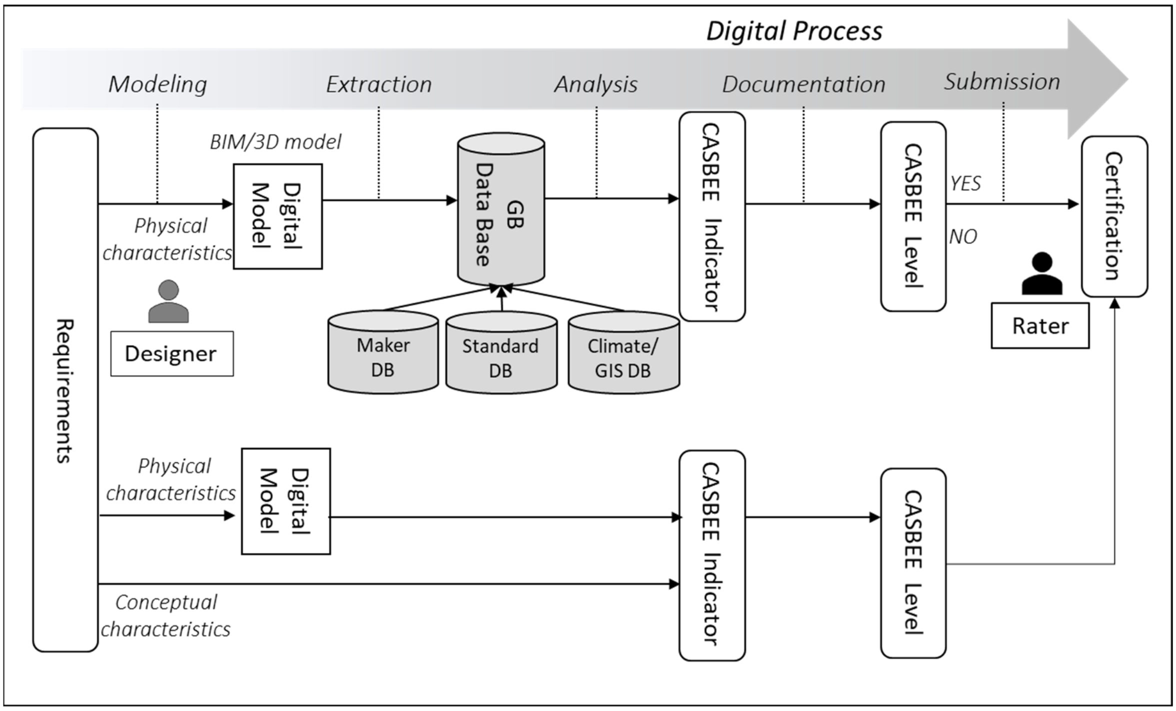


Fig. 1 *Transformation in GBA Data Flow*

3 Classification of CASBEE assessment items

3.1 Creation of matrix classification

The CASBEE Building (New Construction) Assessment Manual [4] was used to classify the reference information for each indicator evaluation of large-scale offices. After classifying whether the reference information belongs to (I) Physical characteristics or (II) Conceptual characteristics, for

(I) Physical characteristics, the evaluation target is either (i) Unit Space or (ii) Component, and the Level of measurement is either Nominal level, Ordinal scale, Interval scale, or Ratio scale [7].

3.2 Summary of classification results

Table 1 shows the results of classifying the evaluation items into nine quadrants according to the evaluation target and measurement level. The following is a list of what can be read from here.

- 58 out of 85 credits were for (I) Physical and 27 credits for (II)Conceptual characteristics.
- (II) Conceptual characteristics includes evaluation of site plans and FM plans such as *Q2-1.3.2 "Securing Maintenance Management Functions"* and *Q3-2 "Townscape & Landscape"*, in addition to design concepts and design methods such as *Q2-1.1.3 "Barrier-free Planning"* and *Q3-3.2 "Improvement of the Thermal Environment on Site"*.
- As for evaluation target of (I) Physical characteristics, 39 credits out of 58 credits were for (i) Unit space, and 19 credits for (ii) Components.
- As for evaluation target of (I) Physical characteristics, 19 credits were on Nominal level, 12 credits were on Ratio scale, eleven credits on Ordinal scale, and six credits on Interval scale.

<table>
<tr><td colspan="3" rowspan="3"></td><td colspan="4">Level of measurement</td></tr>
<tr><td colspan="2">Qualitative measurement</td><td colspan="2">Quantitative measurement</td></tr>
<tr><td>Nominal level</td><td>Ordinal scale</td><td>Interval scale</td><td>Ratio scale</td></tr>
<tr><td rowspan="4">Information Source</td><td rowspan="2">Physical</td><td>Unit Space</td><td>Type1 -11 credits
specific use, function (e.g., Q1-4.3.2)</td><td>Type 2 -6 credits
specific level, rank (e.g., LR3-3.2.3)</td><td>Type 3 -3 credits
temperature, humidity (e.g., Q1-2.1.1)</td><td>Type 4 -9 credits
specific use, technology (e.g., Q2-1.1.1)</td></tr>
<tr><td>Component</td><td>Type 5 -8 credits
specific material, technology (e.g., LR2-1.1)</td><td>Type 6 -5 credits
specific level, rank (e.g., Q1-1.2.1)</td><td>Type 7 -3 credits
finishing interval (e.g., Q2-2.2.2)</td><td>Type 8 -3 credits
material use rate, chemical use rate (e.g., LR2-2.5)</td></tr>
<tr><td colspan="2" rowspan="2">Concep-tual</td><td colspan="4">Type 9 -27 credits</td></tr>
<tr><td colspan="4">Specific Plan or Concept (e.g., Q2-1.1.3 "Barrier-free Planning", Q3-2 "Townscape & Landscape")</td></tr>
</table>

Fig. 2 *Matrix Classification*

4 Case Study

4.1 Identity Data

Representative CASBEE credits can be chose from eight types of the matrix classification (Table 1). Case study of assigning reference information were conducted using sample BIM models. Sample BIM model which are offered for architecture design and MEP design were used [8].

Tab. 1 *Case Studies List*

Credit	**Case1 Q1-4.3.2**	**Case2 LR3-3.2.3**	**Case3 Q1-2.1.1**	**Case4 Q2-1.1.1**
	Control of Smoking	*Restriction of sunlight obstruction*	*Room Temperature Setting*	*Provision of Space & Storage*
Info	Smoking Room (string)	Restriction Level (string)	Room Temperature [°C]	Office Space/person [m²/person]
Credit	**Case5 LR2-1.1**	**Case6 Q1-1.2.1**	**Case7 Q2-2.2.2**	**Case8 LR2-2.5**
	Water Saving	*Sound Insulation of Openings*	*Refurbishment Interval for Exterior Finishes*	*Timber from Sustainable Forestry*
Info	Saving Packing (string)	Insulation Level (string)	Refurbishment Interval [years]	Timber Use Rate [%]

4.2 Study Flow

The study flow is depicted in Fig.3. A case study sheet was created for each case. In the sheet, those contents are written such as reference information extracted from the CASBEE manual, the scope of BIM utilization and the screenshots of the BIM software related to reference information to be added (or already added) to the BIM model. Through this study, the issues of adding information are described. Also, flowcharts of the scoring process were used to identify purpose and scope of BIM use, and BIM screenshots were used to illustrate the usage. Through this study, the position of the reference information to be added in the BIM model and the property set were proposed.

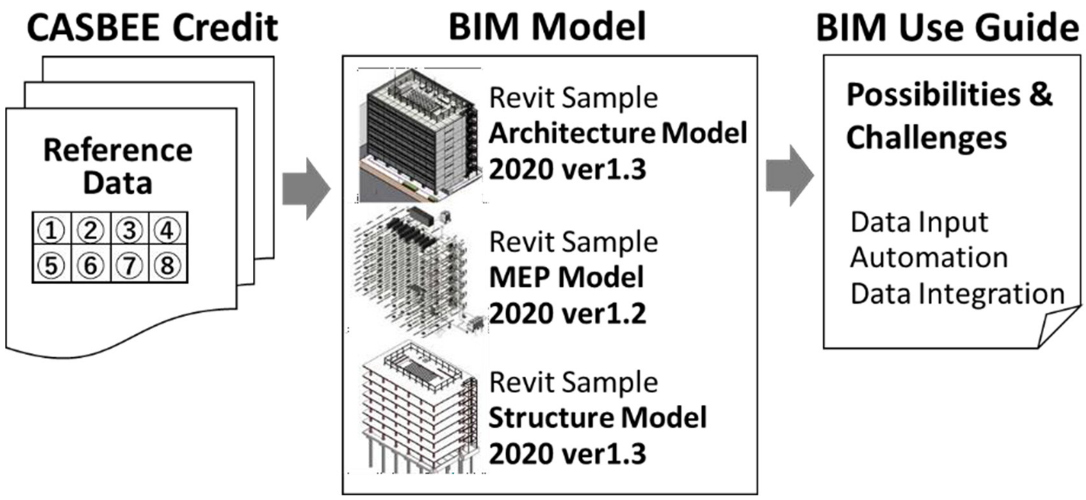


Fig. 3 *Case Study Flow*

4.3 Case Study Results

The case study results are shown in Fig. 4.

4.3.1 Case Study 1: "Smoking Control"

An example of BIM model use is as follows. when the architecture designer names a room "smoking room", CASBEE indicator searches for "smoking room" to determine Level 3 based on the existence of this attribute information. In the sample model (Revit architecture), "smoking room" was not found in any room element' attributes. To add this information, a possible method would be to enter "smoking room" as a value of the name parameter. In extraction phase, if there is an element whose "name" value is "smoking room", CASBEE indicator will output Level 3. From the above, Level 3 judgment can be automated using BIM data but the use of data is limited. In addition, Level 5 judgment will require an advance use of MEP model, which will cause the issue of data integration between several BIM models.

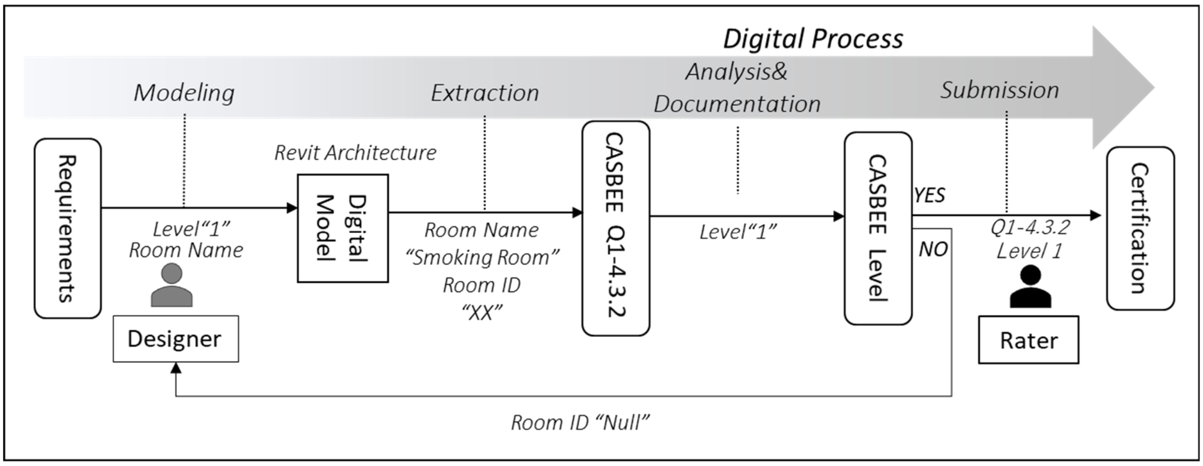


Fig. 4 *Case Study No.1*

4.3.2 Case Study 2: "Suppression of Sunlight Inhibition"

An example of BIM model use is as follows. When an analysis software confirms the building performance on "restriction of sunlight obstruction", CASBEE indicator searches for the "restriction level" from analysis results. Level 3 and Level 4 judgments are based on whether a specific rank is marked. In the sample model (Revit architecture), although "sunshade regulation" is entered in the design brief, it is not processable attribute information but a text annotation. To add this information, a possible method would be to enter "restriction level" or "upper level" in the parameter of sunshade regulation level. In extraction phase, if the value is " restriction level " or "upper level ", the output will be Level 3 and Level 4 respectively. From the above, Level 3 judgment can be automated using BIM data but the use of data is limited. It is necessary to link the environmental standards and climate data. On the other hand, if the reference information is changed from "rank of shading regulation" to "shading time (GL+4m)," the entire process from analysis to input of reference information will be performed within the BIM model.

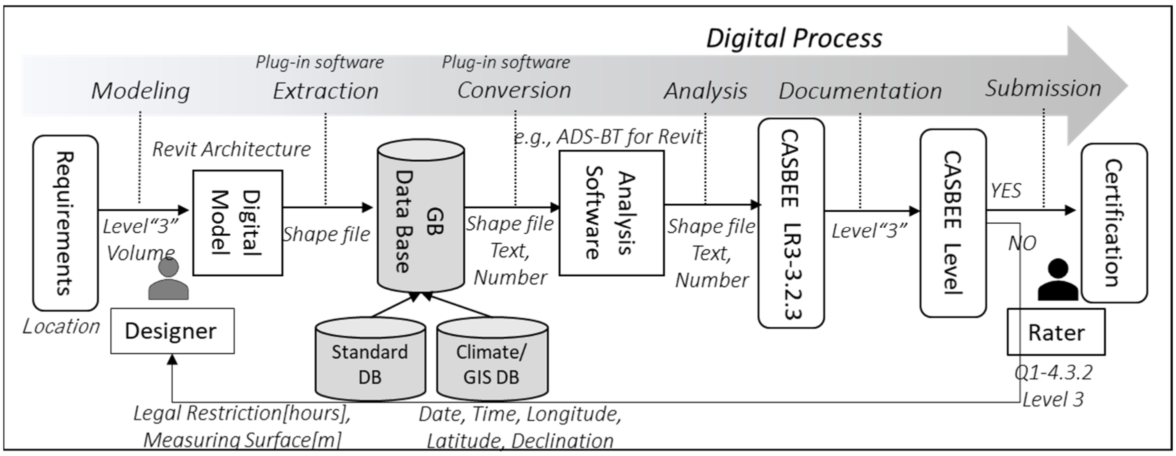


Fig. 5 *Case Study No.2*

4.3.3 Case Study 3: "Room Temperature (Basic Design)"

An example of BIM model use is as follows. When an analysis software confirms the room thermal comfort of the standard room, it can be assumed that the design temperature entered in the room attributes is searched for and compared with the standard temperature to determine Level 1~ Level 5.

As attribute information for the room elements of the BIM model (MEP), the parameters "set heating temperature" and "set cooling temperature" and their values "22(°C)" and "26(°C)" were confirmed. In extraction phase, if the value of "set heating temperature" is more than 24 and the value of "set cooling temperature" is less than 24, it can be judged as level 5, and other levels can be similarly judged. From the above, it is possible to automate the judgment using the data from the BIM model. Furthermore, if it is linked to the database of equipment, it is possible to verify whether the equipment capacity to realize the set room temperature is secured during the implementation design.

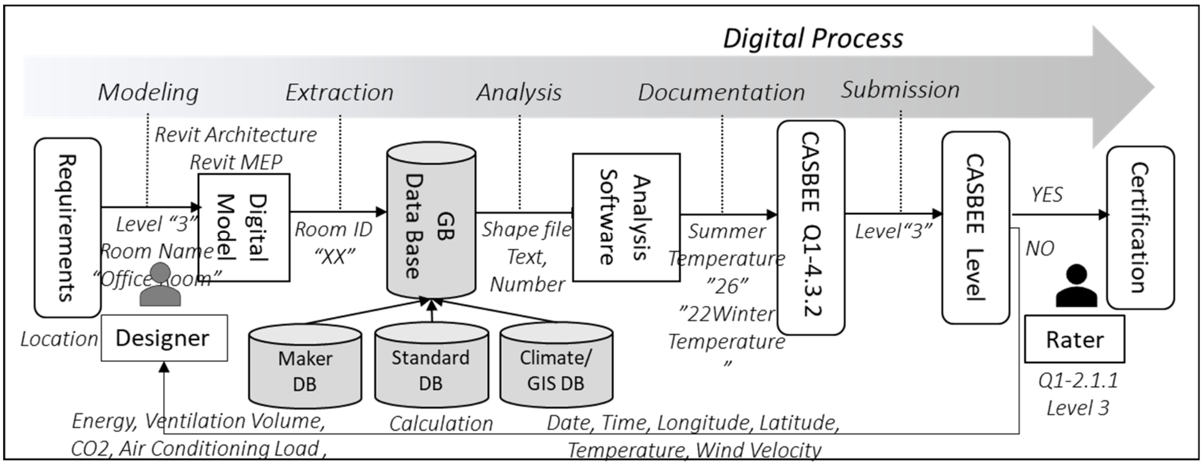


Fig. 6 *Case Study No.3*

4.3.4 Case Study 5: "Water Saving"

An example of BIM model use is as follows. When facility designers use model elements of washbasins and toilets from manufacturers, the flow of searching for "saving package" in the attribute information of the elements to judge Level 1, Level 3, and Level 4 based on the use rate. In the BIM model (MEP), no information corresponding to " saving package" was entered in the attribute information of the washbasins, but information of "6.5 (L)" was confirmed in the "washing water volume" corresponding to "saving package". A possible method of adding information is to enter "YES/NO" for "saving package" value in the manufacturer's model elements, and determine Level 1 when less than half of the elements have both values of " YES ". From the above, it can be expected that the Level 1 judgment will be automated using the BIM model data in Case 5, but it is difficult to envision advanced data use. However, when inputting quantitative data such as unit flow rates, the data can be used to calculate the amount of water and miscellaneous wastewater used in LR2-1.2.1 "Whether a rainwater harvesting system has been installed".

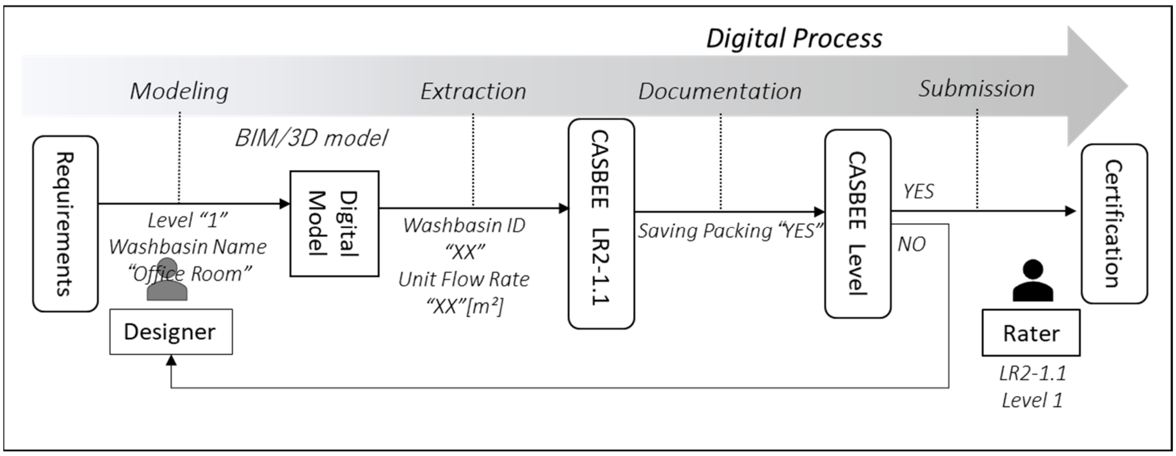


Fig. 7 *Case Study No.5*

4.3.5 Case Study 6: "Sound insulation performance of openings"

An example of BIM model use is as follows. When a model element of a curtain wall mullion or window for a standard room was created, CASBEE indicator searches the "sound insulation grade" entered in the attribute information of the element, and Level 1, Level 3, or Level 5 can be determined based on whether the lowest performance rank is a specific rank. In the BIM model (architecture), the window sash on the south side is an element embedded in the curtain wall, and no information corresponding to the "sound insulation grade" is entered. A possible way to add information is to create a new curtain wall mullion element and enter the parameter "sound insulation class" values "T- 1", "T-2", and "T-3" as attribute. In extraction phase, if the "sound insulation grade" value is "T- 1","T-2", or "T-3", it can be judged as level 1, level 3, or level 5, respectively. From the above, Case 6 is expected to automate judgments using BIM model data, but unification of data positions among different model elements is necessary, and linkage with the manufacturer's database is another issue.

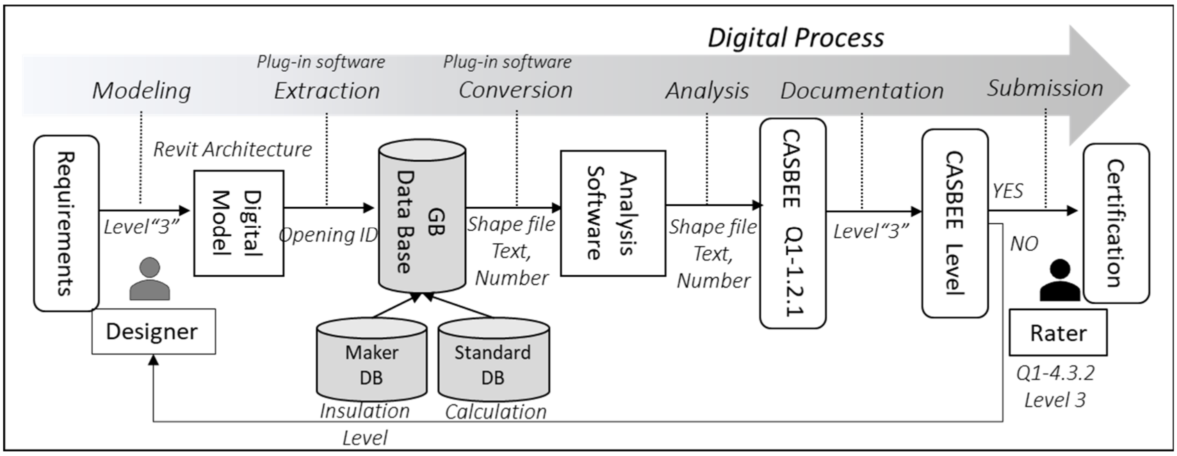


Fig. 8 *Case Study No.6*

4.3.6 Case Study 8: "Wood from Sustainable Forests"

An example of BIM model use is as follows. When the finishing materials for model elements such as walls, floors, and ceilings are specified, CASBEE indicator searches "sustainable forests" entered in material elements' attribute and compares the total "volume" with the specified value to determine levels 2~5. In the BIM model (architecture), no information corresponding to "wood produced from sustainable forests" was entered in the attribute information of the wall element, but the parameter "volume" and its value "508.91 (m²)" necessary for calculating the "use rate" were confirmed. A possible way to add information is to set the material with "Performance" set to "Sustainable Forest" in individual model elements. In extraction phase, Level 5 is judged when the "use rate" of the total volume of each material is 50 (%) or more. Other levels can be judged in the same way. From the above, in addition to the automation of judgment using BIM model data, advanced use of BIM data during the implementation design can be envisioned in Case Study 8. However, a separate linkage to the manufacturer's database is necessary to confirm the origin of each individual piece of wood.

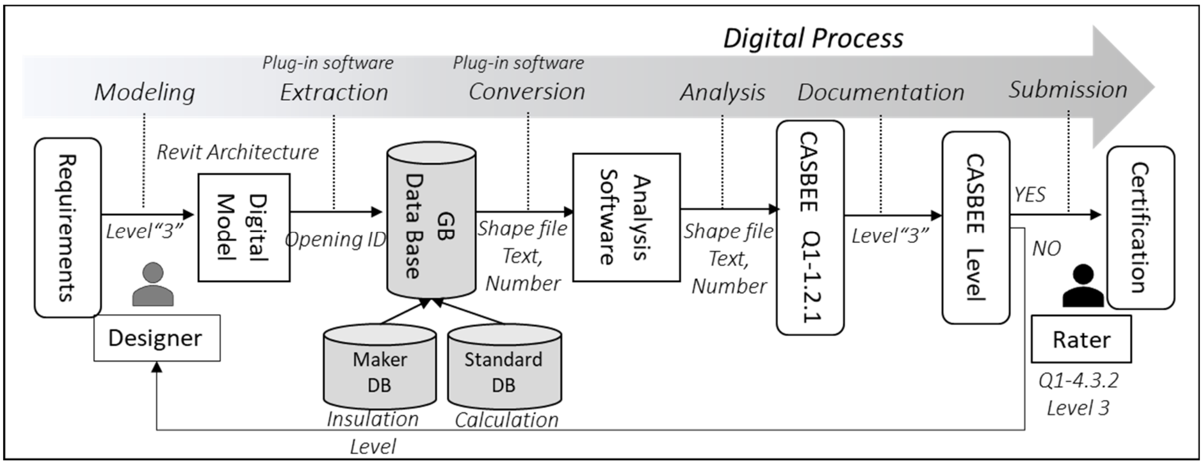


Fig. 9 *Case Study No.8*

4.4 Discussion of the Case Study Results

Through the case study, the following was learned.

- Some cases will improve the use of the BIM model, if the level of measurement is higher and it combines shape information and attribute information for the evaluation.
- If the information that needs to be extracted in CASBEE evaluation is stored as attribute information in the BIM model, it may not be stored even if the LOD is improved. In the first place, attribute information for such categories and concepts may not be set in the BIM data.
- In order to increase the likelihood that necessary attribute information will be entered as the LOD improves, it is thought that a BIM-related database for building components that can be accessed by many practitioners, including designers, should be developed.
- With regard to evaluation items for evaluating unit spaces in CASBEE, BIM data for specific elements such as standard floors and standard rooms can be used.
- For evaluation items that evaluate constituent materials in CASBEE, it is necessary to pick up all the elements of the same material and calculate the percentage, so the use of BIM data is expected to greatly reduce the time and effort required for tabulation.

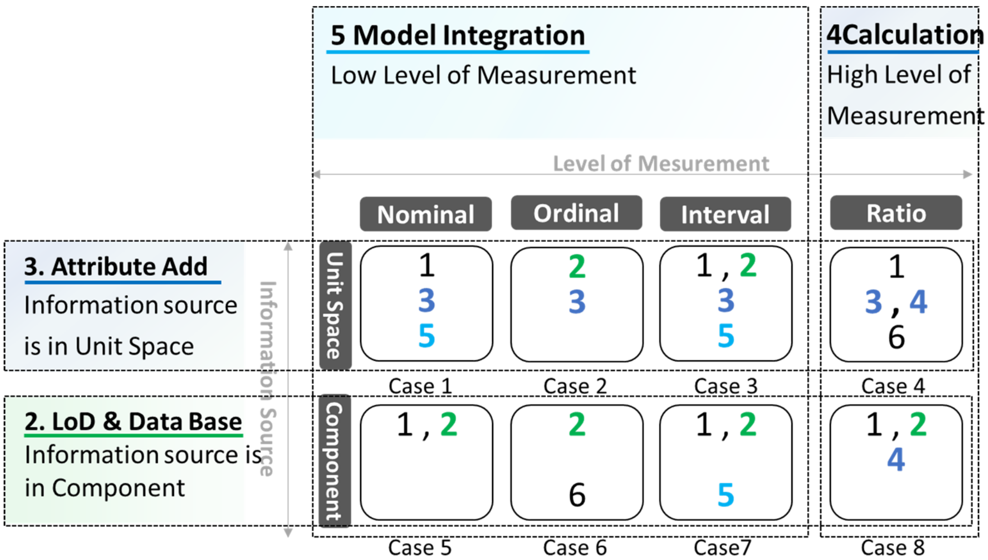


Fig. 10 *Case Study Results*

4.5 Issues on CASBEE indicators

- **Standardization of terminology and development of databases:**
The sample BIM models of the case study lacked attribute information required for several CASBEE credits. To improve this, it is of course necessary to standardize ambiguous terms and input formats. In addition, many of the information source such as "sound insulation class" and "sunshade regulation rank" are input from manufacturers' and local governments' databases rather than from BIM models and development and linking with these external databases is another issue.

- **Improving the accuracy of attribute information:**
If CASBEE indicators of Interval scale or Ratio scale, BIM data can be used more smoothly by increasing the detail of shape information through improving LoD. On the other hand, if the scope of information to be collected and referenced is vague, such as in the case of "wood produced from sustainable forests", it will be difficult to utilize BIM data.

- **Reviewing the evaluation level of reference information:**
In Case Study 5 "Water Conservation" the reference information was changed from "water-saving panels." to "unit flow rate" which can now be used for scoring other items. Similarly, it is necessary to review CASBEE definition about information. In Case Study 2 "Suppression of Sun Shading Obstruction", the information source will be changed from "Rank of Sun Shading Regulation" to "Sun Shading Time" to process within the BIM model from analysis to judgment.

4.6 Issues in BIM models

- **Category of attribute information:**
In Case Study 2 "Suppression of sunshine inhibition" the reference information "sun shading regulation" is entered as a text item and not linked to shape elements. Such information needs to be replaced as attribute information for extraction. Also, in Case Study 6, "Sound Insulation Performance of Openings" and Case Study 4, "Spaciousness and Stowage", the categories of information source are different from BIM family categories, which requires a template for setting categories consistent with CASBEE evaluation.
- **Information sharing between models:**
In Case 1 "Smoking Room" it is necessary to check both the architecture model and the equipment model for Level1-Level 5 judgment. There is room for improvement to make an evaluation without pulling information from different models. In addition, like Case Study 4 "Space and Storage", there are cases where the model to add information and the model to confirm it are different. It is necessary to consider which model to integrate the information from the design improvement scenario.

5 Conclusions

In this study, the CASBEE Building (New Construction) 2016 edition was taken as an example, and the guidelines for utilizing BIM models according to the information structure of CASBEE were examined. In Chapter 3, through the classification based on the target of evaluation of CASBEE evaluation items and the measurement level, the scope of utilization of BIM models was identified for each evaluation item. In Chapter 4, through a case study on the assignment of information, issues and possibilities were mentioned for BIM utilization. As future research, the typology of BIM model utilization guidelines for each evaluation item based on this classification and its data policy will be verified using a BIM model suitable for evaluation for all evaluation items. In addition, for items that use multiple evaluation targets and scale levels, it is necessary to make a proposal to unify the evaluation targets and scale levels, and to position them in the BIM use guidelines.

References

[1] ISO21931-1–*Sustainability in building construction – Framework for methods of assessment of the environmental performance of construction works Part 1: Buildings*, 15.6.2010 [cit. 2021-10-13] WWW: <https://www.iso.org/obp/ui/#iso:std:iso:21931:-1:ed-1:v1:en>.

[2] Biswas, T., Wang,T., Krishnamurti, R. *Integrating sustainable building rating systems with building information models*, Proceedings of the 13th International Conference on Computer Aided Architectural Design Research in Asia, Chang Mai 2008, pp. 193-200.

[3] Wu,W., R.R.A, Issa. *BIM Facilitated Web Service for LEED Automation*, Proceedings of Conference: ASCE International Workshop on Computing in Civil Engineering, Florida 2011, pp. 673-681.

[4] IBEC: CASBEE for Architecture (New Construction), 2020. [cit. 2021-10-13] WWW: <https://www.ibec.or.jp/CASBEE/english/overviewE.htm>.

[5] JIA, *Collaboration between BIM and CASBEE*, Architectural Institute of Japan Conference Panel Discussion Document, JIA Global Environment Committee, 2009.

[6] JIA, *Linkage between BIM and CASBEE Part 2: What we saw from the development of the connector,* Architectural Institute of Japan Conference Panel Discussion Document, JIA Global Environment Committee, 2010.

[7] Stevens, S., *On the Theory of Scales of Measurement*, Science, 103, 1946, pp. 677-680.

[8] Revit User Group, *Sample Model for Japan*, 2020 [cit. 2021-10-13] WWW: <https://bim-design.com/rug/library/>.

Evaluation of Applying BIM Tools and EnerPHit Standards to the UK Housing Stock for Energy Efficiency

Sinan Celal DADAĞILIOĞLU[a], Haniyeh MOHAMMADPOURKARBASI[a], Steve SHARPLES[a]

[a] *University of Liverpool, School of Architecture, Liverpool, United Kingdom, S.Dadagilioglu@liverpool.ac.uk, Haniyeh.MPK@liverpool.ac.uk, Steve.Sharples@liverpool.ac.uk*

Abstract

Existing buildings make a significant contribution to high energy consumption, resource depletion, and carbon emissions in the built environment. In this regard, the UK's 2050 net-zero target aims to refurbish the UK building stock as a sustainable solution for these global issues. Despite an increasing interest of the construction industry, there has been a low uptake of housing refurbishment because of uncertainty about refurbishment strategies, cost overruns, and unexpected refurbishment outcomes. This study aims to set a new conceptual framework for utilising Building Information Modelling (BIM) tools and the EnerPHit standards for energy-efficient housing refurbishment projects in the UK. BIM implementation will be discussed for a theoretical case study within the consideration of EnerPHit standards. The proposed model provided 21-day refurbishment project activities for improved time management to avoid overlapping construction areas. The final simulation results achieved the EnerPHit heating demand criteria of less than 25 kWh/m2 annually.

Keywords: *refurbishment, energy efficiency, BIM, Passivhaus, UK housing stock*

1 Introduction

Over the last few decades, the existing building stock has had an increasing influence on the UK's energy consumption, representing 22% of total greenhouse gas (GHG) emissions [1]. Although the UK government aims to achieve net-zero GHG emissions by 2050, the existing housing stock has been a significant impediment to meeting the 2050 targets (Fig. 1). In this regard, future housing refurbishment strategies have a key role in improving energy efficiency and mitigating the environmental impacts related to the UK housing stock [2]. Various researchers have examined the conventional refurbishment processes, many of which have resulted in ambiguous refurbishment strategies, extra efforts, and dissatisfaction of the refurbishment outcomes to improve thermal performance by making various changes to the building envelope and the other components [3, 4, 5, 6]. Therefore, there has been a low uptake of housing refurbishment amongst homeowners and housing professionals to achieve energy efficiency in the built environment. With collaboration issues because of the lack of a common platform for effective teamwork, conventional methods are not sufficient for the refurbishment project stakeholders from different disciplines, who tend to use distinct design and energy analysis tools individually to implement appropriate refurbishment measures for energy-efficient refurbishment outcomes [7]. To deal with these issues, a new state-of-the-art refurbishment model should be discussed to bridge the gap between expected and actual energy performance after implementing the refurbishment project.

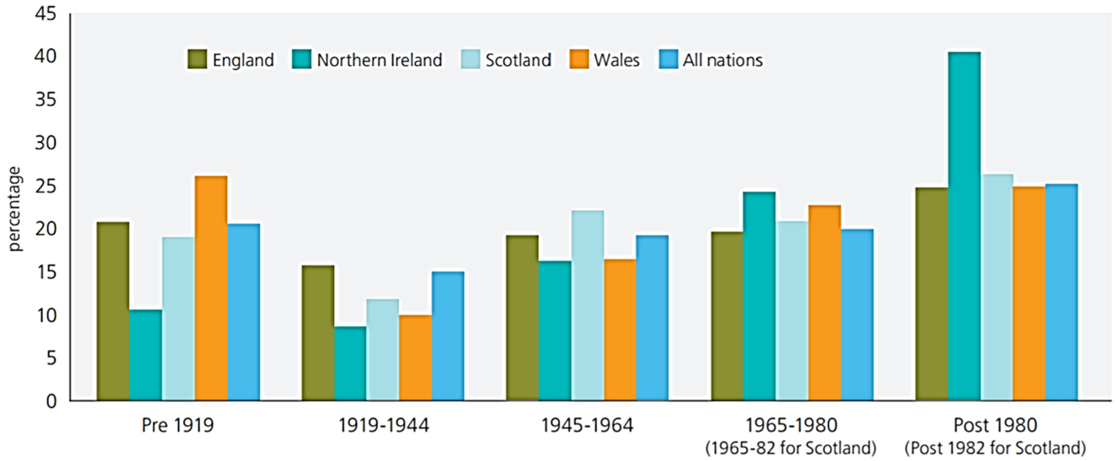


Fig. 1 *Housing age by UK nations (2017) [8]*

Several studies have highlighted a holistic approach to sustainable building refurbishment as a new area of interest [2,9,10,11]. This can be grouped into three key phases:

- Assessment Phase: project setup and data acquisition
- Method & Strategy Phase: data analysis, strategy formulation, and implementation
- Validation & Verification Phase: post-measurement and post-occupancy survey

This study focuses on the Method & Strategy phase of a novel building refurbishment model. As a solution to the conventional building refurbishment issues, the use of BIM has potential for refurbishment projects, given innovative technologies and tools and collaborative platform in order to [12,13,14]:

- avoid remedial works in the refurbishment design stage
- provide visual simulations for better coordination
- make better refurbishment time optimisation
- reduce the required construction material use for building refurbishment

While BIM offers considerable benefits on these subjects, the German Passivhaus standards – named EnerPHit standards for building refurbishment – provide a high level of thermal comfort while using little energy for heating and cooling and focusing on some key principles:

- improved thermal comfort
- thermal bridge free
- improved airtightness
- fresh air with heat recovery
- solar gain

Although BIM provides a new way of sustainable housing refurbishment by addressing the Passivhaus EnerPHit standards, there is limited research in applying BIM tools and the EnerPHit standards for the energy-efficient refurbishment in the UK housing stock [9,11,15,16,17]. This study examines a semantically modelled housing refurbishment project of a hypothetical case study using BIM tools and the Passivhaus EnerPHit standards regarding energy efficiency. For this reason, the aforementioned case-study methodology will explain how to apply the chosen BIM tools and EnerPHit standards. After the methodology, the research findings will be analysed and discussed in order to evaluate the pros and cons of the findings, and finally, the last section will outline the conclusion of this study.

2 Methodology

As its primary objective, this paper evaluates applying BIM tools and Passivhaus standards for the energy-efficient refurbishment of a typical Victorian UK terraced house. The proposed research method addresses solution-oriented research to provide valid knowledge that supports practitioners to solve problems[18]. A clear understanding of the literature review has a key role in the problem definition related to the traditional building refurbishment, which is explained in the literature analysis (section 2.1) in detail. Utilising a BIM framework can propose a solution to the defined problems, which is explained in the BIM framework (section 2.2). As a problem-solving approach to the conventional building refurbishment, 3D BIM (coordination) with its further dimensions – 4D BIM (planning and scheduling) and 5D BIM (cost estimation) – and adaptable tools for the Passivhaus EnerPHit standards have been assessed as an aim of this paper.

2.1 Literature Analysis

To comprehensively review BIM and Passivhaus for existing building refurbishment, both academic and applied publications dated from 2001 to 2021 were examined. From this perspective, 220 articles were identified that contribute to the focal research area (Tab. 1). As one of the essential requirements of a systematic literature review, the categorised publications have begun to be examined from the most relevant to the least relevant. While making the keyword-oriented analysis, other keywords used in the same context were also evaluated in the same category for a comprehensive assessment of the chosen articles. For instance, the publications containing 'retrofit', 'renovation', 'rehabilitation', 'upgrade', and 'maintenance' keywords were identified in the same category, which refers to the context of 'building refurbishment'. The correlation between the chosen keywords shapes a comprehensive and precise idea about the evaluation of the content of the publications reviewed in terms of research trends.

Tab. 1 *Keyword-based ranking analysis between the selected publications*

Total Article Number: 220	**Passivhaus / EnerPHit**	**BIM**	**Energy efficiency / performance**	**Refurbishment**	**Housing refurbishment**	**Decision-making**
Passivhaus / EnerPHit	7	1	7	4	4	0
BIM	1	121	56	32	9	14
Energy efficiency / performance	7	56	135	65	28	23
Refurbishment	4	32	65	107	38	20
Housing refurbishment	4	9	28	38	38	6
Decision-making	0	14	23	20	6	36

From an analysis and the most relevant reviewed publications, there seemed to be some evidence to indicate that there was a significant knowledge gap about the novel building refurbishment model in the Architecture, Construction and Engineering (AEC) industries due to the limited research in BIM and Passivhaus adoption for energy efficiency in housing refurbishments - not only in the UK, but worldwide. Regarding this issue, BIM tools and Passivhaus EnerPHit standards have not been extensively exploited for most of the existing buildings yet. As a result of this literature analysis, the problem statement of this paper was defined precisely and taken up in the research methodology.

2.2 BIM Model

The baseline case study scenario was modelled in ArchiCAD, one of the most convenient BIM tools used worldwide to bring all architecture, engineering and construction disciplines into a unified modelling environment. The proposed hypothetical case study represented a Victorian-style two-storey terrace house located in Liverpool, UK. Liverpool is in a temperate maritime climate of warm, wet summers and cool, wet winters, with temperatures peaking around 20 °C in summer and dropping to around 2 °C in winter. Of the Liverpool's housing stock, 41.0% are terraced, 28.5% are semi-detached, 23.3% are flat, and 7.2% are detached [19]. For this reason, a typical terrace house has a significant role to play in the hypothetical case study definition within the context of Liverpool.

The building has only residential use. It has 134 m^2 total treated floor area, 3.2 m floor to floor height, 19.2 m^2 total glazing area, and 408 m^3 net volume. Table 2 shows the thermal information of the building envelope and the whole-house refurbishment approach to this building is proposed.

Tab. 2 *Construction details of the hypothetical case study*

	Construction detail	**U-value**
External Wall	Gypsum board, concrete wall, membrane, cavity, brickwork	1.65 W/m^2K
Ground Floor	Gravel fill, cast concrete, cavity, timber flooring, carpet	1.35 W/m^2K
Window	Single glazed box-sash windows	4.53 W/m^2K
Roof	Stone chipping, bitumen layers, slate tiles	4.50 W/m^2K

The baseline model of the building was generated in ArchiCAD using its geometric and non-geometric details (Fig. 2). The potential virtues of BIM in the developed housing refurbishment model can be classified as:

- The 3D BIM model can ensure greater coordination between the project stakeholders to avoid remedial works and clash detection before implementing the refurbishment measures for the house.
- The 4D BIM can provide a virtual environment in order to simulate and visualise the whole-house refurbishment process with consideration of construction site coordination and time schedule throughout the housing refurbishment project.
- As one of the advantages of its semantically enriched model, 5D BIM can create an economic opportunity for the refurbishment project's cost estimation, performing the quantity take-off throughout the refurbishment processes related to the selected Passivhaus-certified building components.

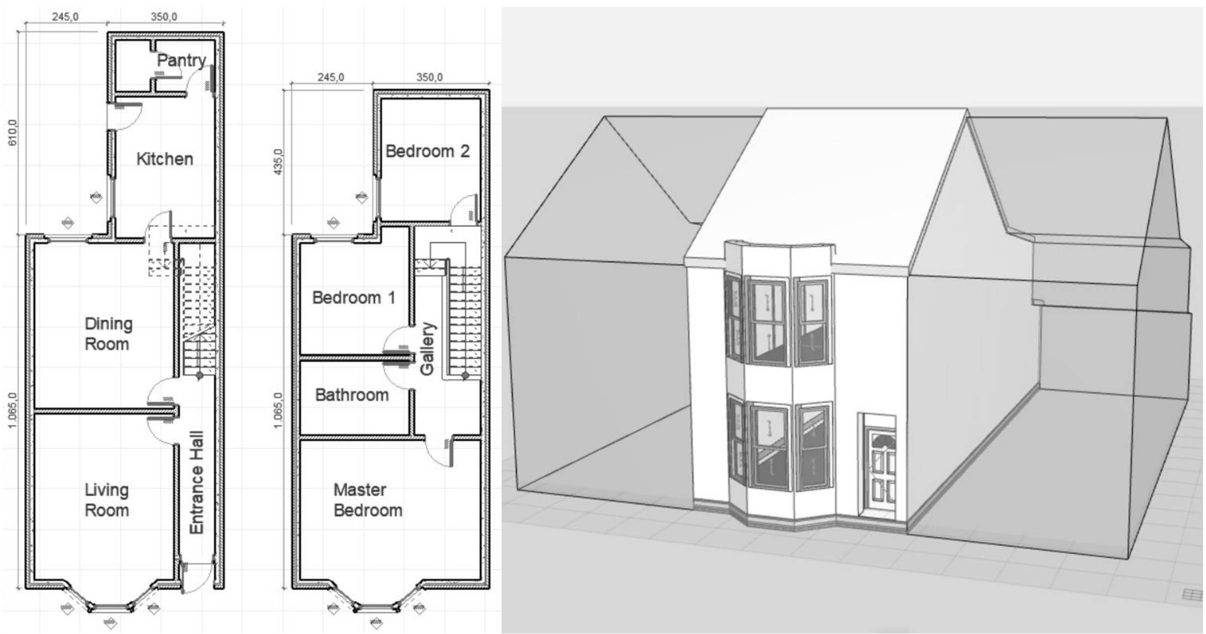


Fig. 2 *Baseline 3D model with its plans*

To refurbish the case study to the Passivhaus EnerPHit standards in the proposed model, it was required to consider the concept of a ‘fabric first’ approach, which addresses heat retention and airtightness in terms of the material selection in the Passivhaus refurbishment project. In this regard, the proposed BIM framework was implemented by a step-by-step refurbishment to address the Passivhaus EnerPHit standards.

3 Analysis and Discussion

To comprehensively analyse energy-efficient building refurbishment issues regarding the UK housing sector, a BIM and Passivhaus-assisted refurbishment process model was proposed with its theoretical and methodological background. A semantically enriched BIM model of the selected hypothetical case study was generated in ArchiCAD as an objective of this research with consideration of some key criteria: 3D coordination, time schedule and planning, cost estimation, and building material selection. The BIM model identified all relevant building components as distinct categories and layers: external and internal walls, floors, roof, windows, and doors.

The 4D BIM simulation of the project provided a considerable opportunity for the organisation of the implementation process of the Passivhaus-certified building components, including the determination of the refurbishment activities’ sequences. The 4D simulation demonstrates 21-day refurbishment project activities, describing the sequences of the external wall, ground floor and roof insulation and windows, doors and ventilation upgrades (Fig. 3). In consideration of the 4D simulation model, different construction areas were defined with specific time slots to enhance time management and avoid overlapping areas during the processes.

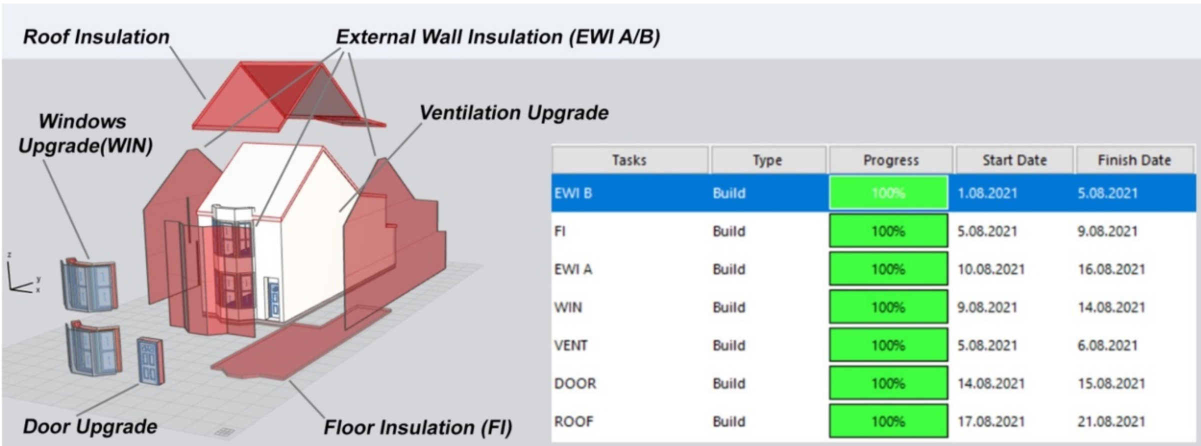


Fig. 3 *4D BIM simulation of the project*

As another dimension, 5D BIM was useful for the cost estimation opportunity for the refurbishment project, calculating the area, volume and unit price information of the BIM model. All building components were defined as different categories and layers. In this way, the geometric and non-geometric data could be obtained from the model to analyse the current condition of the building in terms of energy efficiency. Using these data, the alternative refurbishment scenarios can be assessed for building materials selection by considering Passivhaus-certified building components (Tab. 3).

Tab. 3 *BIM model external wall components (pre-refurbishment and post-refurbishment)*

Name	**Area (m^2)**	**Volume (m^3)**	**Name**	**Area (m^2)**	**Volume (m^3)**
Gypsum Board	68.21	1.07	Gypsum Board	68.21	1.07
Concrete Block	84.24	8.20	Concrete Block	84.24	8.20
Membrane	82.47	0.33	Membrane	82.47	0.33
Air Space	83.75	2.48	Air Space	83.75	2.48
Brickwork	87.05	8.43	Brickwork	87.05	8.43
			Insulation	88.71	12.25
			Fermacell	79.25	0.79

The proposed insulation materials and building components were applied step-by-step in order to improve the house's baseline model using BIM tools and the EnerPHit standards with the comparison of U-values of the alterations before and after implementing the proposed refurbishment model (Tab. 4).

Tab. 4 *Refurbishment steps, including a summary of U-values (W/m^2K), used for each element of the building envelope*

Upgrade	**Insulation**	**External Wall** U-value W/m^2K	**Ground Floor** U-value W/m^2K	**Window** U-value W/m^2K	**Roof** U-value W/m^2K
Base Case	House as-built	1.65	1.35	4.53	4.50
PH-Step 1	EnerPHit wall insulation	**0.23**	1.35	4.53	4.50
PH-Step 2	EnerPHit floor insulation	**0.23**	**0.24**	4.53	4.50
PH-Step 3	EnerPHit double-glazing window	**0.23**	**0.24**	**1.23**	4.50
PH-Step 4	EnerPHit roof insulation	**0.23**	**0.24**	**1.23**	**0.14**

Overall results of the Passivhaus criteria were based on the Passive House Planning Package (PHPP) calculation. PHPP is an Excel-based energy modelling tool for Passivhaus building design, testing the impact on anticipated energy savings of assorted insulation (walls, floor, windows, and roof) improvements. Using PHPP, the specific period of heating demand (kWh/m^2 per month) of the baseline model and proposed final model were calculated step by step (Fig. 4). The monthly heating demand of the house model prior to the refurbishment was between 60 kWh/m^2 and 180 kWh/m^2 in a year. The proposed model implies how the inadequately insulated base case model can be refurbished systematically to achieve the Passivhaus EnerPHit heating demand criteria of less than 25 kWh/m^2 annually. Based on the obtained results, each step of the implemented refurbishment model has an important contribution to high efficiency in energy use for heating demand of the baseline model of the case study. Furthermore, these results have the potential to assess the different energy efficiency gains between the refurbishment steps according to different building components.

The presented refurbishment model of a typical terrace house addresses the real needs of the UK housing stock as solution-oriented research to provide useful knowledge that enables practitioners to solve the issues regarding the conventional refurbishment processes. Applying a BIM tool for this refurbishment model provided better coordination in building material choice, organisational priority for the refurbishment processes, and collective decision making for the project stakeholders with considering the EnerPHit standards. Moreover, 4D BIM provided the virtual environment to simulate and visualise the 21-day refurbishment project activities with enhancing time management and avoiding overlapping areas during the refurbishment processes. Furthermore, 5D BIM made this refurbishment model economically feasible with its cost estimation benefits as a solution for the conventional refurbishment issues such as cost overruns and unsatisfactory refurbishment outcomes.

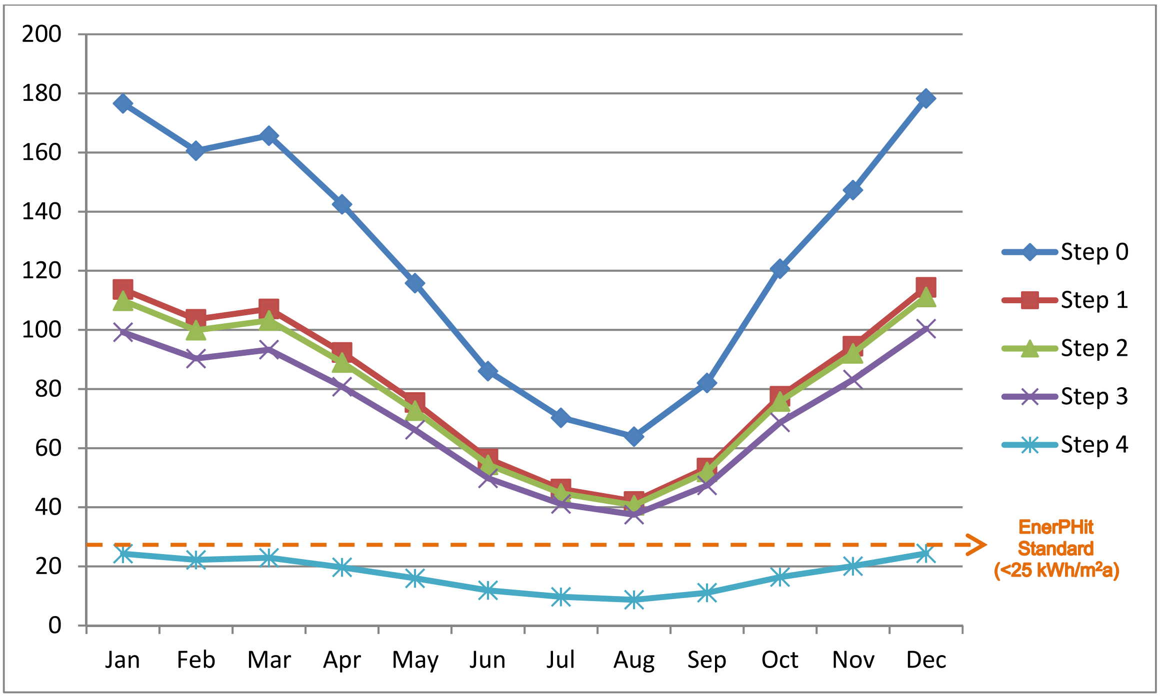


Fig. 4 *Comparison of monthly heating demand (kWh/m^2 per month) of the step-by-step refurbishment of the base case model*

4 Conclusion

This paper has outlined the evaluation of applying BIM tools and the EnerPHit standards to the UK housing stock for energy efficiency by examining a proposed hypothetical case study, which represents a typical terrace house in Liverpool, UK. This study focused on some of the main reasons for the low demand for housing refurbishment in the UK and proposed some feasible and effective solutions to address the problems of the conventional refurbishment processes. Implementing the BIM-based model had a remarkable role to play in effective strategies in energy-efficient housing refurbishment. While the monthly heating demand of the house model was between 60 kWh/m^2 and 180 kWh/m^2 in a year prior to the refurbishment, the monthly average demand decreased below 25 kWh/m^2 after the refurbishment project. The complexity of the conventional housing refurbishment has been discussed with the solution-oriented research methodology and the correlations amongst the chosen BIM tool and the Passivhaus EnerPHit standards as the purpose of this study. With its further dimensions, the BIM tool was evaluated to reach an effective solution for the conventional refurbishment issues with consideration of the benefits of BIM such as better coordination with visual simulations, better refurbishment time optimisation, and reduction of the building refurbishment material use. The main finding of this paper is that the Passivhaus standards could be achieved by implementing the proposed BIM-based housing refurbishment model for energy efficiency to bridge the gap between expected and actual energy performance. Thus, the demand for building refurbishment amongst the UK homeowners would be increased to meet the UK's 2050 net-zero targets regarding the UK housing stock.

Acknowledgement

This study was supported by The Republic of Turkey Ministry of National Education as the main sponsor of my PhD programme. The study was co-funded by School of the Arts Post Graduate Research Support Fund, the University of Liverpool.

References

[1] Committee on Climate Change. Reducing UK emissions: 2019 Progress Report to Parliament Committee on Climate Change. July 2019: 10/07/2019.” TSO, pp. 1–93, 2019, [Online]. Available: www.theccc.org.uk/publications.

[2] Juan, Y. K., Gao, P. and Wang, J. A hybrid decision support system for sustainable office building renovation and energy performance improvement. *Energy Build.*, vol. 42, no. 3, pp. 290–297, 2010, doi: 10.1016/j.enbuild.2009.09.006.

[3] Okakpu, A., GhaffarianHoseini, A., Tookey, J., Haar, J., Ghaffarianhoseini, A. and Rehman, A. A proposed framework to investigate effective BIM adoption for refurbishment of building projects. *Archit. Sci. Rev.*, vol. 61, no. 6, pp. 467–479, 2018, doi: 10.1080/00038628.2018.1522585.

[4] Rysanek, A. M. and Choudhary, R. Optimum building energy retrofits under technical and economic uncertainty. *Energy Build.*, vol. 57, pp. 324–337, 2013, doi: 10.1016/j.enbuild.2012.10.027.

[5] Ustinovichius, L., Popov, V., Cepurnaite, J., Vilutienė, T., Samofalov, M. and Miedziałowski C. BIM-based process management model for building design and refurbishment. *Arch. Civ. Mech. Eng.*, vol. 18, no. 4, pp. 1136–1149, 2018, doi: 10.1016/j.acme.2018.02.004.

[6] Wang, C. and Cho, Y. K. Application of As-built Data in Building Retrofit Decision Making Process. *Procedia Eng.*, vol. 118, pp. 902–908, 2015, doi: 10.1016/j.proeng.2015.08.529.

[7] GhaffarianHoseini A., Tookey, J., Ghaffarianhoseini, A., Naismith, N., Azhar, S., Efimova, O. and Raahemifar, K. Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. *Renew. Sustain. Energy Rev.*, vol. 75, no. December 2016, pp. 1046–1053, 2017, doi: 10.1016/j.rser.2016.11.083.

[8] Piddington, J., Nicol, S., Garrett, H. and Custard, M. The Housing Stock of The United Kingdom. 2020. [Online]. Available: https://files.bregroup.com/bretrust/The-Housing-Stock-of-the-United-Kingdom_Report_BRE-Trust.pdf.

[9] Alwan, Z. BIM performance framework for the maintenance and refurbishment of housing stock. *Struct. Surv.*, vol. 34, no. 3, pp. 242–255, 2016, doi: 10.1108/SS-03-2015-0018.

[10] Ma, Z., Cooper, P., Daly, D. and Ledo, L. Existing building retrofits: Methodology and state-of-the-art. *Energy Build.*, vol. 55, pp. 889–902, 2012, doi: 10.1016/j.enbuild.2012.08.018.

[11] Volk, R., Stengel, J. and Schultmann, F. Building Information Modeling (BIM) for existing buildings - Literature review and future needs. *Autom. Constr.*, vol. 38, pp. 109–127, 2014, doi: 10.1016/j.autcon.2013.10.023.

[12] Gardezi, S. S. S., Shafiq, N., Nurudinn, M. F., Farhan, S. A. and Umar, U. A. Challenges for Implementation of Building Information Modeling (BIM) in Malaysian Construction Industry. *Appl. Mech. Mater.*, vol. 567, no. June, pp. 559–564, 2014, doi: 10.4028/www.scientific.net/AMM.567.559.

[13] Gholami, E., Sharples, S. and Shokooh, J. A. Exploiting BIM in Energy Efficient Refurbishment : A paradigm of future opportunities. *PLEA 2013: Sustainable Architecture for a Renewable Future*, vol. 2, no. September. 2013, [Online]. Available: https://researchportal.port.ac.uk/portal/files/2564792/Exploiting_BIM_in_energy_efficient_refurbishment_A_paradigm_of_future_opportunities.pdf.

[14] Ilter D. and Ergen, E. BIM for building refurbishment and maintenance: current status and research directions. *Structural Survey*, vol. 33, no. 3, Emerald Group Publishing Limited, 2015, pp. 228–56, doi:10.1108/SS-02-2015-0008.

[15] Motawa I. and Carter, K. Sustainable BIM-based Evaluation of Buildings. *Procedia - Soc. Behav. Sci.*, vol. 74, pp. 419–428, 2013, doi: 10.1016/j.sbspro.2013.03.015.

[16] Park, K. and Kim, K. Essential BIM Input Data Study for Housing Refurbishment: Homeowners' Preferences in the UK. *Buildings*, vol. 4, no. 3, pp. 467–487, 2014, doi: 10.3390/buildings4030467.

[17] Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C. and O'Reilly, K. BIM adoption and implementation for architectural practices. *Struct. Surv.*, vol. 29, no. 1, pp. 7–25, 2011, doi: 10.1108/02630801111118377.

[18] Saunders, M., Lewis, P. and Thornhill, A. *Research methods for business students*. United Kingdom: Pearson Education Limited, 2016.

[19] Liverpool City Council, "Liverpool Strategic Housing Market Assessment," no. July, 2016, [Online]. Available: https://liverpool.gov.uk/planning-and-building-control/plan-making-in-liverpool/evidence-monitoring-and-information/strategic-housing-market-assessment/.

Renovating the Existing Residential Building Stock in Turkey with Prefabricated Components for Passivhaus-EnerPHit

Dilek ARSLAN[a], Steve SHARPLES[b], Haniyeh MOHAMMADPOURKARBASI[c]

a University of Liverpool, 25 Abercromby Square, L69 7ZN, Liverpool, UK, Dilek.Arslan@liverpool.ac.uk
b University of Liverpool, 25 Abercromby Square, L69 7ZN, Liverpool, UK, Steve.Sharples@liverpool.ac.uk
c University of Liverpool, 25 Abercromby Square, L69 7ZN, Liverpool, UKHaniyeh.MPK@liverpool.ac.uk

Abstract

In order to keep the future global temperature below 2˚C, significant energy reductions must be achieved in the building sector. Since existing buildings consume the biggest share of the sector's energy budget, then complete, fast, and easy-to-apply energy update methods using prefabrication during the retrofit process are desirable. Although various prefabricated retrofit components have been introduced in different climate contexts, there are very few studies exist on retrofit for buildings in hot climates. In addition, no standard guarantees the operational energy performance of these components. Therefore, this paper aims to adapt one of these prefabricated retrofit solutions, Timber-based Element System (TES), to housing in the hot climate region of Turkey to achieve the Passivhaus-EnerPHit standard in operational energy. Step-by-step interventions were applied to a multi-family building in Istanbul using PHPP software to achieve EnerPHit requirements. While TES successfully decreased the heating demand by 50%, decreasing cooling demand was more difficult and the passive measures were insufficient to lower the cooling energy load. Mechanical ventilation with heat recovery (MVHR) and additional ventilation units were helpful in decreasing the cooling demand to EnerPHit requirement levels and to zero for heating demand. It was concluded that, due to the limiting boundaries in the existing buildings, there may always be a need for a mechanical system for cooling to condition indoor environments in hot climates to comfort levels.

Keywords: *Retrofit, Prefabrication, EnerPHit, Hot Climates*

1 Introduction

In 2016, countries began to pledge to tackle climate change by signing Paris Agreement, and targets were established to decrease carbon emissions to the1990s levels by 2030. However, the latest IPCC report [1] showed that the world is crossing the 2˚C threshold, meaning that current measurements are insufficient. As it is responsible for around one-third of global carbon emissions, this climate emergency pushes the building sector to take rapid actions to decrease carbon emissions. Meeting the emission reduction target is particularly essential in countries that fall behind in the climate mitigation race, like Turkey [2]. It is expected that in 2024 the countries that signed the Paris Agreement will start to establish the total amount of emission reductions that they have achieved. Therefore, Turkey needs to speed up its reduction due to the time constraints and commitments to the recently ratified, Paris Agreement [3]. Although, Turkey has introduced a benchmark for new buildings to achieve at least a C Level in energy performance in its Energy Performance Certificate (EPC) system, there are no specific strategies or targets for the existing buildings. Therefore, country-specific solutions should be considered for retrofitting existing buildings in Turkey.

Retrofitting the existing building stock substantially decreases the operational impact from buildings; however, business as usual, models take too much money, time, and source and disturb occupants in the building during the retrofit process [4, 5]. Standardisation in both operational performance and production can avoid these shortcomings. Therefore, prefabrication and an energy standard should be a part of the retrofit process. While prefabrication ensures the quality in component production and reduces the duration [6], energy standards like Passivhaus control the energy demand [7]. Although these retrofit models exist, they are not necessarily considering hot climate conditions nor highlighting the overheating risk in summers. This brings buildings in hot climates to the attention of researchers, to evaluate the boundary conditions to be overcome.

In this study, a case study of a low-rise apartment block in Istanbul, Turkey was evaluated to show whether prefabricated retrofit panels are good at achieving the Passivhaus EnerPHit performance with Timber-based Element System (TES) energy façade systems or not. Also, to explore the challenges during the retrofits in hot climates. This can be a step for a retrofit model to help Turkey to comply with the Paris Agreement requirements. The Passivhaus Planning Package (PHPP) model was used to evaluate step-by-step retrofit strategies. The results showed that the main challenge in achieving EnerPHit performance was decreasing the energy demand for cooling and dehumidification due to a lack of the possibility of changing some building components like window sizes.

2 Literature

2.1 Retrofit considerations

The majority of a building's energy demand comes from the activities in its operational stage, such as heating, cooling, cooking, and washing. These activities constitute about 50–70% of primary energy demand [8]. While new buildings are more successful in reducing operational energy consumption, existing buildings are still struggling. Although retrofitting buildings is a solution, it often takes more time and money than was expected and disturbs the occupants during the whole process. Also, the boundary conditions of an existing building, such as building orientation and shape or window sizes, affect possible energy reductions. Therefore, people prefer to demolish and reconstruct their houses in most cases, which costs less money and effort than a retrofit [4, 5].

Lately, under the European Union Research and Innovation Program, Horizon 2020 [9] projects have integrated prefabrication to retrofit processes to overcome negative aspects of disturbing occupants by decreasing construction times to 10–15 days and lowering construction waste. These modular systems can achieve up to an 80% reduction in operational demand for nearly zero-energy buildings (NZEB) [10]. Although this is a promising step up in modular retrofit, designing modules for NZEB is not providing a clear path in achieving the energy target. On the other hand, energy standards like Passivhaus are not only specifying the minimum energy demand for heating and cooling and identifying thermal properties for each building component or air change rate to achieve those targets, which aligns more with a *'fabric first'* approach in retrofit. Passivhaus also ensures that implications in every step are understood and planned accordingly, with pre-certification options to avoid the performance gap between design and application processes. EnerPHit is a subsection of Passivhaus for retrofit projects. It requires ≤25kWh/m²/pa for space heating, ≤15 kWh/m²/pa for cooling demand, and ≤120kWh/m² for primary energy demand [11].

2.2 Situation in Turkey

Turkey is one of the signatories to the Paris Agreement. Therefore, it pledged to play its part in combatting climate change. In Turkey's climate change strategy, there are five objectives to be achieved by 2023, which are

- Increasing the energy efficiency in buildings by improving the building skin.
- All new buildings should have an EPC with at least a level C.
- Energy consumptions to decrease by at least 20%.
- Meeting of at least 20% of energy demand with renewable sources.
- Decreasing the 2011 greenhouse gas (GHG) figures by 10% [12].

To achieve these objectives, Turkey introduced Building Energy Code and Energy Performance Regulations in 2007 and 2008, respectively [13]. The regulations basically set a baseline for the thermal performance of the building components according to climate zones – for instance, the U-value of a wall should not be more than 0.70 W/m²K in hot climate regions. Despite these steps being taken, Turkey still falls behind other countries in its climate change contributions [2].

The majority of the buildings in Turkey were built in between 1969 and 1996, constituting about 72% of the total stock. An average apartment block's space heating demand can be up to 200 kWh/m² [14] which covers almost 58% of the total energy demand. These figures are highlighting the poor energy performance conditions in Turkey's existing housing stock as well as the need for an urgent upgrade. Therefore, a modular retrofit model, aiming for EnerPHit performance, was evaluated using a step by step to establish how a step was making a difference in energy demand.

3 Methodology

3.1 Case Study

Since the majority of the building stock in Turkey is in Istanbul, and the city also experiences a Mediterranean climate (characterised by hot, dry summers and cool, wet winters), a case study apartment in Istanbul was chosen. The selected apartment building was built in 1993 and located in Avcılar/Istanbul, which typically experiences the lowest temperature in winter of 3˚C and 32 ˚C as the highest in summer [15].

The apartment represents an example of standard practice in residential projects in Turkey (Fig.1). The building has one basement with a communal area, four stories with eight flats, and two penthouses. All the flats have almost the same layout and are used for residential purposes (Fig. 2). The total treated floor area (TFA) of the building is 1008m² and each floor is 2.8m height. The building has a reinforced concrete structure and has brick walls with no insulation. Heating, cooking, and domestic hot water energy demands are met by a gas boiler, and other needs like lighting and cooling are supported by electricity and mixed ventilation.

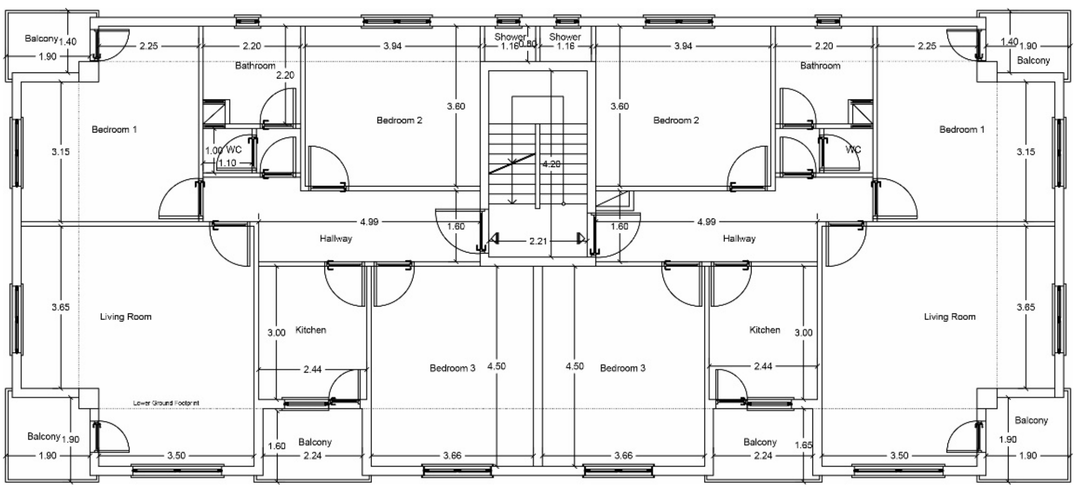


Fig. 1 *Floor Plan of the Apartment*

Fig. 2 *Case Study Apartment (courtesy of Dilek Arslan, 2020)*

3.2 Passivhaus Planning Package (PHPP)

In this study, an Excel-based tool PHPP by Passivhaus Institute (PHI) was used to explore the step-by-step retrofit measures to achieve Passivhaus-EnerPHit targets. PHPP calculation method based on laws of physics aligned to international standards for energy. The tool simply requires the building characteristic information such as treated floor area (TFA), floor height, window quantities, and sizes, building components to estimate the energy demand in total or for heating and cooling. Besides calculating the demand, the tool helps to size the needed shading, mechanical systems, and building loads for hot water heating and cooling to achieve the Passivhaus or EnerPHit target for operational energy [16]. PHPP tool has been widely used in both literature and in practice in Passivhaus and EnerPHıt cases to assure the standard in projects and to show low performance gap between real-life application and the tool [17, 18, 19]. Therefore, it is selected in this study to assess the existing building performance as well as retrofit the building step-by-step.

The building information input in the sheets is followed as in Table 1.

4 Results and Discussion

4.1 Step-by-Step Retrofit

The results from PHPP simulations showed that the heating and cooling demand of the existing building were 161 kWh/m²/pa and 108 kWh/m²/pa, respectively, while the primary energy demand was 310 kWh/m²/pa. When the first step of retrofit, a TES façade (Fig.3), was applied to the building, the heating and cooling demands showed a substantial decrease by 50%, due to thermal bridge free components and low thermal transmittance from the building skin.

Although existing windows were double glazed and in good condition, they were not complying with the Passivhaus-EnerPHit requirements. So, in the second step, windows were replaced with Passivhaus certified timber framed triple glazed windows, and the heating demand decreased by 62% and primary energy demand decreased to 142 kWh/m²/pa, by almost 55%. However, cooling demand increased from 52 to 63 kWh/m²/pa.

In the next step, an MVHR unit was added to the building. It produced a significant reduction in heating energy demand to 9 kWh/m²/pa, a 94% fall, which is a more significant reduction than the other prefabricated retrofit façades [9, 20, 21,]. Whilst the heating demand met the EnerPHit criteria, cooling and dehumidification needed more improvements. Although the cooling demand dropped by 66% of the existing performance, it was not enough to comply with the EnerPHit requirement, meaning that the

Tab. 1 *Existing building characteristics entered in PHPP tool*

Climate	There was no climate data available for Istanbul in PHPP that the climate input derived from Meteonorm tool and put in the PHPP.		
U-Values *Existing Build-ups	**Component**	**Layers**	**U-Value (W/m²K)**
	Exterior Walls	Cement Creed (30mm) + Brick (200mm) + Plaster (20mm)	1.84
	Basement Wall	Bitumen Paint (2mm)Concrete (250mm) + Plaster (20mm)	1.47
	Floors	Timber Flooring (30mm) + Concrete Slab (120mm) + Plaster (13mm)	1.78
	Basement Floor	Screed (30mm) + Concrete Slab (500mm) + Lean Concrete (100mm) + Gravel (150mm)	1.12
	Roof	Timber Battens (100mm) + OSB Board (13mm) + Air Gap (10 mm) + Clay Roof Tiles (25mm)	0.8
Areas	**Area Group**		**Area (m²)**
	Treated Floor Area		1008
	North Windows		41
	East Windows		29
	South Windows		74
	West Windows		29
	Exterior Door		3.45
	External Wall - Ambient		861
	External Wall - Ground		62
	Roof - Ambient		279
	Basement ceiling		161
Ground	Unheated basement option selected here, and thermal properties derived from 'Areas' and 'Components' sections.		
Components	U-Values' inputs and user-defined components here feeds the calculations in the 'Areas' sheet		
Windows	Each window's size, quantity, and installation situation is entered here which feeds the 'Areas' section.		
Shading	No window shading input is entered here.		
Ventilation	No mechanical ventilation is used in the building so no data is entered.		
Additional Ventilation	No mechanical ventilation is used in the building so no data is entered.		

system needed further steps to reduce the cooling load in the building. Therefore, the dehumidification efficiency in the MVHR unit increased from 75% to 95%, which decreased cooling demand from 36 to 30 kWh/m²/pa and heating demand decreased to 6 kWh/m²/pa. Yet, efficiency cannot be guaranteed in these units. Consequently, care should be taken when changing the efficiency, and maintenance should be regularly undertaken in actual designs.

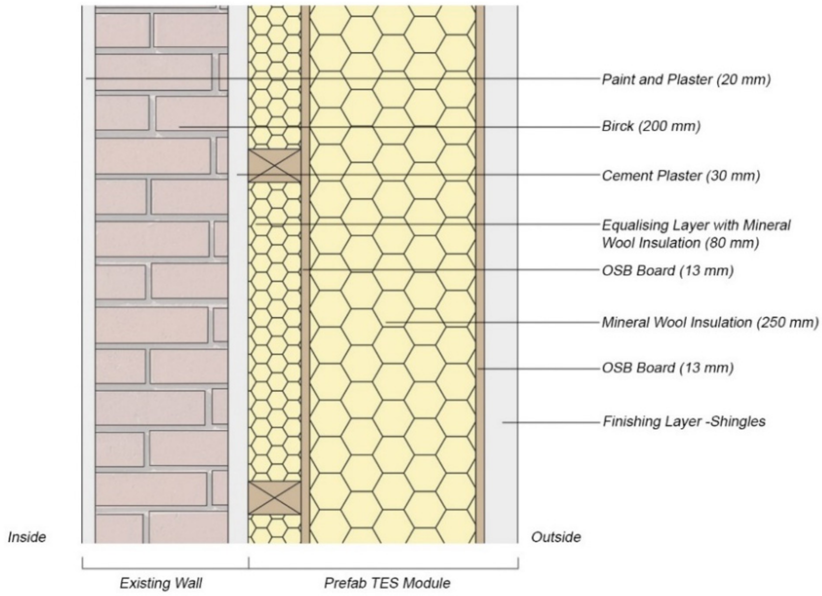


Fig. 3 *Retrofitted Wall Detail*

Further, shading elements were added as an overhang to South, East, and West windows since the solar loads were the highest on those façades at 560, 456, 453 kWh/m$^2_{\text{glazing area}}$ respectively. However, adding shading did not have a tangible impact on cooling energy demand. Therefore, the *Additional Ventilation* tab was activated in the software to lower the energy load from cooling. Smaller size additional ventilation units were added to floor levels in the buildings, which helped achieving the EnerPHit target. Despite the achievements in each domain of the EnerPHit standard, the primary energy demand was still high, being 136 kWh/m²/pa. Therefore, the final step was to add 29 mono-silicon 1.65x0.99m photovoltaic (PV) panels to the south-facing side of the roof. , The PV panels helped to achieve primary energy from renewables criteria which were 64 kWh/m²/pa. With all the interventions applied, the final figures for heating and cooling demands were 0.1 and 14 kWh/m²/pa, respectively (Fig. 4).

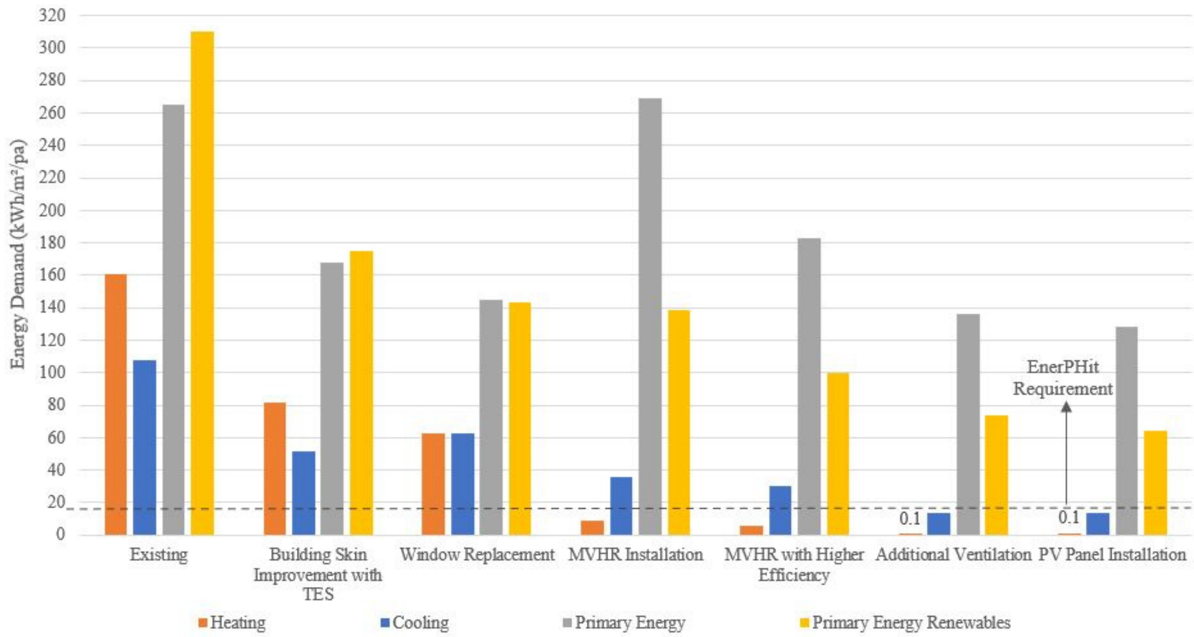


Fig. 4 *Step-by-Step Retrofit Results*

As the heating demand became almost zero, this allowed a decrease in the insulation thickness in the prefabricated components, while the Passivhaus standard recommends keeping the U-value of the external walls between 0.10 and 0.15 W/m²K. This is much flexible in EnerPHit, which allows external walls U-values to be between 0.30 and 0.50 W/m²K for warm-temperate climates [22]. In the proposed TES the improved exterior walls achieved 0.104 W/m²K with 250 mm mineral fibre wool insulation (Tab.1). If the insulation thickness was decreased to 150 mm, the heating demand increased slightly to 0.6 kWh/m²/pa and the U-value of the walls to 0.143 W/m²K. If the insulation thickness decreased to 100 mm, then the heating demand still stayed low at 1.3 kWh/m²/pa; but the cooling demand approached 15kWh/m²/pa threshold, being 14.4kWh/m² annual energy demand. Further, for an insulation thickness decrease to 50 mm, the heating demand went up to 3.4 kWh/m²/pa, but this was the limit for the cooling demand since it went up to 15 kWh/m²/pa. The U-value of the external walls stayed 0.230 W/m²K, which is still low compared to EnerPHit allows. This shows that substantial energy reductions are possible with little insulation in warm climates and, as with other prefabricated retrofit modules, the TES system for the cold climate requires much more insulation, which is not necessary for the buildings in warmer climates.

Tab. 2 *Assemblies and Thermal Properties of Retrofitted Building*

Building Assembly	**Layers with Improvements**	**U-Value (W/m²K)**	
		Case Study	**EnerPHit**
Exterior Walls	20mm Plaster and Paint + 200mm Brick + 30mm Cement Plaster and Mosaic Rendering **+ 80mm Equalising Layer with Insulation + 13mm OSB + 250mm Mineral Wool + 13mm OSB + Finishing Layer**	**0.10**	0.30-0.50
Roof	Ceramic Roof Tiles + 13mm Particle Board + 100mm Wood Battens + 13mm Particle Board + 20mm Plaster and Paint **+ 13mm OSB + 150 mm Mineral Wool**	**0.13**	0.30-0.50
Windows	**Replaced with a PH certified insulated triple glazing with timber frame**	**1.00**	1.05

4.2 Retrofit in Hot Climates

Considering the global climate is getting warmer, in the future, the risk of overheating and cooling issues will be a factor of the cold climate regions. Also, some current studies have reported that even the buildings retrofitted to Passivhaus performance in cold climates can have issues about overheating in the summer, thereby increasing the cooling demand [23, 24]. Step-by-step retrofit processes showed that, although the current solutions like TES façade systems are advantageous in decreasing the heating energy demand in residential buildings with passive measurements, cooling and dehumidification still require active solutions, especially when the building boundaries are limited. Even installing an MVHR unit to a single-family unit is quite expensive, and the total cost of installing MVHR units to each floor level and building level will be double. Therefore, the homeowners will probably not be willing to invest too much money in an old building. Both a changing climate and cost issues highlight that retrofit solutions need more passive solutions to achieve Passivhaus-EnerPHit performance in hot climate countries.

4.3 Limitations

One of the limitations related to the retrofit process was fixed openings. Because the aim of this retrofit model is to avoid occupant disturbance during the prefabricated retrofit installations, the existing openings were kept the same. This affected the flexibility in taking measures to avoid overheating and cooling at certain levels. Similarly, since the building boundaries and direction cannot be changed in the existing building, the building orientation or shape factor could not be changed. Finally, the PHPP software needs validation in the design process. Normally, the only way to validate the Passivhaus performance is to build the building and test its performance on-site, which is not an easy or cheap way of validating energy performance. Although PHPP is claimed to be reliable on calculation results [17], this is not always the case. The performance gap issue in PHPP has been mentioned in literature [25] and may affect its credibility. Also, PHPP allows users to take building level measurements to tackle the issues in the whole building, like overheating or air leakage, not at the individual room/space level.

5 Conclusion

5.1 Summary

This paper indicated that considerable energy savings are possible with the façades improved by prefabricated components, even for challenging summer conditions. The study revealed that decreasing the cooling demand to 15kWh/m²/pa with passive measurements like shading was not possible. Therefore, MVHR units are needed at both building and floor levels in low-rise apartments in the hot climate regions of Turkey to achieve EnerPHit performance. Also, it has been understood that even though a building component does not comply with the Passivhaus requirements, a building can meet heating and cooling demands as well as primary energy demands. Therefore, even though Passivhaus provides step-by-step retrofit guidelines for climate-specific conditions, it still needs some improvements regarding building components being considered in specific country contexts, especially for hot climates.

5.2 Future Work

The main focus of this paper was to assess the challenges faced during the building assessment and achieving EnerPHit performance. Therefore, as a future work, exploring the options and creating a scheme for Turkey's retrofit path will also include the social and economic aspects of retrofit and government funding. Also, Life Cycle Assessment (LCA) of the building components will be included in the prefabricated retrofit process to evaluate the hidden carbon emissions, and energy consumed during the component production called embodied impact. Operational energy and embodied energy play an important role in reducing the impact related to building construction, especially in retrofit. In retrofit projects, since the building has already spent a period of its time, it is important to understand whether embodying extra carbon for the rest of its time is feasible or not. Finally, given the limited insight of a building's thermal behaviour from PHPP, the building energy simulation will be carried out with the dynamic simulation software DesignBuilder to validate the existing performance and indicate the problems that may occur at room/space level and explore solutions to them.

Acknowledgement

This PhD study is funded by the Turkish Ministry of Education, including tuition fees and student expenses.

References

[1] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

[2] Climateactiontracker.org. n.d. *Turkey | Climate Action Tracker*. [online] Available at: https://climateactiontracker.org/countries/turkey/ [Accessed 9 April 2021].

[3] Resmi Gazete, 2021. *Milletler Arası Adlaşma*. [online] Available at: <https://www.resmigazete.gov.tr/eskiler/2021/10/20211007M1-1.pdf> [Accessed 14 February 2022].

[4] Tahsildoost, M. and Zomorodian, Z., 2020. Energy, carbon, and cost analysis of rural housing retrofit in different climates. *Journal of Building Engineering*, 30, p.101277.

[5] D'Oca, S., Ferrante, A., Ferrer, C., Pernetti, R., Gralka, A., Sebastian, R. and op 't Veld, P., 2018. Technical, Financial, and Social Barriers and Challenges in Deep Building Renovation: Integration of Lessons Learned from the H2020 Cluster Projects. *Buildings*, 8(12), p.174.

[6] Richard, R., 2017. Industrialised building system categorisation. In: *Offsite Architecture: Constructing the Future*, 1st ed. Oxon: Routledge, pp.3–20.

[7] Institute, P., n.d. *Passivhaus Institut*. [online] Passivehouse.com. Available at: https://passivehouse.com/02_informations/01_whatisapassivehouse/01_whatisapassivehouse.htm [Accessed 20 September 2021].

[8] Ibn-Mohammed, T., Greenough, R., Taylor, S., Ozawa-Meida, L. and Acquaye, A. (2013). Operational vs. embodied emissions in buildings—A review of current trends. *Energy and Buildings*, 66, pp.232–245.

[9] Horizon 2020 - European Commission. n.d. *What is Horizon 2020? - Horizon 2020 - European Commission*. [online] Available at: <https://ec.europa.eu/programmes/horizon2020/what-horizon-2020> [Accessed 14 February 2022].

[10] MORE-CONNECT. 2019. *Results — MORE-CONNECT*. [online] Available at: <https://www.more-connect.eu/deliverables/> [Accessed 13 September 2021].

[11] Passive House Institute, 2016. *Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard*. [online] Passive House Institute. Available at: https://passipedia.org/_media/picopen/9f_160815_phi_building_criteria_en.pdf [Accessed 13 September 2021].

[12] Turkish Ministry of Environment and Urbanization, 2012. *Turkey's National Climate Change Adaptation Strategy and Action Plan*. Ankara: Turkish Ministry of Environment and Urbanization.

[13] TS 825:2008, 2008. *Binalarda Isi Yalitim Kurallari*. Ankara, Turkey: TSI. [online] Available at: http://www1.mmo.org.tr/resimler/dosya_ekler/cf3e258fbdf3eb7_ek.pdf [Accessed 11 April 2021].

[14] Kazanasmaz, T., Uygun, İ., Akkurt, G., Turhan, C. and Ekmen, K., 2014. On the relation between architectural considerations and heating energy performance of Turkish residential buildings in Izmir. *Energy and Buildings*, 72, pp.38–50.

[15] Mgm.gov.tr. 2021. *Meteoroloji Genel Müdürlüğü*. [online] Available at: https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?m=ISTANBUL [Accessed 13 September 2021].

[16] Passipedia.org. 2021. *PHPP – Passive House Planning Package [ ]*. [online] Available at: <https://passipedia.org/planning/calculating_energy_efficiency/phpp_-_the_passive_house_planning_package> [Accessed 14 February 2022].

[17] Passipedia.org. 2020. *PHPP - validated and proven in practice [ ]*. [online] Available at: <https://passipedia.org/planning/calculating_energy_efficiency/phpp_-_the_passive_house_planning_package/phpp_-_validated_and_proven_in_practice> [Accessed 14 February 2022].

[18] Valančius, K., Vilutienė, T. and Rogoža, A., 2018. Analysis of the payback of primary energy and CO2 emissions in relation to the increase of thermal resistance of a building. *Energy and Buildings*, 179, pp.39–48.

[19] Cui, J., Ianakiev, A. and García-Fuentes, M., 2017. To Examine Appropriate Deep-retrofit Practice using Simulation Results in an EU-funded Urban Regeneration Project. *Energy Procedia*, 105, pp.2549–2556.

[20] ADAPTIWALL, 2018. *Multi-functional light-weight WALL panel based on ADAPTive Insulation and nanomaterials for energy efficient buildings*. [online] Available at: https://cordis.europa.eu/project/id/608808/reporting [Accessed 14 September 2021].

[21] BREASER, 2015. *BREASER system concept design and methodology for a systemic building*. [online] Available at: http://www.bresaer.eu/wp-content/uploads/2017/03/BRESAER-System-concept-design-and-methodology-for-a-systemic-building-refurbishment_D2.2.pdf [Accessed 14 September 2021].

[22] Passive House Institute, 2016. *Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard*. [online] Passive House Institute. Available at: https://passipedia.org/_media/picopen/9f_160815_phi_building_criteria_en.pdf [Accessed 20 September 2021].

[23] Lattke, F., Larsen, K., Ott, S. and Cronhjort, Y., 2009. *TES Energy Facade – prefabricated timber based building system for improving the energy efficiency of the building envelope*. [online] Available at: https://www.researchgate.net/publication/294085946_TES_Energy_Facade_-_prefabricated_timber_based_building_system_for_improving_the_energy_efficiency_of_the_building_envelope_funded_by_Woodwisdom_Net_Research_project_from_2008-2009 [Accessed 14 September 2021].

[24] Fletcher, M., Johnston, D., Glew, D. and Parker, J., 2017. An empirical evaluation of temporal overheating in an assisted living Passivhaus dwelling in the UK. *Building and Environment*, 121, pp.106-118.

[25] Kang, Y., Chang, V., Chen, D., Graham, V. and Zhou, J., 2021. Performance gap in a multi-storey student accommodation complex built to Passivhaus standard. *Building and Environment*, 194, p.107704.

Reconstruction Possibilities to Achieve a Nearly Zero Energy Building

Anna PREDAJNIANSKA[a], Eva ŠVARCOVÁ[a], Imrich SÁNKA[a], Dušan PETRÁŠ[a]

[a] *Slovak University of Technology in Bratislava, Radlinského 11, Bratislava, Slovakia, predajnianska,anna@gmail.com, eva.svarcov4@gmail.com*

Abstract

The aim of the article is to acquaint the reader with the possibilities of reconstruction for a single- family house. The main goal of renovations is to ensure today´s strict conditions for the energy consumption of buildings and thus achieve nearly zero energy buildings. The article is focused on the reconstruction of a family house, which was built in 1960. The desolated house had not been habited for decades. Two different options of reconstruction had been proposed. For comparison, different materials and technical facilities had been used for each option. The final reconstruction design has to provide thermal comfort in the interior. The current state of the family house will be described in the article. This newly renovated house is monitored to evaluate the parameters of thermal comfort.

Keywords: *Nearly Zero Energy Building, Renovation, Reconstruction, Energy Efficiency*

1 Introduction

Slovakia is a relatively small country in the middle of Europe, nevertheless, there are more than 900,000 family houses. More than 100,000 of them were built in the 1950s to 1970s. These family houses were built without thermal insulation, which met the requirements for energy efficiency of buildings at that time. Typical construction of family houses in Slovakia in the mentioned years is showed in Figure 1.

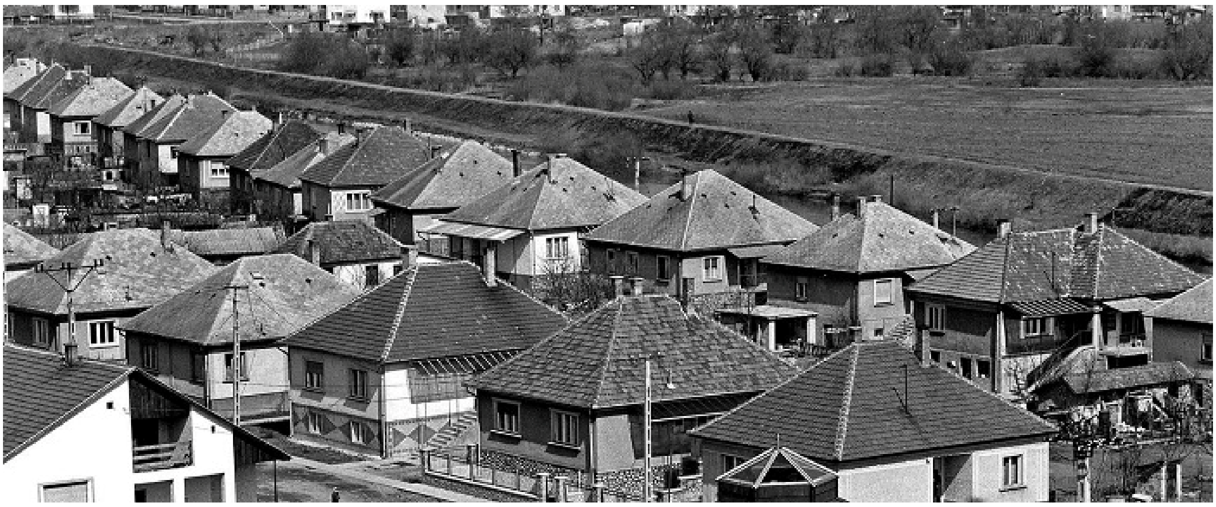


Fig. 1 *Typical construction of family houses in Slovakia built between 50s – 70s [8, 9]*

These typical single-family houses were built as single or double-storey houses with basic square floor plan. Disposition of this houses includes kitchen, living room, one or two bedrooms and bathroom with toilet. The vestibule was situated at the side of the house and deviated from the square floor plan. Typically, external walls were built of slag-concrete blocks without thermal insulation, only with internal and external plaster. The roof of the house was built as a wooden hip or half-hip truss. The roof was built also without thermal insulation. The construction of the floor was in most cases built as a wooden beamed ceiling. The filling between the beams was made of the slag, concrete was mixed with straw or clay. These material design does not meet the current thermal-technical requirements of buildings, which are described in Chapter 2.

2 The thermal-technical evaluation of external structures

In Slovakia Amendment 1 of the thermal engineering standard STN 73 0540-2/Z1+Z2: 2019 Thermal protection of buildings, thermal performance of buildings structures and buildings Part 2 – Functional requirements has been in force since August 2016, which considers the objective of the European directive, which provides these values for the construction of nearly zero energy buildings from 2021. Thermal resistance is a quantity that has characterized the required thermal protection of building structures of walls, roofs, and floors for a relatively long time. In the recent past, the heat transfer coefficient has become the main indicator for external structures. However, the thermal resistance is such a common quantity that is still used. This value is considered in our and foreign technical regulations as a criterion for evaluating the thermal insulation properties of the structures. The quantitative value of this quantity is prescribed in the standard STN 73 0540-2/Z1 of thermal resistance with the symbol R_N or $R_{min.}$ New and significantly renovated buildings must meet the standardized values of normalized thermal resistance (R_N). If renovation is not functionally, technically, and economically feasible, all building structures must meet at least the minimum requirements for energy-efficient buildings, i.e., the value of R_{min}. For new buildings built after 2016, the recommended values of R_{r1} (for ultra-low energy buildings) apply as required values. After 2020, the target recommended values of R_{r2} (for nearly zero energy buildings) will apply as required values.

Tab. 1 *Overview of thermal resistance values [2]*

Structure	Thermal resistance of structure (m^2.K)/W			
	Minimum thermal resistance R_{min}	Normalized thermal resistance R_N	Recommended thermal resistance R_{r1}	Target recommended thermal resistance R_{r2}
Exterior wall and pitched roof above the living space with slope more than 45°	2.0	3.0	4.4	6.5
Flat and pitched roof with slope less than 45°	3.2	4.9	6.5	9.9
Ceiling above exterior	3.1	4.8	6.5	9.8
A wall or ceiling between indoor spaces with different indoor air temperature	2.7	3.9	4.9	6.5

3 The energy performance of buildings

With the year 2021, a revised directive came into force in Slovakia. The revised Energy Performance of Buildings Directive 2010/31/EU was approved by the Parliament and the council in the end of 2009 and contains number of changes. The most important change is that from the 1st of January 2021, all new buildings in the EU building must be constructed as "nearly zero energy buildings" [1].

Ther are many definitions of nearly zero energy buildings. By European Commission, nearly zero energy buildings have very high energy performance. The low amount of energy that these buildings require comes mostly from renewable sources. Another explanation by Kurnitski et al. is that nearly zero energy building (nZEB) is typically a grid connected building with very high energy performance. nZEB balances its primary energy used so that the primary energy feed-in to the grid or other energy network equals to the primary energy delivered to nZEB from energy networks. An annual balance of 0 kWh/(m^2.a) primary energy use typically leads to the situation, where a significant amount of the on-site energy generation will be exchanged with the grid [4]. The concept of nearly zero energy buildings is describes in the article by Delia D´Agostino and Livio Mazzarella and is showed in Fig. 2 [10].

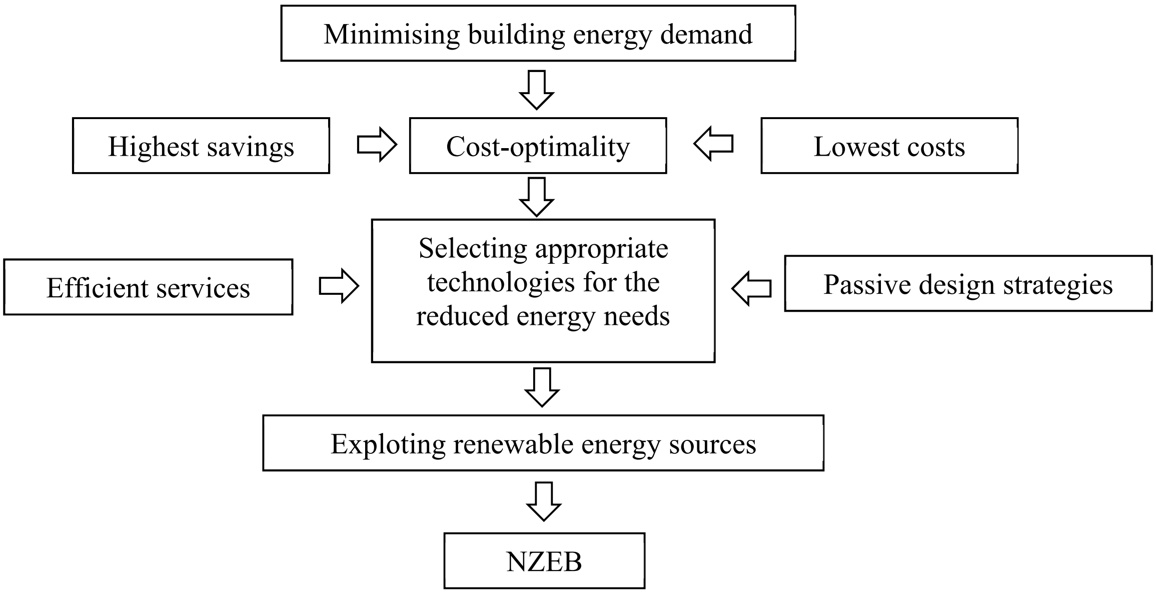


Fig. 2 *The concept of nearly zero energy buildings [10]*

The building can be qualified as a nearly zero energy building when the building has a very low energy consumption for heating. This should be achieved by very high level of thermal insulation and excellent air tightness to decrease heat losses. To evaluate the complete heating system, and not only the level of thermal insulation of buildings envelope, heat losses and auxiliary energy for the technical system need to be added to the energy need for heating. The resulting energy performance indicator is called the energy use. By the Regulation 364/2012 Z. z., the heating system can be classified in one of the energy classes A to G. The same classification system applies for the energy use for domestic hot water [4]. Buildings are classified by the total energy use for a building, which presents the sum of all energy uses for the technical systems. The criteria on the specific total energy use for different types of buildings as defined also in the Regulation 364/2012 Z. z.

Energy needed for heating, cooling, ventilation, domestic hot water, lighting, and other appliances is a necessary input to calculate the primary energy, which is the global indicator and presents the energy that has not been subject to any conversion or transformation process. The primary energy is calculated using primary energy factors, which are given at national level and vary for different energy carriers [4]. The energy classes by the primary energy are showed in Table 2.

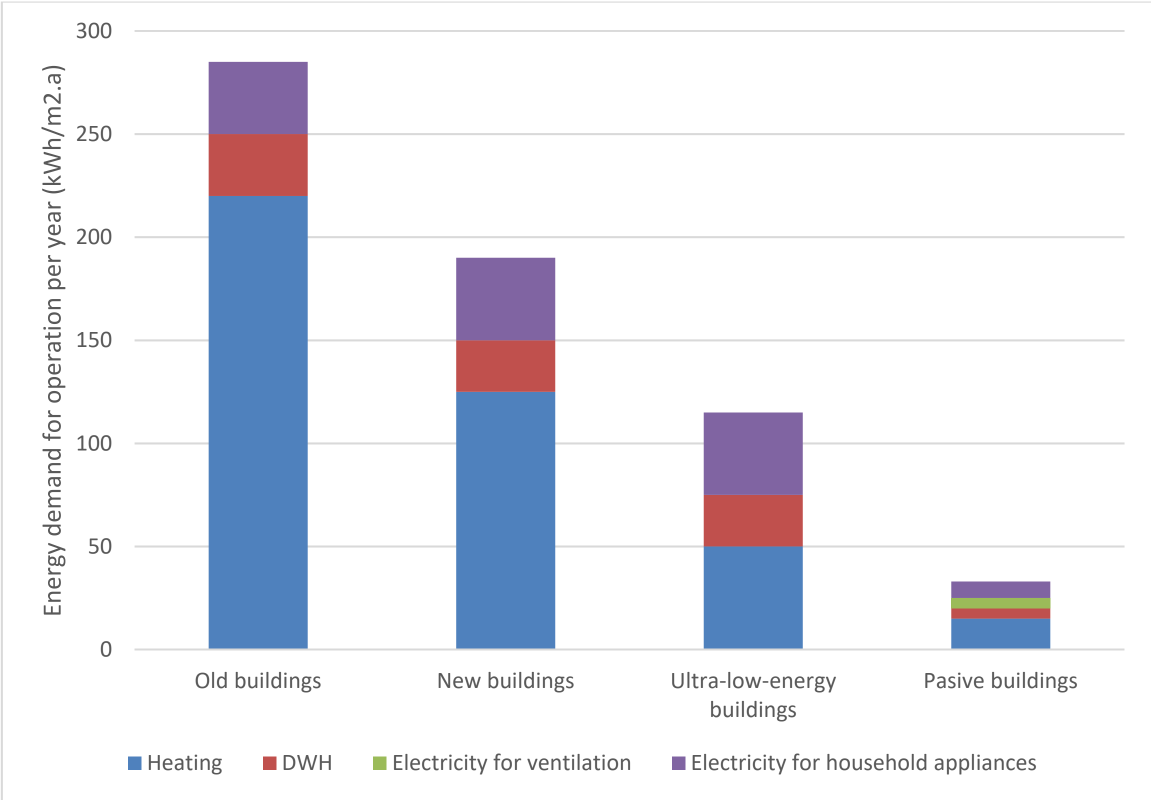


Fig. 3 *Energy demand for operation per year [11]*

The development of reducing the energy efficiency of buildings began at the level of low- energy buildings. Later, energy efficiency was further reduced, resulting in ultra-low-energy and nearly zero energy buildings. At present, there is also talk of passive or zero buildings, which are not defined in Slovak legislation. Figure 3 shows the development of reducing the energy efficiency of individual types of buildings.

Tab. 2 *Energy classes by the primary energy [2]*

	Building types	Energy performance classes							
		A0	A1	B	C	D	E	F	G
Global indicator – primary energy	Family houses	≤ 54	55-108	109-216	161-324	325-432	433-540	541-648	> 648
	Apartment buildings	≤ 32	33-63	64-126	127-189	190-252	253-315	316-378	> 378
	Office buildings	≤ 60	61-120	121-240	241-360	361-480	481-600	601-720	> 720
	Schools and educational facilities	≤ 34	35-68	69-136	137-204	205-272	273-340	341-408	> 408
	Hospitals	≤ 96	97-192	193-384	385-576	577-769	770-961	962-1153	> 1153
	Hotels and restaurants	≤ 82	83-164	165-328	329-492	493-656	657-820	821-984	> 984
	Sport halls and other sport facilities	≤ 38	39-76	77-152	153-258	259-304	305-380	381-456	> 456
	Warehouses and retail trade buildings	≤ 85	86-170	171-340	341-510	511-680	681-850	851-1020	> 1020

4 The renovation of the family house

The main proposals for this family house reconstruction will be described in this chapter number 4. In subchapter 4.4 The state of a renovated house will be described the current condition that had been applied.

4.1 The state of the house before renovation

Solved family house was built between years 1956 to 1960 in Šaľa, Slovakia. Family house is showed in Figure 2. It is a typical single-storey family house with a typical square floorplan and non-residential attic. External walls were built as a slag-concrete blocks without thermal insulation. Roof system was degraded by the time and weather effects. The supporting part of the roof are wooden rafters with battens and roofing, again without thermal insulation. Roof system was in desolated condition. Windows were also a big problem for this family house. Old wooden double windows with single glazing were used in this house. The ceilings were made of wooden beams without thermal insulation. The heat source was an old oven connected directly to the chimney for years, into which it was necessary to manually add wood or coal.

Family house was inhabited for years. This family house does not meet the energy efficiency required by the 1 January 2021. Therefore, it is necessary to renovate this family house. In Chapter 4.2 and 4.3 we will introduce two renovations of family house, which are applicable to all similar family houses [6, 7, 8].

Fig. 4 *The solved family house in Šaľa [8]*

4.2 The renovation proposal 1

The thermal-technical evaluation of this renovation proposal was made regarding values valid after the year 2016. The biggest step of this renovation proposal was replacing of all windows. In this renovation proposal were used plastic windows with triple insulating glass. The thermal insulation of the external walls was 160 mm. The old, degraded roof system was replaced by new, with thermal insulation of 320 mm. Thermal insulation with thickness of 120 mm was add also into the floor construction.

Every successful renovation proposal is not only about thermal insulation of external structures. It is necessary also design heating system and heat source replacement. In this renovation proposal number 1 was designed floor heating. As a heat source was designed gas condensing boiler in combination with storage heating system of domestic hot water preparation. In this renovation proposal was not considered the air recuperation, only natural ventilation. The investment costs of the first renovation proposal would be 50,000 € [7].

4.3 The renovation proposal 2

For the second renovation proposal, the thermal-technical evaluation was made regarding values valid after the year 2020. The strict values for nearly zero energy buildings requirements was followed in this second proposal. The thermal insulation for external walls were designed with thickness of 250 mm. Roof insulation was designed with thickness 380 mm. Thermal insulation thickness of floor was the same as in the first renovation proposal, 120 mm. The replacement of the windows were also the same-with triple insulating glass.

This second renovation proposal was more technically difficult. In this case heat pump air-air was designed as a heat source. Part of this renovation proposal was photovoltaic panels and solar collectors situated on the rooftop. Ventilation was hybrid – natural ventilation in living rooms and the air extraction from the bathrooms. The investments costs of this renovation proposal would be 100,000 € [7].

4.4 The state of the renovated house

Currently, the renovated family house was designed with the recommended values of heat transfer coefficients valid since the 1st of January 2021. The thicknesses of the thermal insulation in the second renovation proposal were not economically feasible. This is one of the reasons why the thicknesses values have been changed. This is economically favourable and at the same time make it possible to achieve nearly zero energy building. Therefore, the external walls were insulated with the thermal insulation system with thickness of 200 mm, the roof system with thickness of 380 mm and floor with thickness of 120 mm. Old wooden windows with single glazing were replaces by new plastic windows with triple insulating glass.

Due to the high investment costs for the second renovation, the investor´s request was that heat source must be condensing boiler in combination with storage heating system for domestic hot water preparation. Also, due to high investment costs, the investor was not interested in solar collectors and photovoltaics panels installation. Ventilation in this house is hybrid – natural ventilation of the living rooms and the air extraction from bathrooms. The ais recuperation units are used in living rooms. The investment costs for applied renovation proposal for the family house were 75,000 €. With this renovation we prove that it is possible to create nearly zero energy building also with the lower investment costs [7].

A significant renovation also took place in the interior of the family house. The degraded truss was removed and a new one was built. This creates a residential attic and two children´s rooms and a bathroom. In the residential attic, wooden columns have been preserved, which are part of the truss, which elegantly fits into the architecture of the house. Construction work on the project was completed in July 2019. To the family moved into the house in September 2019.

5 The energy evaluation of the designed renovation proposals

The energy efficiency evaluation focus on the comparison of the energy intensity of the family house with the different variant of the renovation proposals. Aim of this evaluation is the energy efficiency of building comparison and classification based on energy need for heating and domestic hot water preparation, total energy indicator and mainly for the global primary energy indicator.

The energy evaluation showed that the Renovation proposal 2 is the most advantageous. By this renovation should be achieved class A0 which is at the present required as a standard. It is necessary to be aware of the high investment costs, which are big disadvantage. This was the main reason, why we had to make some changes in the final state of the renovated house. As the results show, we can achieve requirements of nearly zero energy buildings also with small changes in the renovation. This can be seen in energy evaluation of the current state of the single-family house renovation.

Tab. 3 *The energy classes by the total energy use [2, 7]*

The state of family house	Energy needs for		Total Energy Indicator	Global Primary Energy Indicator	CO_2 emissions
	Heating	DHW			
	(kWh/m^2.a)	(kWh/m^2.a)	(kWh/m^2.a)	(kWh/m^2.a)	(kg/m^2.a)
Before renovation	353.0	34.0	378.0	425.7	117.92
	G	C	G	D	
Renovation 1	53.7	15.4	69,1	76.0	28.03
	B	B	B	A1	
Renovation 2	40.8	12.2	53.0	33.2	6.37
	A	A	A	A0	
Current state	40.5	11.4	51.9	29.3	18.36
	A	A	A	A0	

6 The cumulated cash flow of the renovation

The main purpose of the financial analysis is to verify the sustainability of project operation. In this analysis it is necessary to define difference between operating income and operating expenditure. This is the part revenue which after payment of operating expenditure, will remain available for reimbursement capital expenditures. The above difference, by which operating income exceeds operating expenditure, is called “net income”. This is compared with amount of capital expenditures. If the net income exceeds the investment expenses, the project is profitable. Next step is determination of the reference period. The reference period is the number of years for which they are reported in the cost-benefit analysis predictions. Predictions regarding the future trend of the project should be formulated for a period which is proportionate to its economically useful duration, and which is quite long to include its likely longer-term effects. Duration varies by the investments. For this project was reference period determined as 20 years. Cashflow is a simplified expression of surplus revenue over expenditure project. The calculation of cash flow is based on the calculation of estimated project revenues. Only cash flows are considered, so the current amount of cash that the project repays or accepts. So, for example, non-cash accounting items such as depreciation and provisions for unforeseen losses may not be included in the discounted cash flow analysis. Cash flows must be considered in the year in which they arose and during the reference period. If actual economically useful duration of the project exceeds the considered reference period, the residual value of the investment must also be considered. Ideally, it is calculated as the present value of expected net cash flows during the economic year durations exceeding the reference period [5].

The renovation of the family house was financed from a commercial loan provided to the investor by the bank. The amount of loan was 75,000€. The loan interest rate was 7%, the loan repayment is 25 years. Annual amount owed per year is 2,675€. The additional investment each year represents the cost of overhauling the heat source which is condensing gas boiler. The calculation of the cumulated cash flow showed that the renovation of the family house will have a return after 14 years. Cumulated cash flow of solved family house can be seen in Figure 5 [8].

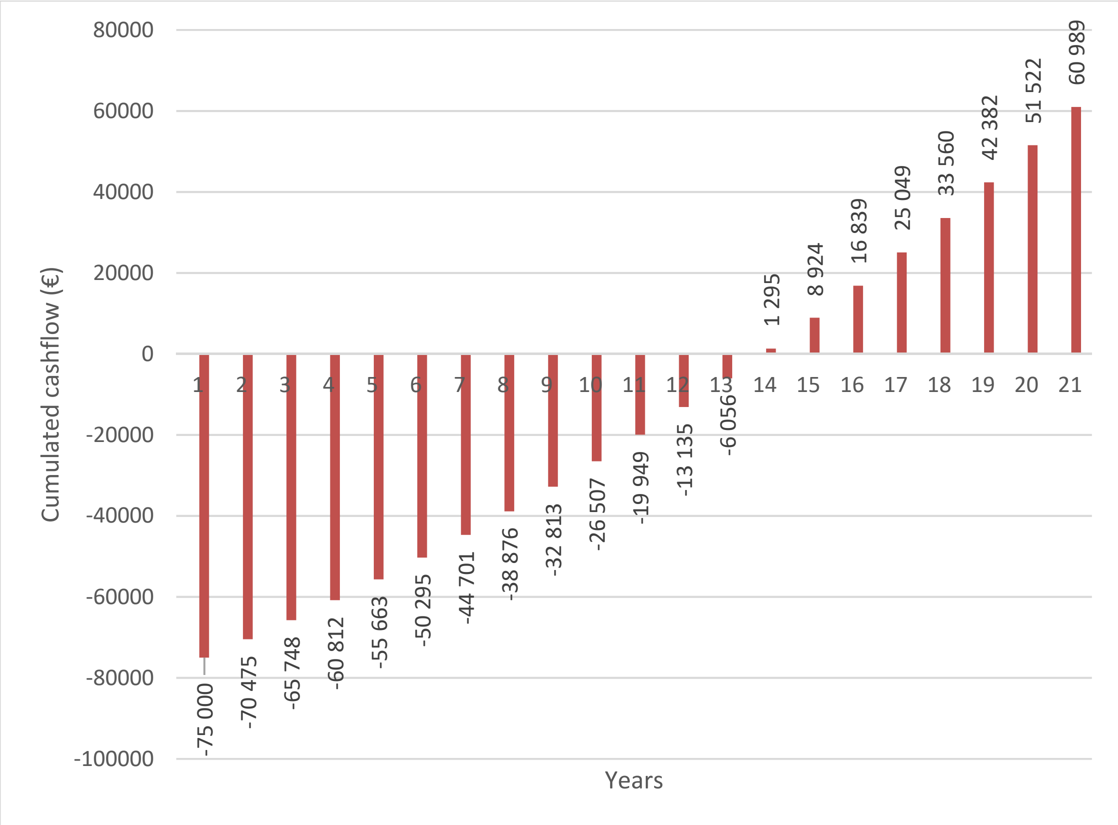


Fig. 5 *The cumulated cash flow [Author]*

7 Conclusions

With the several recovery proposals for a family house, we can assess multiple reconstruction options that can extend the lifetime of the old family house for further generations. This proposal process is based on the assessment of the current state of the object, after the proposal and subsequently the assessment. In this case, we also supervised the amount of the investment costs and adapted the proposal to meet the requirements which is not economically expensive. This proposal will contribute to total energy savings and overall operating costs shall be reduced. This renovation has shown that although the family houses do not meet today's standards, but with the correct design, we can renovate houses to meet the required standard values. These aspects can be achieved by using modern thermal protection and the correct application of the indoor building environment technology. Example renovations are applicable to all family houses, built between 1950s and 1970s.

In the following years, the measurements of key parameters for the assessment of the indoor climate will be carried out in cooperation with the Department of Building Services at the Slovak University of Technology in Bratislava, to verify the effectiveness of the reconstruction of the family house. The current pandemic situation has not allowed us to make measurements in these days.

Acknowledgement

This work was supported by the Ministry of Education, Science, Research and Sports of the Slovak Republic through grants VEGA 1/0303/21, VEGA 1/0304/2021 and KEGA no. 005STU-4/2021 and Velux Slovakia.

References

[1] *Directive 2010/31/EU of the European Parliament and of the council of 19 May 2010 on the energy performance of buildings*, 2010, Slovakia

[2] *Regulation 364/2012 Ministry of Transport, Construction and Regional Development of the Slovak Republic, implementing Act. No. 555/2005 Coll. on the energy performance of buildings and on the amendment of certain laws,* 2012, Slovakia

[3] *STN 73 0450-2/Z1+Z2 Thermal protection of buildings. Thermal performance of building structures and buildings. Part 2 – Functional requirements,* 2019, Slovakia

[4] KRAJČÍK, M. *Energy Balance and Indoor Environment of Building with Low-Exergy Heating and Cooling Systems,* Habilitation thesis, 164 p., Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Department of Building Services, 2015, Slovakia, ISBN 978-80-227-4611-4

[5] KRAJČÍK, M., PETRÁŠ, D., SKALÍKOVÁ, I. *Energetické hodnotenie budov,* Second addition of materials for assignments, STU in Bratislava, 220 pp., ISBN 978-80-227-4903-9

[6] FÖLDVÁRY, V., BEKÖ G., PETRÁŠ D. *Seasonal variation in indoor environmental quality in non-renovated and renovated multifamily dwellings in Slovakia,* Proceedings of Healthy Buildings Europe 2015, Eindhoven, Paper ID 242

[7] PREDAJNIANSKA, A., SÁNKA, I., PETRÁŠ, D. *Environmental technology for buildings with almost zero energy demand – Velux RenoActive*, In Proceedings of 29. international scientific-professional conference on the topic – Alternative energy sources for bbuildings with almost zero energy demand Vykurovanie 202, Horný Smokovec, High Tatras, Slovakia, pp. 423-426, ISBN 978-80-89878-72-7

[8] SÁNKA, I. *Indoor Air Quality in Neartly Zero Energy Buildings*, Dissertation thesis, Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Department of Building Services, 2021, Slovakia

[9] *Online source: https://kislabnyom.hu/hir/valtozatok-%E2%80%9Ekadar-kocka%E2%80%9D-korszerusitesere*

[10] D´AGOSTINO, D., MAZZARELLA, L. *What is a Nearly zero energy building? Overview, implementation and comparison of definitions,* Journal of Building Engineering, Elsevier, October 2018, ISSN 2352-7102

[11] Institute for passive buildings Slovakia, Bratislava, online source: https://iepd.sk/

A Private Space in a Public – Challenges and Opportunities of Balcony Addition in Retrofitting

Marta SMEKTAŁA [a]

[a] *Doctoral School of Wrocław University of Science and Technology, Faculty of Architecture. Wybrzeże Wyspiańskiego 27, Wrocław, Poland, marta.smektala@pwr.edu.pl*

Abstract

The challenge of limiting GHG emissions with housing retrofitting, in addition to improving building performance, should prompt the discussion about living environment enhancement. The experience of social isolation from the pandemic has shown the importance of access to private outdoor spaces such as balconies, which many tenement houses are deprived of. The role of balconies in retrofitting by their impact on indoor climate has been studied thoroughly, while research on the design of outdoor spaces, influencing the quality of living is forsaken. The study consists of a series of interviews with inhabitants and actors responsible for shaping estates, demonstrating their perspective about the usability and conflicting position of balconies - situated in a public zone but remaining a private space with the on-site observation of activities and furnishings placed on balconies. The analysis aims to extend the discussion about sustainability to social aspects' role in retrofitting [1] and indicate the design challenges related to the outdoor space "in-between".

Keywords: *Balconies, Social Sustainability, Retrofit*

1 Introduction

Buildings account for 40% of worldwide energy consumption. To meet the EU requirements of climate neutrality, the current pace of existing estates' modernization process should rise from 1% to 3%. per year [2]. Faced with the potential intensification of building renovation, the current discussion of this challenge should not be limited only to the energy efficiency, but be extended to reflection on the general quality of living space. The current development intensification and provision of apartments with a decreasing average floor area every year [3] lead to the apartments' quality deterioration. This process also contributes to the uncontrolled cities' development and the families' migration looking for better living conditions outside on the outskirts or rural areas [4]. In existing urban development, there are still many apartments deprived of any access to private outdoor spaces (POS). Equipping apartments with spacious balconies could reverse this trend of urban sprawl.

Anterior to social housing projects, balconies were mostly perceived as a viewing platform for an upper-class society. Its hygienic properties of providing access to fresh air have led to their introduction into multi-family residential projects [5]. Research on psychological and environmental factors influencing the quality of housing estates reveals that POS additionally fulfils the human need for diversity of experiences and functions in the living space [6]. A well-designed balcony can substitute the house garden [7, 8] and significantly affects mental and physical health of residents [9], which could be experienced especially during the pandemic [10, 11]. In some cultural contexts, the balconies have become newly-made public spaces that gather people in proximity, thus reduce the feeling of self-isolation [12]. For these reasons, houses and cities should be provided with a healthy living environment in the case of future pandemic consequences [13].

The specific position of balconies, although private, but visible from the public spaces, in some contexts appears as a continuation of the public realm, which gathers strangers living nearby to experience some common events, observed from their POS [14, 15], or as an inside-outside space with perspective dominating over the street and passers-by [16], sometimes even contributing to the vibrant image of the streets [17] or as a place of stimulation of the neighbours relationship [18]. Since they are visible from the public, in some cases they trigger a social pressure to fit an unspoken set of housing rules contributing to a pleasant image of the neighbourhood. Thus, in this case, the balconies play more an aesthetical role, of the visible by neighbours living room and some limits on freedom of use [19]. In other cultural contexts, the residents have more functional expectations about their outdoors spaces which are used for: ventilation, hanging clothes, planting flowers, kitchen's extension for cooking, drying food, cooking, keeping kitchen appliances in the fresh air, children's playing [20].

The capacity of balconies to improve the indoor thermal environment has been thoroughly studied [21]. The recently implemented built-in balconies in the thermal modernization, improve the housing's energy efficiency and spatial quality. Properly designed balcony extension, enlarging floor area and improving daylighting, may literally transform small social flats into luxurious apartments [22, 23]. However, in some cases, balconies transformed into conservatories lose their functionality due to the uncomfortable indoor climate during extreme weather conditions and very limited space [24].

Equipping an apartment with a balcony is not required formally, but it is caused by the client's expectations and sales results [25–27]. Therefore, it is reasonable for developers to provide private outdoor spaces, but due to the return rate of real estate investments, the design and floor area of balconies are minimal and often determined more by aesthetic values than functionality [5]. In Polish construction law, the balcony is not required in residential buildings, and its design principles are limited to safety regulations [28]. In some countries, the recommendation of minimum dimensions and area appears [29]. In Neufert's Architects' Data, several basic typologies of balconies and design principles due to the dwellers' privacy needs and the orientation of the building are presented. Although some basic functions of balconies are listed, the attached drawings are determined by the dimensions of the sunbeds and tables, thus it is treated as a space for leisure, which inherently meets the architects' expectation about resident's pattern use [30].

The above studies confirm the importance of the role of the POS in residential architecture and its challenging position "in-between". Large balconies are desirable and could enhance the living environment of tenement housing *(Fig.1)*. For these reasons, their implementation should be considered in the modernisation process of the housing tenements. Nevertheless, the approach to balcony design primarily reflects aesthetic demands rather than user expectations. The purpose of the research is to fill this demanding reflection gap and to answer questions about what elements should be considered in balcony design, in order to meet the dwellers' requirements and what features influence their functionality and user's satisfaction.

Fig. 1 *The typical inner courtyard tenements' elevations in Wrocław in Poland, where potentially balconies could be added*

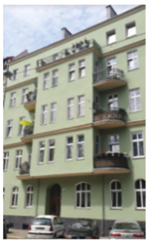
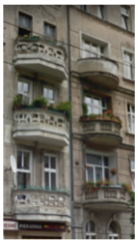
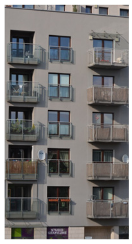
2 Research methods

The first objective of the research was to explore if the balconies' features and context influence the variety and intensity of their use. In order to evaluate balcony usage, the research was divided into 3 parts: the quantitative analysis of the record of balconies' furnishing indicating dwellers' habits of use and adaptation of their private outdoor space, the observation of inhabitants' activities performed on balconies, and the qualitative research method of the interviews conducted with persons involved in creating and using balconies.

2.1 Fieldwork research

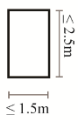
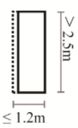
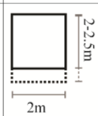
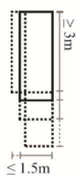
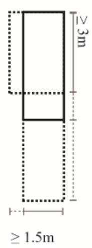
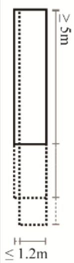
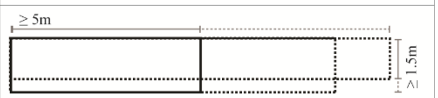
The fieldwork research sample consists of over 3000 balconies from distinct housing estates in Wrocław, in Poland. The estates selected represent all key typologies for the city: the pre-WWII housing estates and tenements (1880–1930), socialist blocks of flats (1959–1985), cooperatives from the 1990s–2000s, and recently delivered developer led investments. The spatial context of the observed balconies was captured, i.e. its orientation and exposure to noise as well as privacy level of the surrounding. Also design features such as balcony dimensions, typology (loggia, exposed or recessed balcony) and railing types: opaque balustrade, openwork, perforated, transparent and mixed were recorded [31] *(Tab.1, Tab.2, Tab.3).*

Tab. 1 *Compilation of research sample*

 1STC*	 2STN*	 3ETR*	 4ETbR*	 5EBR*	 6EBR*	 7SBR*
 8ECN*	 9ECR*	 10ECR*	 11EDR*	 12EDR*	 13EDN*	

**Coding pattern: 00ABC*
0 – The estate number
A –E-Estate , S- Buildings along the street
B: Building age (D – New built developer housing estate built after 2015, C – Cooperative housing estate built between 1990-2000, B – Post-war block of flats, T – Tenements, Tb – Pre-war block of flats).
C: Dominant exposure: Q – Quiet street, N – Noisy street, R – remaining (courtyards, open views, facing the river)

Tab. 2 *Balconies' size schedule*

Size coding	XS	S(n)	M(s)	M	L	L(n)	XL
Dimen-sions	lengths ≤ 2.5m; depth ≤ 1.5m; area <3.8m²	lengths > 2.5m; depth ≤ 1.2m area < 3.8m²	2mx2m ÷ 2mx2.5m	3.8m² ≤ ≤ area < < 6m²	depth ≥ 1.5m; 6m² ≤ ≤ area < < 11m²	depth < 1.5m; 6m² ≤ ≤ area < < 11m²	area ≥ 11 m2
Scheme	 ≤ 2.5m ≤ 1.5m	 > 2.5m ≤ 1.2m	 2-2.5m 2m	 ≥ 3m ≤ 1.5m	 ≥ 3m ≥ 1.5m	 ≥ 5m ≤ 1.2m	 ≥ 5m ≥ 1.5m

Tab. 3 Balconies' types

Exposed	Loggia	Recessed
		

2.1.1 Balconies' furnishing

All the objects visible on the balconies were listed and then grouped into main 11 categories: 1) Plants (potted flowers, pergolas, ivy etc.), 2) Furniture (chairs, tables), 3) Privacy protection (screens, mats, partitions), 4) Storage (bicycles, cabinets, wardrobes), 5) Solar gain protection (blinds, curtains, umbrellas), 6) Laundry dryers (fixed and moveable laundry racks), 7) Cleaning Equipment (buckets, brooms) 8) Adaptation to animals/pets (for pets: nets, cats towers etc., and against: i.e. spikes against pigeons), 9) Decoration (pictures, candles, decorative lamps, bells), 10) Property protection (grates, blinds), 11) Mess (garbage, cardboard boxes). The following remaining categories, were not considered in figures because of marginal number: Manifestation n=40 (advertising, flags), Children's playground n=12 (toys, sandboxes), Sports equipment n=13 (stationary bikes, pull-up bars), and Hobby n=1 (telescope).To each balcony were assigned categories according to its furnishing. Some abnormalities may occur in the statistics since materials or elements covering the balustrade and the position of the balcony preclude recording all the furnishing.[31]

2.1.2 Observation of inhabitant's activities performance on balconies

The fieldwork took place during the sunny and warm days in June and July 2021, and was set for three two-hour slots per day: 9:30–11:30 a.m., 1:00–3:00 p.m. and 5:00–7:00p.m. This research aimed to study how the usability of balconies vary during the day and if the context or physical features influence it. Each elevation of the estate was observed twice during these 2 hours, for a short time, coding all the observed activities on paper. The activities were divided into 2 types passive (without a inhabitants participation) and active: short, usually referring to household duties, and long/optional, mostly happening if the balcony's features foster staying there [31] ***(Tab.3).***

Tab. 3 Activities performed on balconies during the fieldwork.

Activity type		**Activity name**	**Recorded activities number**		
			Morning	**Afternoon**	**Evening**
Passive		Leaving open doors for ventilation	n=767	n=786	n=799
		Drying laundry	n=210	n=219	n=223
Active	**Short activities/ household duties**	Hanging the laundry	n=11	n=29	n=12
		Watering plants	n=14	n=10	n=8
		Smoking cigarettes	n=17	n=10	n=13
		Cleaning/maintenance	n=13	n=12	n=7
		Short observations/outgoing to the balcony	n=27	n=27	n=30
	Long/ optional activities	Sitting, relaxing, reading a book	n=28	n=35	n=48
		Eating/drinking	n=4	n=3	n=3
		Conversation in a group	n=12	n=8	n=18
		Conversation with a neighbour	n=1	n=4	n=2
		Children's play	n=3	n=10	n=14
		Long observations	n=20	n=22	n=20
		Sunbathing	n=0	n=3	n=2
		Homeoffice	n=2	n=1	n=3
		Repairing something	n=0	n=2	n=3
		Animals' presence	n=12	n=7	n=6
		Phone call	n=10	n=4	n=16

2.2 Interviews

First, the interviews with representatives from the sale departments of new housing estates developers (5), developers specialising in commercial tenements modernization (3) and estate agents (3) were conducted to question their approach to the POS design and the clients' interest in them. Subsequently, the perspective of architects (4) and opinion of an expert from municipality heritage conservation department (1) were investigated. The analysis of the gathered comments revealed the problem of a narrow definition of balcony use among people involved in the real estate market. Later, residents (28) with various balcony features, likewise in the furnishing observation, were questioned about their manner of using the balcony and its influence on their life. Most of the responders were recruited through posts placed on social media groups, 3 from the personal network, and 3 were met during the fieldwork. As most of interviewees volunteered through social media, there is a risk that research presents the perspective of young balcony-enthusiasts, whereas the view of balcony-sceptics, who are reluctant to take advantage of POS remains unidentified. The interviews were recorded on audio and video, transcribed and coded thematically in Atlas.ti software [31].

3 Results

3.1 Balcony furnishing and activities performance

First of all, the studies reveal that the balconies have wide range of use pattern *(Fig.2).* The observed different types of category objects prove that POS is not only dedicated to leisure activities, as it is expected by designers or sales departments. Balcony may significantly facilitate the household, work as a space for children's play, keeping animals or an occasional workshop. For these reasons, it is not always representatively looking space and the designers should take it into account. Its usability and adaptability depends primarily on its context and size. The small balconies exposed to public street (as in the case of tenements 1STC and 2STN) are significantly less equipped and active in comparison to the other estates from the sample. However, they are substantially decorated with plants, and people avoid leaving laundry drying there, what might result from internal force or external social expectation to decorate the publicly visible elevation. This pattern proves that they are less useful for residents' personal need and play more a representative role. If the spatial context is more favourable, the residents are more eager to domesticate their balconies and adapt to their needs. The activity observed per development generally increases with an increase in number of objects observed. However, in this study it is substantial to indicate the kind of activity type. Short and necessary activities can be observed at balconies of all sizes and also in noisy locations. More diverse and optional activities happen on large balconies with favourable spatial contexts, in particular with river view [31].

3.2 The interviews' results

3.2.1 The perspective of actors shaping balconies

The agents and developers confirm that considering the liquidity of the estate market, equipping apartments with balconies is mandatory, unless other qualities, such as location, increase the value of the estate, especially when the property is a rental investment. For this reason, the developers renovating tenements, localized in the city centre, whose clients are interested in capital investment, do not recognize the benefit of adding balconies to apartments. Furthermore, they claim that it could raise the risk of construction time extensions thus, the costs increase. Although a balcony is a desired piece of dwelling equipment, it is treated more as an extra addition than an integral part of the apartment, equally important as floor plan arrangement. An average client does not have high expectations about the balcony and accepts the market's standard. Accordingly, the balcony design is often limited to meeting the basic needs, safety requirements, and materials selection influencing the façade appearance. Even if

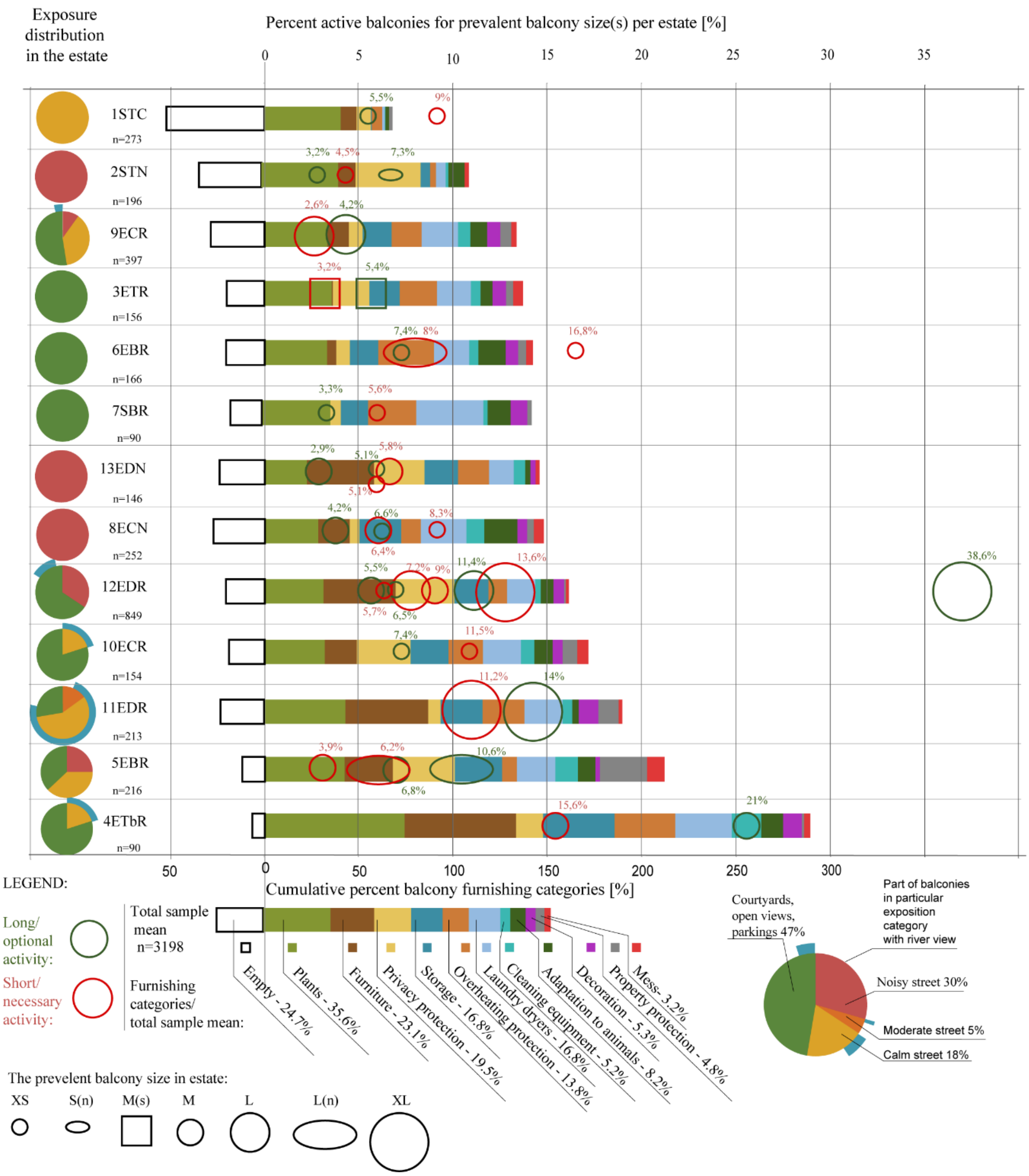


Fig. 2 *Balcony furnishing and activity per estate*

architects or developers aspire to design spacious and attractive balconies, their ambition is limited by investment expenses and return. The standard balcony amounts 3,5–5 m^2, with depth 1,2–1,5m, enough to fit the basic furniture set with small table and chairs, usually placed next to the living room, with preference to the south or west elevation. The sale rate is a design indicator. Therefore, due to the high demand of the estate market, the quality of the balcony is not a subject of evaluation unless a technical malfunction appears. Attractively designed, spacious balconies are in scarce in supply and only dedicated to prosperous clients, because of high expenses. The balcony floor space tends to be proportional to the apartment area thus, small flats usually have very basic balconies. Both architects and developers identify themselves with the investment and expect from residents to use the balcony as a pleasantly arranged space for leisure, contributing to the presumed attractive image of the neighbourhood [31]. The expert from the municipal heritage conservation department claims that adding balconies to the tenements' inner courtyard elevations is crucial to facilitate the apartments and prolong the use of these buildings, but the size of the balconies should be limited and proportionally match the façade.

3.2.2 The perspective of balconies' users.

It was a difficult choice: a house with a garden or an apartment… But I like city life, so for now we have chosen the city, so a balcony was a must. (...) I love sitting here. I wish I could do more here, but I miss a bit of space, but we manage anyway. (…) It would be nice if it was bigger, but we have seen so many apartments (…). But to be honest, if it was at least two meters deep, it would be great *(F30-40TEQ*.)*

Here, at (…) larger balconies or terraces, many things happen. People sunbathe there and you can see that they are much more decorated. You can often see that the neighbours spend time there, (…) it functions like a second living room. *(F25-35TER*)*

Spatiality is the main feature that affects the balcony user's evaluation. ***Enlargement*** is the most common response from respondents to the question of their wish for the features they could change on their balconies. If they decide to live in a city looking for an apartment with a balcony is a criterion to comply with, but they refuse special demand about it and accept current low market standard. At the same time, large balconies have an impact on apartment evaluation and its liquidity on the market. One of the interviewers admits that she ***decided to choose an apartment with a large balcony, at the cost of an interior floor area*** *(F25-35DER*)*. The housing estates sale departments asked about the balcony size usually describe its total area without pointing dimensions (width and depth), whereas the proportions influence on its functionality. Some activities that people would like to perform outdoors, such as a family meeting and having a dinner at the dining table, are hindered due to the narrow size of the balcony. Some respondents with narrow balconies point their preference ***to more square proportions*** *(M25-35BLR*)*. Although designers claim that 3,5-5m2 is sufficient to place basic furniture set on a balcony, respondents admit that it is not sufficient if they need to do several things simultaneously. On the other hand, the owners of long balconies appreciate the possibility of ***separating functional zones for relaxation, children play, gardening*** and find it ***as an external corridor*** *(FandM30-40DER*)* facilitating and making apartment more flexible [31].

During the observation of the research sample, it was noticed that some residents decide to build on a balcony and transform it to the indoor space. This intervention only apparently appears to improve the apartment by adding extra floor space. Most of the respondents negatively assessed the idea of changing balconies into conservatories. They expressed a fear of losing the space of another experience with the feeling of outdoor air and contact with the surrounding. One of the interviewers has describe it as follows: ***Absolutely not. To me, it would lose the properties of a balcony. Some people make it, (…) it is quite common pattern, especially in loggias (...). No, unless I need more indoor space (…) for me the balcony must be outside. There must be access to fresh air, sounds from the surrounding and everything that is outside. Otherwise, I would feel isolated.*** *(F30-40TER*)*

Residents expect to feel at home on their balconies. If a balcony is supposed to be functional, they prefer to treat it as an integrated extension of the apartment, where they can observe the environment, but without being exposed to the public:

(…) Being on the balcony, I would like to be shielded from any neighbours as much as possible. So we could not see each other. A balcony is my personal link with the outdoors and only to the outdoors, not with any people. (…) I could not use a balcony exposed directly onto another balcony. Then, such a balcony would lose meaning to me. (...) [I prefer a balcony] with a view to the water, in Wrocław – the riverside, some green areas, some trees *(M25-35BLR*)*.

For this reason, exposed balconies with views to public street are significantly less used than loggias facing the courtyard with greenery or open view to the river. Residents from developer estates point to feeling uncomfortable during their stay on balconies due to their exposed form and the close distance to the neighbours' possession. One of the interviewed developer's estate residents describes it as: ***I feel space-invaded, as if I was on display (...) well, here the windows have a view direct to other windows (…). I thought about installing panels such as the bamboo ones, but on the other hand... Firstly, cats would not have a view. Secondly, there is a risk that there will be less daylight*** *(F25-35DER*).* In contrast, residents who decided to live in tenement quarters argue their decision with a negative impression about balconies and their spatial context in compact developer estates: ***I think this [historical] estate is well designed, because there are no balconies in front of each other, as in the developer estates. (…) It was designed with a thought that most apartments have balconies, but on alternate sides, so everyone has privacy*** *(M30-40TLR*).* Actually, in a significant majority of balconies in tenements are small and face the street. Users of such balconies express the discomfort of limited use: ***I don't leave the laundry there to dry, because I don't want it to get dusty. Dust gathers there terribly*** *(F30-40TEQ*),* and social pressure to treat it representatively: ***I have never thought of drying my laundry there. I'd rather put up a laundry rack inside, leaving the balcony door open. (...), but it may be due to self-limitations that I know that it is not big enough. (...) The flowers should be there for sure, as they are. Few things fit there, just one chair, too little to socialize. (…) So, it has only decorative features. But I cannot imagine that there would be no flowers there, it's kind of standard.*** *(F50-60TQ*)* [31].

The sense of intimacy improves the surrounded greenery. Many residents use potted plants or let the ***ivy grow, to separate themselves from the neighbours*** *(F25-35DER*, and F35-45DER*).* Interviewers often acknowledge the presence of wide tree crowns covering their private space: ***Well, the close distance to these blocks is a problem, right? So it is not that nice in general, but thanks to these trees…, they cover them in the summer, when there are leaves, there is no problem*** *(F40-50DLR*).* Additionally, users indicate that old trees, especially from tenements have an impact on indoor climate during scorching days: ***This tree limits heating, which is a plus*** *(F25-35TLR*)* [31].

**Interviewers coding pattern: A00-00BCD*
***A**: Gender (**F** – female, **M** – male). **00-00** – Age. **B**: Building age (**D** – New built developer housing estate built after 2015, **C** – Cooperative housing estate built between 1990-2000, **B** – Post-war block of flats, **T** – Tenements, **Tb** – Pre-war block of flats).**C**: Balcony type (**L** – Loggia, **E** – exposed balcony, **R** – recessed) **D**: Exposure: **Q** – Quiet street, **N** – Noisy street, **R** – remaining (courtyards, open views, facing the river).*

4 Conclusions

The purpose of the research was to recognize the variety of balcony use pattern and features that influence its usage. The spatial context, dimensions, and isolation from public or neighbour interactions impact on its functionality. The recognised features should be implemented in the balcony design process. It should be acknowledged that balconies, in addition to being a leisure space, function as a facility for household duties. For this reason, their design should not only be dominated by aesthetic demands but is expected to allow adjustment to the personal user's needs regarding the right to individual space domestication, its functionality and the sense of intimacy. Physical features such as minimum size, screens, balustrades, and position in relation to the environment should be considered and defined in design guidance. Due to the user's need to experience the properties of outdoor space, the built-in balconies are recommendable only if during the warm seasons the components are demountable or openable enough to give the quality of an outdoor space.

The research proves that equipping the apartment with a balcony significantly enhances the living standard. Even respondents who admit to not spending much time on the balcony due to being visible on the public, appreciate having it for apartment ventilation, household duties, or keeping animals. Developers and designers have limited understanding of the residents' needs about balconies. Since possessing large balconies with proper context facilitates essentially living environment, adding balconies to tenement apartments could prolong the usability of the tenements and stimulate their liquidity on estate market among the individual clients. Furthermore, especially in the case of families with children and pets, the balcony extension could reverse the trend of young families' migration to the outskirts. Especially, in the case of Wrocław, where the courtyards are spacious, the POS could benefit from the old-growth trees. For these reasons, balconies should be implemented in modernization process of the tenement housing.

References

[1] GRUIS, V, H VISSCHER a R KLEINHANS. Sustainable neighbourhood transformation. In: . 2006.

[2] ECONOMIDOU, Marina, Bogdan ATANASIU, Dan STANIASZEK, Joana MAIO, Ingeborg NOLTE, Oliver RAPF, Jens LAUSTSEN, Paul RUYSSEVELT, David STRONG a Silvia ZINETTI. *Europe's buildings under the microscope. A country-by-country review of the energy performance of buildings*. 2011. ISBN 9789491143014.

[3] GUS. Efekty działalności budowlanej w 2020 roku. 2021.

[4] KERR, Sophie-May, Natascha KLOCKER a Chris GIBSON. From backyards to balconies: cultural norms and parents' experiences of home in higher-density housing. *Housing Studies* [online]. 2020, **36**, 1–23. Available at: doi:10.1080/02673037.2019.1709625

[5] KOOLHAAS, Rem, James WESTCOTT, Stephan PETERMANN, Ben DAVIS, Tom AVERMAETE, Rebecca BEGO, Anna SHEFELBINE a International Architectural EXHIBITION. *Elements of architecture*. 2018. ISBN 3836556146 9783836556149.

[6] PETERS, Terri. Social Sustainability in Context: rediscovering Ingrid Gehl's Bo-Miljø. *ARQ* [online]. 2016, **20**, 371–380. Available at: doi:10.1017/S1359135516000488

[7] LEVITT, David a Jo MCCAFFERTY. *The housing design handbook : a guide to good practice* [online]. 2019. ISBN 9781351338103 1351338102 9780203704516 0203704517 9781351338110 1351338110. Available at: http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=1909690

[8] GRAY, K. J. R. Are outdoor spaces important? An investigation into the provision of outdoor space for medium density housing developments. B.m., 2014. University of Otago.

[9] WHO. *WHO Housing and Health Guidelines*. 2018. ISBN 978-92-4-155037-6.

[10] *The State of Housing in Europe 2021* [online]. 2021. Available at: https://www.stateofhousing.eu/The_State_of_Housing_in_the_EU_2021.pdf

[11] AYDIN, Dicle a Gevher SAYAR. Questioning the use of the balcony in apartments during the COVID-19 pandemic process. *Archnet-IJAR: International Journal of Architectural Research* [online]. 2020, **ahead-of-p**. Available at: doi:10.1108/ARCH-09-2020-0202

[12] GRIGORIADOU, Efthalia. The urban balcony as the new public space for well-being in times of social distancing. *Cities & Health* [online]. 2020, 1–4. Available at: doi:10.1080/23748834.2020.1795405

[13] POUSO, Sarai, Ángel BORJA, Lora E FLEMING, Erik GÓMEZ-BAGGETHUN, Mathew P WHITE a María C UYARRA. Contact with blue-green spaces during the COVID-19 pandemic lockdown beneficial for mental health. *Science of The Total Environment* [online]. 2021, **756**, 143984. ISSN 0048-9697. Available at: doi:https://doi.org/10.1016/j.scitotenv.2020.143984

[14] ZACKA, Bernardo. What's in a Balcony? The In-Between as Public Good. In: . 2020.

[15] ARENDT, Hannah. *The Human Condition*. Chicago: The University of Chicago Press, 1958.

[16] LEFEBVRE, Henri. *Rhythmanalysis: Space, Time and Everyday Life* [online]. 1. vyd. London: Continuum, 2004. ISBN 978-1-4725-4738-5. Available at: doi:10.5040/9781472547385

[17] JACOBS, Jane. *The Death and Life of Great American Cities*. New York: Vintage Books, 1961.

[18] GEHL, Jan. *Life between buildings: using public space*. B.m.: The Danish Architectural Press, 2001.

[19] STENDER, Marie a Marie BLOMGREN JEPSEN. An outdoor living room: Balconies and blurring boundaries. In: *Architectural Anthropology*. 2021.

[20] KARIMI, Reyhaneh, Behnaz AVAZPOUR a Samad SEPASGOZAR. Effective Factors on Desirability of Private Open Spaces: A Case Study of Kuye Nasr Residential Buildings, Tehran. In: [online]. 2020. ISBN 978-1-83880-199-1. Available at: doi:10.5772/intechopen.89335

[21] RIBEIRO, Catarina, Nuno M M RAMOS a Inês FLORES-COLEN. A Review of Balcony Impacts on the Indoor Environmental Quality of Dwellings. *Sustainability* [online]. 2020, **12**(16). ISSN 2071-1050. Available at: doi:10.3390/su12166453

[22] ALONSO, Rafael, Olivier DAMBRON a Florencia COLLO. Improving climate and well-being via winter gardens in Naboni, E & Havinga, L. C. (2019) Regenerative Design in Digital Practice: A Handbook for the Built Environment. Bolzano, IT: Eurac. 2019.

[23] KONSTANTINOU, Thaleia. A Facade Refurbishment Toolbox Supporting Energy Upgrade of Residential Building Skin. In: [online]. 2015. Available at: doi:10.3217/978-3-85125-397-9

[24] CAMPONOVO, Reto, Jean Yves MAGNIN a Peter GALLINELLI. Thermal rehabilitation: Assignment of balconies into conservatories; the „Libellules" case study. In: *PLEA 2006 – 23rd International Conference on Passive and Low Energy Architecture, Conference Proceedings*. 2006, p. 6–8.

[25] FINLAY, S, I\ PEREIRA, E FRYER-SMITH, A CHARLTON a R ROBERTS-HUGHES. The way we live now: what people need and expect from their homes. Research report for the Royal Institute of British Architects, Home wise [online]. 2012. Available at: doi:10.1086/712234

[26] *7 ud af 10 vil betale mere for en lejlighed, hvis den har altan* [online]. [vid. 2021-09-20]. Available at: https://www.boligsiden.dk/nyheder/2019/02/7-ud-af-10-vil-betale-mere-for-en-lejlighed-hvis-den-har-altan/?fbclid=IwAR0LgRzxHEH3NoVvfxkCXv-ILh1oBEgB7kVDGeaiBpvDHH-q0gAf_cetU7s

[27] KUOPPA, Jenni, Niina NIEMINEN, Sampo RUOPPILA a Markus LAINE. Elements of desirability: exploring meaningful dwelling features from resident's perspective. *Housing Studies* [online]. 2020, **35**(10), 1661–1683. Available at: doi:10.1080/02673037.2019.1680812

[28] Polish Minister of Infrastructure and Economic Development. Regulation of the Polish Minister of the Infrastructure and Economic Development of 8 April 2019 on the Technical Conditions, Which Are to Be Met by Buildings and Their Location J. Laws 2019, no.

[29] *London Housing Design Guide*. B.m.: London Development Agency, 2010.

[30] NEUFERT, Peter, Bousmaha BAICHE a Nicholas WALLIMAN. *Architects' Data*. 2002. ISBN 0632057718.

[31] SMEKTAŁA, Marta a Magdalena BABORSKA-NAROŻNY. The use of apartment balconies: context, design and social norms. *Buildings and Cities*. 2022. Available at:
doi: https://doi.org/10.5334/bc.193

Why Is Timber Not Widely Implemented in Large Volume Constructions?

Aída SANTANA-SOSA[a,b,*]

[a] *Vienna University of Technology (TU Wien)/Institute of Architectural Sciences, Structural Design and Timber Engineering, Karlsplatz 13, 1040 Vienna, Austria, e11734193@student.tuwien.ac.at*
[b] *University of Applied Sciences Campus Wien (FH Campus Wien)/Competence Center for Building and Design, Favoritenstraße 226, 1100 Vienna, Austria, , aida.santana_sosa@fh-campuswien.ac.at*

Abstract

Timber is proposed as a suitable material to reformulate construction since its production is less carbon intensive, it is renewable and stores carbon for the long term. Modern timber constructions are industrially manufactured, subdivided into similar elements being produced in a factory and bringing several positive aspects like higher productivity, speed of execution, fewer errors, higher quality and reliable cost and time plans. However, it needs a specific systematised and integral planning to achieve optimized results. Following this discourse, a Lean approach is proposed from design along production to execution with the purpose to explore the barriers and opportunities of timber towards industrialization and its application as main material within mid-rise buildigns. A qualitative comparative analysis is proposed based on extended literature review, case studies, experts' interviews and interdisciplinary workshops regarding to the overall process, and the design and production assessment of multi-storey timber buildings.

***Keywords**:* *Multi-storey timber buildings, design and construction process, prefabrication, system-based design, design assessment, production assessment.*

1 Introduction

Construction industry is the largest producer of CO_2 emissions worldwide, ahead of transport and food industry [1]. One of the largest responsible is cement production. Therefore, the promotion of timber in construction has been seen as an important strategy for achieving the climate goals set by 2015 in Paris [2], since its production is less carbon intensive, it is renewable and stores carbon for the long term. Thanks to changes made in Austrian building regulations, the use of timber in multi-storey buildings has been unlocked where new elements, components and systems of construction are being tested and developed, living a renaissance. Besides, industrialized manufacturing methods have pushed mid-rise timber buildings forwards. Although there exists a remarkable enthusiasm about the wide use of this material due to its inherent positive properties and performance capabilities, the rate of mid-rise buildings in Austria and Germany, where timber works as main structural material is still around 1,5%, where in Switzerland is around 10% [3]. That means there is great potential to extend its use. Planning and building with timber requires particular expertise, therefore, a large concern about its use is regularly found within the industry, and the predisposition to work with timber is remarkably lower than with another conventional materials like concrete or brick. Furthermore, planning and building modern timber constructions implies different approaches as in traditional mineral buildings due to prefabrication, and there is yet no common understanding about interdependences between disciplines and trades, leading to an inefficient collaboration, that causes large conflicts throughout the process [4].

The later those conflicts are faced, the higher is the impact in costs, affecting also the team in terms of tension, stress and dissatisfaction. Nevertheless, the rate of mid-rise timber buildings is expected to considerably arise in the upcoming years. Aiming to support this enhancement and since there exists a lack of specific literature about design and construction processes in mid-rise timber buildings, this study deals with the constraints and challenges related to the design assessment and product development of mid-rise timber construction. Following the Lean Management philosophy, the focus of this study relies on making problems visible in order to solve them, increasing throughout the production flow capacity performing just value-adding activities.

2 Scope of the work

The scope of this approach is to analyse and describe the current design and construction processes of multi-storey timber buildings in Austria, in order to identify their specific requirements, enablers and barriers, and the most common paths of wasteful practices. Based on this, potential improvements will be uncovered and some strategies from a Lean Thinking perspective will be proposed. The aim of this project is to bring agility within the design and construction process by assessing building elements, components, systems and methods to meet design requirements and avoid re-design work or negative iterations in further stages. In other words, the aim is to develop a model for an automated set-based design with the purpose to minimize deviations and stabilize processes performing just value-adding actions improving the end product.

3 Research method and work structure

The research method used within this study is the "Design Science Research" (DSR), since it serves a bridge between research and praxis. DSR or "constructive research" occupies a middle ground between descriptive theory and actual application, since it deals with an existing problem and aims to create a solution, while delivering a scientific contribution. The study is focused on the goal of identifying the challenges of implementing timber as main material within multi-storey buildings. The specific research method used within this approach consists of three main phases that are represented in Fig. 1. They structure the whole approach of the thesis and of this paper, where phase 1 is described in chapter 4 "process analysis", phase 2 in chapter 5 "design assessment" and phase 3 in chapter 6 "production assessment".

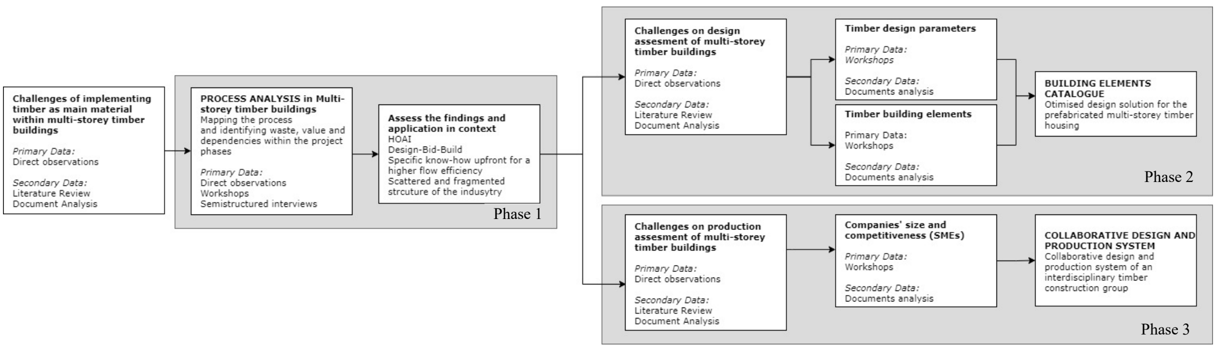


Fig. 1 *Research Method*

The first phase of the research is based on a qualitative analysis of extended literature review and semi-structured experts interviews. The focus of this phase relies on the analysis of the design, production and construction process of multi-storey timber buildings, identifying barriers and opportunities, and formulating recommendations based on those with the main objective of support a widely implementation of timber within the sector of mid-rise buildings. Interview partners were selected according to their long experience and their expertise in planning, production and erection multi-storey timber buildings. Since a holistic review was desired, different disciplines were covered from design to production and to construction. The hypothesis built within this first phase served as basis to the next two phases of the research, which are focused on the design and the production assessment of multi-storey timber buildings.

The research method of the second phase is an exhaustive analysis of different design parameters and building elements with the goal to choose the most suitable design parameters and constructive variations with the main purpose to reduce the overwhelming amount of possible available solutions on the market, when designing a large volume timber construction. By doing so, an optimized solution for the design of multi-storey timber housing is to be presented according to structural performance, fire resistance, noise and heat insulation, and ecological and economic impact. Main goal is to enhance standardization among the sector to avoid negative iterations in the design process, which means re-design work, what is not remunerate, and cost and time overruns.

The third phase consist on the production assessment of multi-storey timber buildings. Based on a series of workshops with construction companies, architects and experts, where the construction of two different buildings is to be simulated, weakness, strengths, opportunities and threats throughout the process are to be highlighted. At the same time an ideal process is cooperatively to be developed where architects and companies can work together maximizing prefabrication grade and customization.

4 Process analysis

Modern timber constructions comprehend industrialized manufacturing processes whereby timber panels and other elements are prefabricated and shipped to the construction site for assembly, delivering a building as an end product. Therefore, a constellation of three co-dependent scenarios can be recognized, namely design, production and assembly [5]. Within this study all three scenarios are analysed, where the strategy consists on collecting qualitative data from primary and secondary sources. Starting with a literature review, the theoretical framework of the study was built. The empirical approach was run in form of semi-structured expers interviews, involving 15 timber experts, including timber engineers, timber constructors, architects, project managers and construction managers. The structure and questions conforming the interview were formulated based on the results reported after a round of kick-off workshops where the focus relied on identifying the barriers and challenges to implement timber as main material within mid-rise buildings [6]. As a result of this first empirical approach, barriers were identified, key wins were explored and long term strategies were proposed.

4.1 Data gathering

Buildings are becoming more complex because of higher performance requirements. The integration of different experts is crucial to achieve the desired parameters regarding building physics, technical systems and structural performances. When combined with industrialized manufacturing methods, also production requirements and assembly considerations, including transport requirements need to be integrated. Therefore, when selecting suitable interview partners, all phases were covered to assess the big picture. Wide experience in timber construction was a requisite and it was proven by the author based on direct observations, previous meetings, attended lectures and documents analysis. Table 1 represents the background of the selected interview partners.

__Tab. 1__ Interview partners constellation

Interview partners	N°	%
Architect	6	40
Timber engineer	2	13
Timber constructor	3	20
Project Manager	2	13
Timber manufacturer	2	13
Total	15	100

The interviews were run personally with an average duration of around one hour. Since the interview partners were specialized in different areas, the interviews followed an established structure but were run open to enhance discussion. The following topics structured the interview guide:

1. Personal information: academic and professional backgrou;nd, experience, field of activity and consultation sources.
2. State of the art: market share situation, academic and empirical training, expertise, barriers and enablers.
3. Process definition: overall design process, constraints, risk areas, efficient procedures, inefficiencies.
4. Production and on-site: strengths, weaknesses and potential improvements, interfaces between design and production, prefabrication level, fragmentation of the industry.
5. Construction management: low productivity, conventional and industrialized construction management, lean management and construction.
6. BIM: Definition and experiences, state of the art within the sector, impact on overall process, readiness of the sector.
7. Conclusions: Future trends and developments, overall potential improvements, lessons to learn from other industries, general feedback or suggestions.

Before starting, interview partners were asked for permission to get the sessions recorded. After finishing, the sessions were transcribed, and iteratively coded, categorized and characterized, leading to a process mapping where barriers and opportunities were identified, and recommendations were proposed. Since those were categorised according to their corresponding project stage, the next steps of the study were focused on the stage "design" and "production", and their assessment.

5 Design assessment

Building with timber requires different design and construction approaches than with other conventional materials like concrete or brick. While within conventional buildings, the structure is firstly erected and then windows and façade are built, and modifications are allowed, within timber buildings, wall and ceiling elements are produced with windows, façade and interior panelling in the factory away from weather detriments, and on-site work is reduced to assembly work and late changes are no reasonable. By doing so, a higher production quality and accuracy of the elements and reliable cost and schedule plans are achieved, while the time spent on site is reduce to assembly tasks. By arising the prefabrication degree, all complex tasks are moved from the site to the factory increasing the mentioned benefits, and reducing the coordination of the trades on site, the material transportation to the field and the space required for construction site facilities like containers or material storage. Nevertheless, the prefabrication grade has to be suited specifically for the project depending on local conditions, switching between 2D elements, 3D modules and their combination. In order to take advantage of the benefits of prefabrication, key factors regarding production and construction must be taken into account and important decisions must be made in early stages of the project. Moreover, design must be finished by the time of prefabrication and no changes should be done afterwards. This approach requires different trades working together and making decision earlier than in conventional construction.

5.1 Problematic

Many aspects need to be jointly analysed by the election of the most suitable system to a specific project, from structural performance, to transport and production size and through building physics. In timber construction, there is a wide range of buildings systems and elements with respective properties delivering different results. A common issue in the praxis is to choose smartly between Cross Laminated Timber (CLT) and timber frame construction or so-called panels, since both are planar elements and can be implemented both within walls and ceilings. Furthermore, the great chances of their combination still need to be explored, wherein their benefits need to be exploited. Once the system is chosen, the type of structural timber still needs to be assessed, together with isolation material and panelling. This multi-layered performance of timber building elements makes the selection of the most suitable system extremely complex and represents a barrier to the widespread of the use of timber as main material within large volume buildings. Many initiatives have been run aiming to address this issue, delivering different building elements catalogues. However, they are mostly developed by companies with the legitimate goal to promote their own products. Dataholz, on the other hand, is a non-profit catalogue, where building elements are targeted according to their system, their noise and fire performance, isolation capacity and used materials. It is an extremely helpful tool for planners by filtering the huge amount of elements available on the market. However, the digital database includes more than 3.000 different building elements and their variations. Besides, some other possible solutions are missed, and there is no information regarding costs, production art and time and structural performance. The main goal of this study is to analyse different building elements to reduce the amount of option to the most suitable ones and throughout ease standardisation. By doing so, a narrowed number of building elements would be established on the market being produced by any company with no radical modifications and being able to get compared. Special solutions would still be on the market, but beyond the standards.

5.2 Methodology

An interdisciplinary complex study was run involving experts from different areas like architecture, building physics, structural design and constructive economy, with the main objective to fix some rules or parameters for the design and construction of timber residential buildings. Within the first phase design parameters were analysed taking into account architectural and technical factors, wherein a system of different but limited ground-floor-confections was developed. Within the second phase, different structural situation (Fig. 2) were analysed according to the design parameters fixed by the first phase. Slabs and walls were main elements of the study implying different span widths for the slabs, and different load situations and categories for the walls. The specific building elements to be analysed were extracted from existing and proven catalogues. In order to embrace all possibilities different sources were consulted (dataholz, Binderholz, Lignum, Egger KLH, Stora Enso). For a better assessment of the solution, insulating material, panelling and structural elements were functionally separated and cross-combined. Throughout, further dependencies between certain components were uncovered and documented.

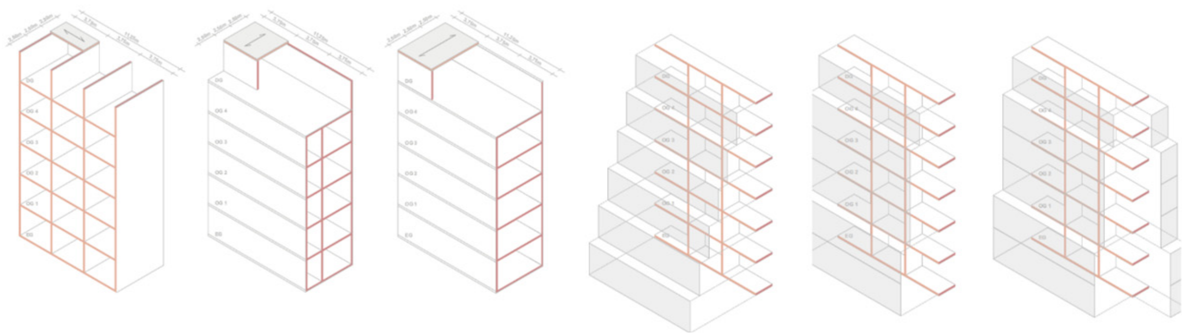


Fig. 2 *Schema of the analysed structural situations*

Firstly, their structural performance was analysed, together with their fire resistance according to the regulations. Further, their noise and heat insulation capacity was grouped into 3 load and 3 performance categories, and last their surface quality was also assessed. Secondly, their ecological and economic impact were examined. Other important parameters were also taken into account like the constructive height of the slabs, depth of the wall elements, due to their corresponding more or less usable area, and the prefabrication degree, what have a remarkable impact in construction time and costs. Since the smartest way to build installation intensive areas like kitchen and bathroom is through prefabrication as 3D modules, those were excluded from the analysis and assumed to be produced in the factory and be transported to the field with the only need to be assembled on site. Furthermore, external corridors and staircases were supposed to be built in concrete due to fire regulations and their requirement of being built with non-combustible materials. Throughout this analysis, several switches between different systems and their combination were, in dependence of the requirements, allowed and enforced. Regarding to fire resistance, the both methods of protection, namely through cladding or through an extra layer of timber, were also calculated, compared and combined.

6 Production assessment

Since wood as a building material has a long history in German-speaking countries, a remarkable amount of manufacturers and timber construction companies in Austria are able to produce a wide variety of building elements and components within more or less industrialized processes. Prefabrication level also defers from one company to another, what increases the organization of trades on the field. Therefore, it is proposed the prefabrication level to arise in order to increase the efficiency of design and production. Based on the HOAI planning schema [7], planning and construction are separated and the specific constructive details comes with the handover. That leads to a re-design phase where the building elements and joints need to be adapted to the own systems, platforms and providers of the involved companies, provoking uncertainty in terms of time and costs. Contrary, prefabricated housing industry works with standard buildings from an own catalogue with fixed price and time, but less architectural freedom. The approach proposed within this study related to the production assessment occupies a middle position between those, being based on a building system set following a lean approach (Fig. 3).

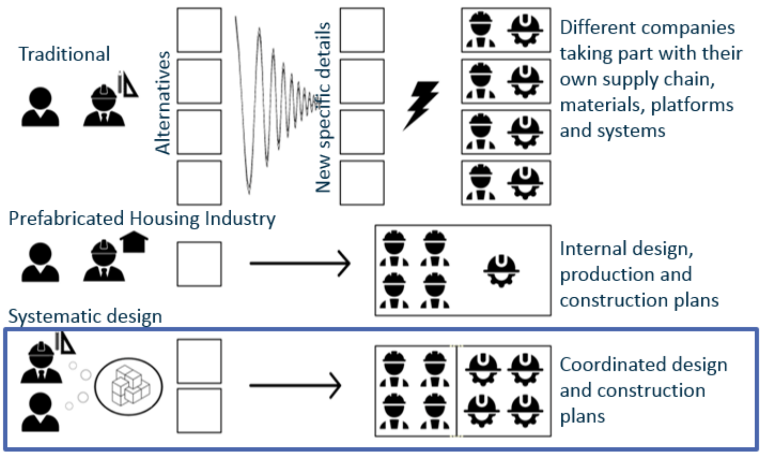


Fig. 3 *Systemized design*

Few previous studies have identified some synergies between both industries, timber and automotive [8, 9]. Some focused on technology or digital platforms, some other in upfront knowhow implementation or collaboration models within the design phase. In this study, though, the most relevant aspect to overtake from the so-called Lean Management is the Design for Manufacturing and Assembly. DfMA is a design approach based on the prefabrication and preassembly of an asset´s components that facilitates the manufacture, delivery and assembly of a product, simplifying the production structure, reducing manufacturing and assembly costs, and to quantifying improvements [10]. Before starting with this study, an intensive experimental workshop was run with students of architecture to develop creative solutions based on predefined modular construction elements and overcome the prejudice that prefabrication kills creativity and architectural freedom and quality [11].

6.1 Methodology

Because of traditional approaches and projects sizes, timber construction companies in Austria are small and scattered, what makes their involvement in large-volume construction projects very difficult. Main goal of this section is to increase their competitiveness, so they can erect mid-rise timber buildings. For that, a study is here proposed, where Key Performance Indicators for the production assessment are to be analysed collaboratively. By doing so, each timber construction company would be able to establish their paths to prefabricate efficiently in their own factories under controlled conditions complete components or entire modules with all installations and shafts. The teamwork implies a theoretical load, together with a practical approach, where experts from science and practice are taking part, assessing the own requirements of the participating companies, including company-specific experiences, problem areas and established solutions to certain challenges in multi-storey timber construction. Therein, a platform for the discussion and definition of the most relevant KPIs are eased with the purpose to measure the efficiency within the production process of the different elements. The term efficiency is also to be discussed, since main goal is to assess sustainability, including aspects that can hardly be measured, like those related to the social sustainability or the aesthetics of a building. The goal of establishing these indicators is to create a model that includes several key aspects, and is therefore applicable to several projects without major adjustments, with the main purpose to ease comparison and increase the overall efficiency.

7 Conclusions and discussion

The fragmented traditional planning schema based on the HOAI (Honorar Ordnung für Archikteten und Ingenieure) [7], appeared to be one of the most relevant barrier when planning and building mid-rise timber construction, since it is discrete, linear and material-unspecific. The sequence of the different stages do not fit with an efficient planning because: i) a higher level of detail as in traditional planning is needed, due to prefabrication and its consequent integration in construction plans, and ii) a timber-specific adaptation of the norm is missing, since planning during construction, and on-site interventions, as in traditional buildings, are not an adequate approach when building with timber. Within this schema, planning and construction are separated and consequently, the specific expertise comes often late. That leads to a re-design phase and re-work what provokes time overrun and eventually cost overruns. On the other hand, if such parameters are not taken into account and a low level of detail is developed, deviations, variations and uncertainty would outcome in further stages. One main goal for actual and upcoming procedures is to alleviate on site work and relocate most complex tasks in factories under optimal working conditions and permanent monitoring. Hence, within production, relevant on-site considerations as assembly sequence, joint systems, or transport constraints need to be implemented to increase flow efficiency. Following this discourse, supply chain, platforms and systems regarding production should be also taken into account within the design phase. Therefore, the design assessment process and design management present an opportunity to improve overall project performance and value creation, since key decisions are made having the largest influence to the lowest costs. The implementation of specific expertise upfront and the interfaces and interactions between these three scenarios need to be assessed. Collaborative planning and process stream mapping could enhance transparency and a leaner building production by defining interconnection of activities, coordination of people, materials and tools and interplay between technology, situations and decisions.

Regarding the design assessment of timber building, and by analysing the possible constructive elements for the slabs, the most relevant parameter regarding to structural performance is the span width, followed by the construction thickness, being spans of 4 to 5 metres an adequate frame to work with using conventional cross-sections. The direction of the spans defines the complete structural schema of the building, wherein the internal walls or the façade are the responsible to transfer the loads to the foundation. While load-bearing interior walls allow design freedom within the façade, load-bearing exterior walls allow flexible floor plans for eventual further adaptations or refurbishment. Contrary to mineral constructions where the most loaded wall is the one selected as standard for the calculation, in timber construction is smarter to calculate them in accordance to their specific load and requirements to sound and heat insulation. In order to reduce the complexity they can be added to load-bearing groups and performance categories, wherein the differences are negligible. An accurate approach is herein needed since higher load capacity often means lower heat and sound insulation and higher costs. Therefore, a compromise is needed between all key parameters.

In terms of production assessment, a model for the evaluation of the production efficiency of multi-storey timber constructions are expected to be delivered. Specific problems from practice are to be exchanged, analysed and discussed with Austrian timber construction enterprises. Based on a cooperative and interdisciplinary project, an overall consideration of the KPIs related to different companies is promoted and inputs are directly applied. Through discussions with experts from academia and practice, an exchange of experience, knowledge and a connection between innovative approaches and best practices takes place. The inclusion of different disciplines during the study is also intended to promote a mutual professional understanding. In this way, integral planning process of the prefabricated timber construction method will be optimised, systematised and established, which will continue to promote the use of timber as building material for multi-storey buildings.

Acknowledgments

The author wants to thank everyone taking part in this study, including interview partners, students, timber experts and construction companies. Special thanks to my supervisor and co-supervisor.

References

[1] Abergel, T., Dean, B., & Dulac, J. (2017) *Global Status Report 2017: Towards a zero-emission, efficient, and resilient buildings and construction sector*. International Energy Agency (IEA) for the Global Alliance for Buildings and Construction (GABC) & UN Environment Programme

[2] United Nations (2015) *Paris Agreement*. 21st Conference of the Parties of the United Nations Framework Convention on Climate Change.

[3] Bauer, W. (2018) *Eine Alternative Vorfertigung: Vollflächige Elementierung*. In: 1. Kongress HolzBau Wirtschaft HBW, 133-140.

[4] Kaufmann, H.; Krötsch, S.; Winter, S. (2017) *Atlas Mehrgeschossiger Holzbau* (DETAIL. München).

[5] Santana-Sosa, A.; Riola-Parada, F. (2018) *A theoretical approach towards ressource efficiency in multi-story timber buildings through BIM and lean*. In: World Conference of Timber Engineering. Seoul, Republic of Korea.

[6] A Santana-Sosa and A Fadai 2019 IOP Conf. Ser.: Earth Environ. Sci. 323 012015

[7] *Honorarordnung für Architekten und Ingenieure (Official scale of fees for services by architects and engineers in Germany) HOAI*. Germany. 201.

[8] Lattke, F.; Hernandez-Maetschl, S. (2016) *leanWOOD – Advancing performance of design teams in timber construction*. In WCTE 2016 - World Conference of Timber Engineering 2016. Vienna.

[9] Le Roux, S.; Bannier, F.; Bossanne, E.; Stieglmeier, M. (2016) *Investigating the interaction of building information modelling and lean construction in the timber industry*. In WCTE 2016 - World Conference of Timber Engineering 2016. Vienna.

[10] Boothroyd G., Dewhurst P. and Knight W.: Product Design for Manufacture and Assembly, 2nd Edition, Marcel Dekker, New York, 2002.

[11] Santana-Sosa, A., Fadai, A., Aichholzer, A., Kamenik, M. (2021) *Systemized Design to Deliver Leaner Mid-Rise Timber Housing.* In: World Conference of Timber Engineering. Santiago, Chile.

One Endangered Station, Railway Heritage, and Unsustainability of Demolitions

Jan Červinka[a]

[a] *Research Centre for Industrial Heritage FA CTU Prague, Thákurova 9/2700, 166 34 Praha 6-Dejvice, Czech Republic, jan.cervinka@fa.cvut.cz*

Abstract

Railway buildings and areas are an important part of industrial heritage. As technological and industrial landmarks, they have long been systematically mapped and the professional public recognises their urban, architectural and preservation value. Recently, the national media have become more interested in railway heritage, which has become a topical social issue in connection with the gradual renewal and development of railway infrastructure, with the railway construction fund experiencing another dramatic period. In addition to exemplary repairs and conversions, demolitions of historic buildings, including station buildings, have been getting a great deal of coverage. The demolition of the original Nymburk Central Station is also under consideration. A town whose appearance and importance were fundamentally transformed by the arrival of the railway; at the end of the 19th century, this smaller agricultural town became one of the industrial centres of the Middle Elbe Region. The paper presents the current situation in Nymburk and focuses on arguments for the preservation of the station building, issues surrounding its possible new use, the role of the professional public in promoting the protection of listed heritage and the possibilities for using research findings in design.

Keywords: *Industrial heritage, Adaptive reuse, Conversions*

1 In the jubilee year, the ‘railway town’ allowed the demolition of its railway station

In 2020, the railway celebrated 150 years of its existence in Nymburk [1]. The city owes the railway to modern development with significant benefits for the local population, economic prosperity as well as for construction production, architectural and urban design [2]. Progress and the modern age once travelled to the city on the tracks. In 2019, the Museum of Regional History in Nymburk commemorated the jubilee and prepared an extensive exhibition called From the History of the Railway in Nymburk. For the anniversary, the local publishing house released a popular science publication compiled by a regional writer and amateur historian [3].

But the end of the jubilee year brought very worrying news. In a survey, city officials turned to the public to vote on one of the two framework variants of a future project for the reconstruction of the Nymburk Central Station (Fig. 1) and its surrounding area (Fig. 2). The city announced that the majority opinion of the public would be binding and would be handed over to the state organization Railway Administration (Správa železnic – SŽ in Czech), which manages the station buildings as state property. Surprisingly, the survey offered a variant with the demolition of the historic station building. The public vote was not preceded by any construction research, detailed analysis or professional discussion. Thus, the fundamental steps of defining all the essential values of the station building and naming the deeper meanings it includes were omitted as well as the participation of both the general and professional public. The survey rightly provoked criticism.

Fig. 1 *Nymburk Central Station*

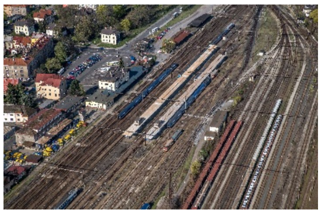


Fig. 2 *Nymbur0k Central Station*

Paradoxically, the results of the survey were announced at the very beginning of 2021, which had been proclaimed as the European Year of Rail. This is a symbolic gesture by the European Union to promote the use of trains as a safe and sustainable mode of transport and it is also seen as part of the world's cultural heritage. In addition, in the same year the historic building of the Prague-Vysočany railway station was demolished. This building was built by the same company as the railway station in Nymburk and in Prague-Těšnov which was pulled down in 1985. The demolition of this station is still perceived as a barbaric act of the then political regime. The question arises as to why we behave similarly today.

2 Industrial heritage and the legacy of the railway

The fields of transport sciences and civil engineering have been interested in the railway heritage, especially in connection with the gradual renewal and development of railway infrastructure and rail transport. Railway line construction has significantly influenced both the landscape and surrounding settlements and railway stations represent places of junctions of traffic arteries. Today's transport terminals operate in connection with older railway constructions and thus they can be found close to historical centres.

At the same time, railway constructions and areas attract attention as a significant part of the industrial heritage. As monuments of technology and industry, they have been systematically mapped for a long time, and the professional public is dedicated to identifying their urban, architectural, monumental and cultural-historical values. At the beginning of the systematic interest in industrial heritage, the railway station buildings played an important role [4]. One year after the demolition of the Prague-Těšnov railway station, the Section for the Protection of Industrial Heritage was established in 1986 at the National Technical Museum, headed by prof. Emil Hlaváček [5]. In 1998, the professional engineering organizations ČKAIT and ČSSI founded the College for Technical Monuments ČKAIT and ČSSI, chaired by Svatopluk Zídek. Since 2001, the Section and the College have been holding regular international meetings called the Biennial Vestiges of Industry [6]. The Biennial was co-organized by the Research Centre for Industrial Heritage (VCPD) under the leadership of Benjamin Fragner, which was established in 2002 at the Czech Technical University in Prague (CTU) [7]. This institution has been a member of the International Committee for the Conservation of the Industrial Heritage (TICCIH) [8] and has been operating at the Faculty of Architecture of the CTU since 2010 [9]. Besides, industrial heritage has been documented by the National Heritage Institute where a specialist Eva Dvořáková works. In 2014, the National Heritage Institute established the Methodical Centre of Industrial Heritage in Ostrava. From the pedagogical point of view this topic is approached by the Department of Architecture of the Faculty of Civil Engineering at the CTU, specifically by Tomáš Šenberger. Lastly, industrial heritage is researched at the Faculty of Architecture, mainly at the Department of Theory and History of Architecture led by Matúš Dulla, and at the Department of Architectural Conservation headed by Václav Girsa.

In 1996, professional organizations of civil engineers ČKAIT and ČSSI organized the first international conference of Municipal Engineering, which had been taking place every year in Karlovy Vary and in 2018 and 2019 in Cheb. In 2006, the conference focused on the topic of Railways and the City, and in 2016 on the City and the Conversion of Industrial Areas. Since 2019, ČKAIT and ČSSI have been organizing an international conference Engineering Problems of Monument Restoration in Teplá. As part of the International Biennial Vestiges of Industry, a workshop on the topic of the Žižkov freight railway station took place in 2011. In 2012, VCPD organized an exhibition and subsequently also an international conference Prague Railway Stations Un/Used and launched a publication of the same name [10]. In the same year, the non-profit organization Institute for Monuments and Culture organized the conference ProPamátky – Restoration and Use of the Railway Stations. In 2013, the National Heritage Institute established the Commission for the Protection of Monuments in the Field of Railway Transport, which is a specialized advisory board of the general directory. The seventh year of Crossroads of Architecture conference in 2015 focused on the topic of railways, the city and architecture. In 2017, the Department of Architecture of the Faculty of Civil Engineering (CTU) organized the conference Railways – Specifics, Challenges and Limits of Protection and New Use of Railway Heritage, from which a comprehensive publication was subsequently created [11]. A year later, the state organization managing the railway constructions, the Railway Administration, provided information about a plan for the demolition of the station buildings and their replacement by modular building containers. An open letter from the representatives of the professional public addressed to the general director of the National Heritage Institute was written. The authors were the leading experts in the field Tomáš Šenberger, Karel Hájek and Benjamin Fragner. In 2020, the Railway Administration announced the next stages of railway modernization including a list of stations intended for demolition. A wave of criticism from civil society and professional public resulted in more media interest. In response to the modernization plan a bachelor thesis on the reuse of the station buildings was created. The author Štěpán Mládek developed it within the student project Modern Trends in Railway Transport. The topic of railway construction heritage also resonates on social networks, where several thousand supporters have come together. Furthermore, various NGOs and museums taking care of specific buildings and railway areas have been active in this field. In 2000 an important institution developing and protecting the legacy of the railway heritage called the Railway Museum of the National Technical Museum was founded.

The current state of the railway heritage can also be described by statistical data. So far, over 18,000 objects have been registered in the VCPD FA ČVUT database, of which around 1,500 are railway stations [12]. Another database edited by the National Heritage Institute registers 100 railway stations, which are protected as cultural monuments by the state. In 2012, the state, through its railway organizations, owned 6,000 railway buildings, of which 1,000 were railway stations. The railway network of the Czech Republic is 9,000 km long and is the ten densest in Europe. In 2019, 186 million passengers were transported on our railways.

3 The impact of the railway on modern Nymburk

The following data present the railway heritage in Nymburk. The VCPD FA ČVUT database currently registers 70 buildings in Nymburk, out of which over 20 are railway-related, for instance the Nymburk central station, the railway workshop (Fig. 4), former officials' and workers' colony (Fig. 6, 7, 8), marshalling yard (Fig. 3), the Nymburk-Město railway station, railway bridges (Fig. 5), warehouses (Fig. 10), guard house, waterworks, former railway school and a unique Vagónka street (Fig. 9) where the houses are made of old railway carriages. The railways surround the city from three sides – north, west and east and include eight railway bridges in the city and its immediate surroundings. To this day, the vestige of the railway in Nymburk is significant. Nevertheless, none of the railway buildings is protected by the state as a cultural monument.

Fig. 3 *Nymburk, marshalling yard*

Fig. 4 *Nymburk, railway workshop*

Fig. 5 *Nymburk, railway bridge and brewery*

Fig. 6 *Nymburk, officials' and workers' colony*

Fig. 7 *Nymburk, officials' and workers' colony*

Fig. 8 *Nymburk, officials' and workers' colony*

Fig. 9 *Nymburk, Vagónka street*

Fig. 10 *Nymburk, warehouse*

The beginnings of the railway in Nymburk are connected with the general development and support of transport routes in Austria-Hungary after the defeat of the monarchy in the Prussian-Austrian war in 1866. The preparatory committee for building the railway between Kolín and Mladá Boleslav was founded a year later in 1867 and soon it was merged with the Austrian Northwestern Railway company, which was designed and supported by the outstanding transport engineer Wilhelm Hellwag. Extensive land was purchased for the construction of the railway in the then Bobnice suburb in the north of Nymburk.

At the turn of the 1860s and 1870s, there was already a typology of railway buildings which were built in large numbers throughout Austria-Hungary. A neo-renaissance one-storey type II.B was chosen for the station building in Nymburk. Its author was another important figure in Austrian railway architecture, Karl Schlimp. The station building was put into operation in 1870 [13]. The rapid development of the railway in the region (construction of lines to Prague and Děčín) and the decision to build the logistics and administrative centre of the Austrian Northwestern Railway in Nymburk radically increased the importance of the city as a railway junction. As early as 1873, the station building was increased by one floor and extended by two ground-floor wings with a transport and telegraph office on one side and a restaurant on the other, and a platform porch was added. At that time, a large area of officials' and workers' colony was already being established in the immediate vicinity. No more significant interventions in the original form of the station building took place. At the turn of the century, the capacity of the station building was again insufficient and repeated suggestions from the city caused the creation of a project for an extensive extension towards the city. The project was approved in 1912, with the Viennese architect Emerich Richter as the author. However, the implementation of the extension was prevented by the First World War. The insufficient capacity of the Nymburk station building led to the proposal of the politicians of the time to build a completely new modern station building and use the existing one for the accommodation of employees.

In economic, urban and demographic terms, the presence of a major railway junction played a crucial role in the development of the city. The population of Nymburk alone almost tripled from 3,000 in the early 1870s to the outbreak of World War II. At the beginning of the 20th century, the number of people tied to the railway reached several thousand. A very specific part of the city was the area of the railway workers' and officials' colony near the station.

In the interwar period, the construction of a new station building was under preparation. These plans were interrupted due to administrative reasons, and a new project was subsequently created, envisaging the extension of the existing building towards the city, thus essentially returning to the pre-war design. In 1928, the Nymburk City Council also lobbied for the project of a new station building at the Ministry of Railways. A comparison of the estimated costs of constructing a new building and extending the existing one led the ministry to choose a cheaper option, which was to extend the existing building. This project was not implemented due to the economic crisis. From the middle of the 20th century, the surroundings of the station building were most affected by the abolition of the adjacent park on the site of today's bus station and car park at the end of the 1970s. Then there are two newly built platforms with underpasses and a luggage tunnel from 1972–1980.

4 In the new millennium

As at the end of the 19th and throughout the 20th centuries, efforts were repeatedly made after 2000 to address the inadequate capacity of the station building, its insufficient maintenance and the unsatisfactory condition around Nymburk Central Station. In 2005, a proposal for the solution of the area of the front station and railway station was created at the request of the city. In 2011, České dráhy, the national rail operator, commissioned a study for the reconstruction of the Nymburk transport terminal. In 2017, four parallel projects were even developed. The Railway Administration was preparing the modernization of the line passing through the city, as well as the reconstruction of the station building. The city developed a project for a front station with a bus terminal and a project for a new large car park west of the station. Based on a tender, the Railway Administration commissioned a study on the reconstruction of the station building. The project was developed in a variant with the existing building and in a variant with a new building. This proposal provided for the demolition of the historic station building, to be replaced by a bus terminal, which would, however, be inappropriately adjacent directly to the track. The city commissioned a project for an architectural and urban design of the front station and car park.

At the end of 2017, the Railway Administration supported a variant of the project for the reconstruction of the station building with a new building and the demolition of the historic one, which it justified by the fact that it had no use for it. The council subsequently adopted a resolution stating that from the city's point of view, demolition was not desirable, with the building being an important part of the development, defining the public area of the front station, separating the residential development from the railway tracks and acting as a visual dominant. In the resolution, the city states that the possibilities of using the existing building have not been exhaustively examined, such as the possibility of its completion. In 2018, the historic station building owned by the Railway Administration was offered to the city for purchase for more than CZK 11 million, which the city refused because it had no be use for it either. However, it declared an effort to contribute to its preservation. The response was criticism from a section of the Nymburk public and, at the beginning of 2019, a petition from local residents for the rescue of the historic station building, which was supported by 800 signatories. The city reassured the public that new negotiations had begun with the Railway Administration, which brought about an agreement on the preservation of the existing building. The publication of the information on the common understanding of the city as a participant in the construction procedure with the Railway Administration as an investor to preserve the historic building calmed the situation.

At the end of last year, on 26 November 2020, the city surprisingly published a survey (http://www.mesto-nymburk.cz/anketa_nadrazi/), in which the general public was called to choose one of the two framework variants of the future project of reconstruction of the station compound and its adjacent surroundings. A highly non-transparent method of voting via anonymous text messages was inappropriately chosen. The whole event was not sufficiently communicated to the public and was also launched at a time when, due to government measures in connection with the pandemic, it was not possible, for example, to organize a representative public debate. The survey was based on a conceptual study commissioned by the Railway Administration in 2020. The variant presented in the document as clearly more advantageous provided for the demolition of the historic building. This is despite the fact that the second variant inconspicuously provided probably the most important information that the Railway Administration had a new use for the existing building. The Administration would move the offices of the Communication and Security Technology Unit from another building in the city. It is not so important from an architectural or urban point of view, it can be more easily adapted for other purposes, and possibly sold.

The survey rightly provoked criticism, a reaction by the civil society, and subsequently the professional public also commented on it. Marek Ďurčanský and Jan Červinka initiated and wrote an open letter in support of the preservation of the historic building of the railway station in Nymburk at the beginning of December 2020 and asked for the support of a significant authority in the fields of conservation, architectural history, technical history and other scientific disciplines. In a very short time, the open letter was supported by over 30 personalities, as well as professional organizations and research institutions including VCPD FA ČVUT, the College for Technical Monuments ČKAIT & ČSSI, the Vestiges of Industry Platform, the Old Prague Club, the Society for History of Sciences and Technology and the Czech Association of Art Historians. An open letter was also sent to the Director General of the Railway Administration, Chairman of the Czech Chamber of Architects, President of the Czech National Committee ICOMOS – International Council for Monuments and Sites, Chairman of the Commission for the Protection of Monuments in the Field of Railway Transport of the National Heritage Institute, and to the official architect of the city of Nymburk. The initiators presented the letter and the list of supporters at the December meeting of the city council and thus intervened in the public debate about the historic station building and the form of the survey itself. Subsequently, media also turned their attention to the situation.

In the end, the survey turned out to be favourable and convincing: out of 723 respondents, 544 spoke in favour of preserving the building and 179 in favour of demolishing it. The city has committed itself to handing over a clear result to the Railway Administration, together with the opinion of the city council, which adopted a resolution favouring the modernization option associated with maintaining the existing station building. According to published information, the Railway Administration is planning an architectural competition. The city announced that it would continue to communicate with the Railway Administration and offer maximum cooperation, including all available documents for the announcement of an architectural competition for the revitalization of Nymburk railway station, while preserving the historic station building. The city informed that it is also in its interest that the architectural competition be prepared in the best possible way. Therefore, it will continue to negotiate with the Railway Administration and the professional public and will strive to ensure that the city has a representative on the jury that will evaluate the architectural designs. After the survey, the initiators of the open letter informed the city on the absence of professional evaluation of the station building as a construction work of the past and recommended to ensure an erudite architectural history survey.

5 The values of Nymburk railway station and the search for responsible and sustainable solutions

The open letter in response to the survey contributed to a discussion of the historical, urban, architectural, monumental and cultural-historical values of the Nymburk station building. The construction of the station building initiated the creation of a whole new district of the city and outlined its basic structure. With its mass, it closes the residential development and separates it from the track and related railway operations. It naturally acts as a dominant feature of the immediate surroundings. When comparing the oldest images and the current state, it is clear that the mass of the station building itself has not undergone significant changes and major structural modifications in 150 years. It is an example of a standardized building II.B designed by Karl Schlimp. This type, preserved for example in Hlinsko, Nový Bydžov and Všetaty, was supplemented by another floor and a pair of side ground wings shortly after construction in Nymburk. Since then, only completions, demolitions and new buildings have been planned but never completed. The monumental value of the building stands out all the more as the oldest preserved building of the once extensive railway area, which brought prosperity to Nymburk and, due to the urban and architectural significance of the colony, also fame. The building thus represents an important symbol of the modern history of the city, which can also be perceived in connection with the literary legacy of the writer Bohumil Hrabal and his connection to the city and the railway themes in his life and work. The significance of the railway in the town is recalled in the long tradition of the museum exposition on the history of the railway of the Museum of National History in Nymburk, which has so far been presented in the former Jewish synagogue. Could it not be partially installed in one of the authentic railway buildings and areas?

It should also be noted that not all of the possibilities of new use have been exhausted. A detailed analysis of needs and services in the city and in the area near the station should examine whether the station building could house, for example, the city police, an information centre, the Nymburk beer shop and other regional brands, a supermarket, museum exhibits, a library branch, a coworking space, the basic art school or another educational institution, a model railway, the archive and deposit of the town or another office, etc. Some objects in the former colony, such as the medical facility in the former administrative building or the office of the railway organization in the former school may serve as an inspiration. In the case of a new use of the station building, this would not be the first idea of its conversion. During the First World War, the construction of a new building was considered and the existing one was to be used to accommodate employees. The building of the Nymburk-Město railway station also includes the housing function. Benjamin Fragner's idea concept for successfully bringing the industrial heritage back to life includes three crucial moments, which are place, shape and program [14]. The place has its continuity, character and memory, dominants and experienced communication directions. The new feature brings the place to life. The shape enriches the environment with authentic experience, a story of origin and development, proof of technical solutions and ambitions of the builder and builder. The shape covers the architectural intervention. The program means finding a new use. It is a prerequisite for sustainable development and is ideally tested in gradual steps. From the general principles of the approach to conversions, the capture of the characteristic atmosphere and the sensitivity of new interventions apply.

Looking back at recent events, it is clear that some steps in the process of preparing the revitalization of the station complex, including the station building, were erroneously omitted. Above all, it is the phase of research, documentation, detailed knowledge of the form and understanding of the various stages of development. This phase should be characterized by close cooperation with the professional public. Due to the importance of the station area and the station building, adequate space should belong to documents such as the City Development Strategy, the Spatial Plan or the Spatial Analytical Data. At the same time, the vision of the Policy of Architecture and Building Culture of the Czech Republic (a document adopted at the governmental level in 2015), which is to improve the quality of the environment created by construction, should be taken into account [15]. The transformation of unused buildings has the potential in the development of new activities in the area and in the creation of new local centres. Related to this are the principles of sustainable adaptation and the pillars of sustainable development – environmental, social, and economic. Among the sustainable development goals, mention may be made in particular of creating inclusive, safe, resilient and sustainable cities (Objective 11), sustainable consumption and production (Objective 12) and building resilient infrastructure, promoting inclusive and sustainable industrialization and innovation (Objective 9).

As the Czech Chamber of Architects points out, the demolition of historically and architecturally significant public buildings should always be the last option, based on an exhaustive professional debate and important, not only economic, reasons. It is short-sighted to remove valuable buildings only because they do not currently serve their original purpose and are not well maintained. This raises the question of responsible management and disposal of state-owned property and the question of a responsible approach to the environment, with the construction industry producing over 60 percent of all waste in our country.

If in Nymburk they still manage to go in the right direction in the form of a public architectural competition with a precise assignment, including a new use of the historic station building, it will be a positive example for other cities. Last but not least, it could also be a contribution to the cultivation of social and political culture in relation to the building of quality public architectural infrastructure from public budgets. The events surrounding the station building also raised the question of whether at least some of the remains of the Nymburk railway heritage should not obtain a state-guaranteed monument protection.

Acknowledgement

The text was created within the project SGS21 / 122 / OHK1 / 2T / 15 Searching for the current topic. New use of industrial heritage in student projects at CTU.

References

[1] PLAVEC, M. *Kapitoly z dějin královského města Nymburka. Od nejstarších dob do roku 2009.* Cheb: Svět křídel, 2010. 978-80-86808-75-8.

[2] KUČA, K. *Města a městečka v Čechách, na Moravě a ve Slezsku, díl IV*. Praha: Libri, 2000. ISBN 80-85983-12-5.

[3] ŘEHOUNEK, J. *150 let železnice v Nymburce*. Nymburk: Kaplanka, 2020. ISBN 978-80-87523-28-5.

[4] DVOŘÁKOVÁ, D. – GUZIK H. – ZIKMUND J. *Architektura v přerodu: 1945-1948, 1989-1992*. Praha: ČVUT v Praze, 2019. ISBN 978-80-01-06524-2.

[5] HLAVÁČEK E. – FRAGNER B. (eds.). *Industriální architektura: nevyužité dědictví*. Praha: Národní technické muzeum v Praze, 1990.

[6] FRAGNER B. – HANZLOVÁ A., *Industriální stopy / Architektura konverzí průmyslového dědictví v České republice 2000–2005. Katalog výstavy. Vestiges of Industry / Architectural Conversion of Industrial Heritage in the Czech Republic: Karlínská studia, Praha září–říjen 2005*. Praha: ČVUT v Praze, 2005. ISBN 80-239-5440-7.

[7] VORLÍK, P. (ed). *Druhý dech průmyslové architektury: sborník z výstavy alternativních studentských projektů na téma nové využití průmyslového dědictví jako podnět nebo nástroj územního rozvoje: 4. mezinárodní bienále Industriální stopy, září 2007*. Praha: ČVUT v Praze, 2007. ISBN 978-80-01-03805-5.

[8] DOUET J. (ed.). *Industrial Heritage Re-tooled / The TICCIH Guide to Industrial Heritage Conservation*. Lancaster: Routledge, 2012. ISBN 978-1-85936-218-1.

[9] FRAGNER, B. – VALCHÁŘOVÁ L. *Industriální topografie / Architektura konverzí, Česká republika 2005–2015. Industrial Topography / The Architecture of Conversion, Czech Republic 2005–2015*. Praha: ČVUT v Praze, 2014. ISBN 978-80-01-05592-2.

[10] FRAGNER B. – SKŘIVAN T. (eds.). *Pražská nádraží ne/využitá: urbanismus průmyslového dědictví / Alternativní projekty pro Nákladové nádraží Žižkov*. Praha: ČVUT v Praze, 2012. ISBN 978-80-01-05009-5.

[11] ŠENBERGER, T. – POPELOVÁ L. (eds.). *Železniční dědictví / Od velké minulosti k budoucí využitelnosti*. Praha: ČVUT v Praze, 2018. ISBN 978-80-01-06478-8.

[12] FRAGNER, B. (ed.). *Přehlížené drobné zapomenuté industriální stopy v krajině a sídlech*. Praha: ČVUT v Praze, 2017. ISBN 978-80-01-06327-9.

[13] KREJČIŘÍK, M. *Česká nádraží. Architektura a stavební vývoj, díl IV.2*. Litoměřice: Vydavatelství dopravní literatury, 2005. ISBN 80-902706-7-0.

[14] FRAGNER, B. (ed.). *místo_tvar_program / Industriální situace / Architektura konverzí*. Praha: ČVUT v Praze, 2021.

[15] *Politika architektury a stavební kultury České republiky*. Praha: Ministerstvo pro místní rozvoj, 2015. ISBN 978-80-87147-83-2.

Author Index

YRSB22 is a PhD conference focusing on actual research development in the field of sustainable building. The goal is to bring young researchers in sustainable building together to share research outcomes, discuss and get feedback from their colleagues.

YRSB22 Topics are:

- **Adapting buildings to climatic goals**
- **Innovative materials, products and systems for sustainable buildings**
- **Integration of principles of circular economy into building design process**
- **Decision-support tools and assessment methods for sustainable built environment**
- **Sustainable retrofitting of existing buildings**
- **Sustainable urban development**

YRSB22 Proceedings:
https://cesb.cz/yrsb22/download/yrsb22__proceedings.pdf