



9TH INTERNATIONAL WORKSHOP  
**WHEN SOCIAL SCIENCE  
MEETS LEAN AND BIM  
TOWARDS INDUSTRY 5.0**

20TH AND 21ST JUNE 2022

Western Sydney University, Australia (host)

University of Huddersfield, United Kingdom

Universidade Federal do Rio Grande do Sul, Brazil

Edited by

Patricia Tzortzopoulos, Carlos Torres Formoso, Michail Kagioglou



Front cover image © by Sally Tsoutas, Western Sydney University

ISBN 9781741085433

DOI 10.26183/1z3j-sx28

Western Sydney University

Locked Bag 1797

Penrith NSW 2751

© Patricia Tzortzopoulos, Carlos Torres Formoso, Michail Kagioglou, 2022

## Book of Abstracts

### 9th International Workshop When Social Science meets LEAN and BIM

**Edited by**

Patricia

Tzortzopoulos

Carlos Torres

Formoso

Michail Kagioglou

**PETER SHERGOLD BUILDING**

**PARRAMATTA**

**AUSTRALIA**

20<sup>th</sup> and 21<sup>st</sup> June 2022

## Workshop Organisation

### **Technical Chairs:**

Prof Patrícia Tzortzopoulos, University of Huddersfield (UK)

Prof Carlos Formoso, Federal University of Rio Grande do Sul (Brazil)

Prof Michail Kagioglou, Western Sydney University (Australia)

### **Organising Committee**

Prof Patricia Tzortzopoulos, University of Huddersfield (UK)

Prof Carlos Formoso, Federal University of Rio Grande do Sul (Brazil)

Prof Mike Kagioglou, Western Sydney University

Kim Vincent, Western Sydney University

### **Advisory Board:**

Prof Robert Amor, The University of Auckland (New Zealand)

Prof Dayana Costa, Federal University of Bahia – UFBA (Brazil)

Prof Makarand (Mark) Hastak, Purdue University (USA)

Prof. Hanelle Kerosuo, University of Helsinki (Finland)

Prof. Lauri Koskela, University of Huddersfield (UK)

Prof Doris Kowaltowski, UNICAMP (Brazil)

Prof. Kathy Michell, University of Cape Town (South Africa)

Prof Srinath Perera, Western Sydney University (Australia)

Dr Algan Tezel, Aston University (UK)

## INTRODUCTION

Industry 5.0 has been defined in different ways. Essentially, it relates to taking the next step from Industry 4.0 where the focus is on improved automation and optimisation across cyber-physical systems utilising Artificial Intelligence (AI), sensors, robots, machine learning, Internet of Things (IoTs), virtual and augmented reality, additive manufacturing, etc. As such, it seeks to introduce a more human-centric and human-machine interaction approach to technology across collaborative models, moving from technology centric models. At its broader scope, Industry 5.0 embraces and embeds circular economy as part of the production system, an embedded environmental consideration which adopts the minimisation of waste (including the use of materials and processes that have a harmful impact to the environment) and an inherently social dimension to humans operating in industries as well as the interaction between them.

The previous 8 International Workshops focused on Lean Construction, Building Information Modelling (BIM) and digitalisation more broadly as central means supporting ongoing transformation and improvements across the construction industry. They recognised that research has so far mainly emphasised the technology or production process aspects through the successful adoption of technologies and processes. They also recognised that successful implementations have depended as much on social aspects like collaboration and the business environment, indicating that there is a clear need and opportunity for a social science perspective in this context. Indeed, it can be argued that the current fragmented transformation in construction provides an interesting challenge for social science research.

Historically, the field of management, understood as social science, has dissociated itself from concerns related to design and production. This creates difficulties in explaining phenomena that are intrinsically embedded in production activities. The challenges explored in previous workshops have highlighted important aspects of Lean and BIM and their understanding through the lenses of social sciences. With Industry 5.0 however, production and human-machine interactions are inseparable and integral providing limited opportunities to observe one against the other, but rather observe and make sense of a system.

There is an opportunity for social science researchers to observe interesting social phenomena in Industry 5.0 settings, such as creativity, human-machine interactions, problem-solving, collaboration in human-technology systems, co-creation, commitment and trust, which may lead to improved methods and models of production management. The evolving digital and business landscape provides many interesting issues for researchers to study.

The Workshop is jointly organised by School of Arts and Humanities' Innovative Design Lab (IDL) of the University of Huddersfield, UK; the Building Innovation Research Unit (NORIE) of the Federal University of Rio Grande do Sul (UFRGS) in Brazil, and the School of Engineering, Design and Built Environment at Western Sydney University in Australia.

Thirty-one extended abstracts are part of this publication. All abstracts were reviewed by the advisory board members, as well as the editors. The workshop itself included three keynote speakers. The authors and presenters come from ten countries, demonstrating the global reach of the workshop themes. We would like to sincerely thank all members of the advisory board, keynote speakers and the authors/presenters, for sharing their insights and ideas, as well as for their help and invaluable contributions to the workshop.

Professors Patrícia Tzortzopoulos, Carlos Formoso and Michail Kagioglou,  
Technical chairs

## TABLE OF CONTENTS

<b>KEYNOTE SPEAKERS</b>	<b>5</b>
REAL-LIFE DEMONSTRATION OF CIRCULAR ECONOMY, LIVING LABS, PEOPLES PRACTICES AND BUILDING AUTOMATION SYSTEMS – TOWARDS LOW EMBEDDED AND OPERATIONAL ENERGY AND CARBON IN BUILDINGS REFLECTIONS ON THE USE IOT ON VISUAL MANAGEMENT TO FOSTER BEHAVIOUR CHANGE TOWARDS LEAN PRODUCTION LEAN CONSTRUCTION 4.0 AND THE NEED FOR HUMAN CENTRIC SYSTEMS IN CONSTRUCTION	
<b>SOCIAL HOUSING</b>	<b>6</b>
EXPLORING BIM IN SOCIAL HOUSING UPGRADING WITHIN A LIVING LAB SETTING <i>Samira Awwal, Patricia Tzortzopoulos, Joao Soliman-Junior, Mike Kagioglou, and Morolake-Ayo-Adejuyigbe</i>	7
THE CHALLENGES OF SOCIAL HOUSING UPGRADING FROM A SOCIAL SCIENCE PERSPECTIVE <i>Janine Pöβneck</i>	10
EVALUATION OF TOOLS FOR IDENTIFYING USER VALUES IN SOCIAL HOUSING UPGRADING <i>Morolake Ayo-Adejuyigbe, Patricia Tzortzopoulos, Mike Kagioglou, Joao Soliman-Junior and Samira Awwal</i>	12
UPGRADING SOCIAL HOUSING FROM “WHAT IS” TO “WHAT MIGHT BE”. ARE ROADMAPS ENOUGH? <i>Ariovaldo D. Granja, Doris C. C. K. Kowaltowski, Vanessa G. da Silva, Daniel de Carvalho Moreira, Regina C. Ruschel, Marcelle E. Bridi, Elisa A. D. Muianga, and Clara H. B. Pereira</i>	15
USER-VALUED INNOVATIONS FOR SOCIAL HOUSING UPGRADING THROUGH TRANS-ATLANTIC LIVING LABS (U-VITAL): RESEARCH DEVELOPMENT IN THE UNITED KINGDOM <i>Joao Soliman-Junior, Patricia Tzortzopoulos Mike Kagioglou, Samira Awwal and Morolake-Ayo-Adejuyigbe</i>	17
<b>URBAN SUSTAINABILITY</b>	<b>20</b>
SUSTAINABLE CITIES: URBAN TRANSITION LABS AS INNOVATION CATALYSTS <i>Yreilyn Cartagena</i>	21
THE QUEST FOR DEVELOPING A NEIGHBOURHOOD SUSTAINABILITY ASSESSMENT TOOLS <i>Benedict Okundaye, Alireza Moghayed, Patricia Tzortzopoulos, Yun Gao, Kathy Michell</i>	24
<b>DIGITALISATION &amp; AUTOMATION</b>	<b>27</b>
DIGITAL BUILDING PERMIT BASED ON AUTOMATED CHECKING SYSTEMS: AN INVESTIGATION FROM THE AEC SECTOR OF A BRAZILIAN MUNICIPALITY <i>Douglas Malheiro de Brito, Dayana Bastos Costa, and Emerson de Andrade Marques Ferreira</i>	28
USING DIGITAL TECHNOLOGIS FOR AUTOMATED IDENTIFICATION OF BUILDING PATHOLOGIES: A LITERATURE REVIEW <i>Alisson de Souza da Silva, Dayana Bastos Costa</i>	31
INSIGHTS ON THE DIGITAL TRANSFORMATION IN BRAZILIAN CONSTRUCTION COMPANIES FROM A SOCIOTECHNICAL PERSPECTIVE <i>Luara Lopes de Araujo Fernandes and Dayana Bastos Costa</i>	35
DEVELOPING A BLOCKCHAIN-BASED POST-CONTRACT WORK AND PAYMENT CERTIFICATION FRAMEWORK FOR CONSTRUCTION PROJECTS <i>G. Thilini Weerasuriya, Srinath Perera, Rodrigo N. Calheiros</i>	38

MANAGING RISK IN PROJECTS WITH DIGITAL TWINS: A RISK SCIENCE PERSPECTIVE <i>Irem Dikmen</i>	41
OBSTACLES TO THE IMPLEMENTATION OF DIGITAL TWINS: A REVIEW IN THE CONSTRUCTION INDUSTRY <i>De-Graft Joe Opoku, Srinath Perera, Robert Osei-Kyei, Maria Rashidi, Keivan Bamdad</i>	43
<b>THE ROLE OF TECHNOLOGY AND HUMAN INTERACTION IN INDUSTRY 5.0</b>	<b>46</b>
MANAGEMENT OF CUSTOMER COMPLAINTS IN RESIDENTIAL BUILDING PROJECTS USING SPATIAL ANALYSIS AND BUILDING INFORMATION MODELS <i>Jordana Bazzan, Carlos Torres Formoso, and Márcia Echeveste</i>	47
INDUSTRY 5.0: IMPROVING CONSTRUCTION SAFETY USING WORKER-CENTRIC TECHNOLOGY <i>Matt Stevens</i>	50
DISRUPTIVE TECHNOLOGIES AND HUMAN INVOLVEMENT IN AUTOMATING CONSTRUCTION INDUSTRY TOWARDS INDUSTRY 5.0: A NEW ZEALAND PERSPECTIVE <i>Azam Zavvari, Wajiha Shahzad and Monty Sutrisna</i>	52
THE IMPORTANCE OF OCCUPANT BEHAVIOUR WITHIN INDUSTRY 5.0 <i>Laura Almeida, Vivian Tam, Matt Stevens, Alan Todhunter and Peng Zhang</i>	55
<b>DESIGN</b>	<b>59</b>
A CONCEPTUAL MODEL FOR UNDERSTANDING THE VALUE HIERARCHY OF HEALTHCARE BUILT ENVIRONMENTS AND SERVICES <i>Giulie Anna Baldissera, Carlos Torres Formoso, and Patricia Tzortzopoulos</i>	60
DESIGN PLANNING AND CONTROL OF FAST COMMERCIAL REFURBISHMENT BUILDING PROJECTS <i>Douglas C. Hamerski, Carlos Torres Formoso, and Eduardo L. Isatto</i>	63
DIGITAL WHITEBOARDS AS A VISUAL MANAGEMENT STRATEGY TO SUPPORT COLLABORATIVE INTERACTIONS IN CIVIL ENGINEERING DESIGN <i>Bárbara Pedó, Patricia Tzortzopoulos, Lauri Koskela and Algan Tezel</i>	66
BIM AND KNOWLEDGE MANAGEMENT AS A LEAN TOOL FOR THE IMPROVEMENT OF PREFABRICATED BUILDING SYSTEMS: USER-DRIVEN INNOVATION IN THE CONSTRUCTION PROCESS <i>Lucianne Casasanta Garcia, Simone Barbosa Villa</i>	69
<b>PRODUCTION</b>	<b>72</b>
PROBLEMS ASSOCIATED WITH THE ADOPTION OF OFFSITE CONSTRUCTION <i>Kola Olayiwola, Srinath Perera, Mike Kagioglou, Xiaohua Jin, Pejman Sharafi</i>	73
REQUIREMENTS FOR OFFSITE PRODUCTION PROCESSES OF VOLUMETRIC SYSTEMS FOR MASS CUSTOMISATION <i>Tamiris Capellaro Ferreira, José Carlos Paliari, Patricia Tzortzopoulos</i>	76
CONSTRUCTABILITY ASSESSMENT: A LEAN TOOL TO IMPROVE CONSTRUCTION PROJECTS <i>João Paulo Marcel de Abreu, Fernanda Marchiori, Vera Lucia Correia and Silva, Rafael Fernandes Teixeira da Silva</i>	79
SERIOUS GAMES FOR LEAN MANAGEMENT – NEW TOOLS FOR LEARNING LEAN MINDSET IN ARCHITECTURE AND CONSTRUCTION <i>Maria Antonietta Esposito, Caterina Ferraro</i>	82
THE PEIRCEAN CATEGORIES MEETING DESIGN AND PRODUCTION <i>Lauri Koskela, Ergo Pikas</i>	85

<b>SUSTAINABILITY</b>	<b>87</b>
PHOTOVOLTAIC SYSTEMS AND BIM INTEGRATION: TRENDS AND POSSIBILITIES <i>Bruna Brito Liberal, Thales Henrique Castro de Barros, and Rachel Perez Palha</i>	88
DYNAMIC IMPACTS OF POLICIES ON THE RECYCLING RATE OF CONSTRUCTION AND DEMOLITION WASTE <i>Mingxue Ma, Vivian WY Tam, Khoa N Le, Robert Osei-Kyei</i>	91
RECYCLED AGGREGATE CONCRETE: A PATHWAY TOWARDS CIRCULAR ECONOMY AND SUSTAINABILITY <i>Weiqi Xing, Vivian Tam, Khoa Le, Jian Li Hao, Jun Wang</i>	94
MORE ACCURATELY PREDICTING THE LIFE CYCLE ENERGY CONSUMPTION OF RESIDENTIAL BUILDINGS IN CHINA BASED ON THE EA-LSTM MODEL <i>Lei Liu, Vivian W.Y. Tam, Khoa N. Le</i>	96
SENSITIVITY ANALYSIS ON BUILDING DESIGN VARIABLES FROM LIFE CYCLE ASSESSMENT PERSPECTIVE <i>Yijun Zhou, Vivian WY Tam, Khoa N Le</i>	99

## KEYNOTE SPEAKERS

### **Real-life demonstration of circular economy, Living Labs, peoples practices and building automation systems – towards low embedded and operational energy and carbon in buildings**



**PROF. GREG MORRISON**

Western Sydney University, Australia

Greg Morrison is the Lang Walker endowed chair in Urban Transformation at Western Sydney University. His research has focused on Living Labs and innovation/net zero precincts. He has published extensively on innovation through Living Labs, circular economy and sharing solar energy. He has built one Living Lab in Sweden and one in Perth (Australia) which has attracted significant industry and society sponsorship. Greg is also on the Board and is a co-founder of Climate-KIC Australia which drives innovation and entrepreneurship in climate solutions in Australia.

### **Reflections on the use IoT on visual management to foster behaviour change towards lean production**



**PROF. AGUINALDO DOS SANTOS**

Federal University of Parana (UFPR), Brazil

Prof. Aguinaldo dos Santos has a B.Sc. degree in Civil Engineering (UFPR), an M.Sc. in Construction (UFRGS), and a Ph.D. from the University of Salford, U.K. He is an associated professor in the Design Department and the Head of the Design & Sustentabilidade Lab at the Federal University of Paraná. He has supervised 47 M.Sc. and 7 PhD. students, and is the author of 4 patents concerned with sustainability of the built environment. His current research interests are Design of Product-Service Systems, Design for Sustainable Behaviour, Distributed Economy through Digital Manufacturing, Social Housing and Open-Source Design.

### **Lean Construction 4.0 and the need for human centric systems in construction**



**DR FAROOK HAMZEH**

University of Alberta, Canada

Dr. Hamzeh is a Lean Construction expert. His theoretical and applied research in the US, Canada, and the MENA region aim at improving the design and construction of projects. Dr. Farook Hamzeh is an Associate Professor in Civil and Environmental Engineering at the University of Alberta. He was full time faculty at Colorado State University and at the American University of Beirut. Dr. Hamzeh is an active member of the International Group of Lean Construction (IGLC) and has published heavily on Lean Construction and related topics. Dr. Hamzeh has worked for more than seven years in the construction industry on several mega projects: the \$1.7 Billion Cathedral Hill Hospital in San Francisco, the 333 m high Rose Rotana Hotel in Dubai, Losail motor-bike racetrack in

Qatar, Olympic Tower in Qatar, Al-Amal Oncology Hospital in Qatar, Serail 1374 Building in downtown Beirut, and Sibling Cement factory 2nd production line in Lebanon.

## **SOCIAL HOUSING**

## EXPLORING BIM IN SOCIAL HOUSING UPGRADING WITHIN A LIVING LAB SETTING

Samira Awwal<sup>1\*</sup>, Patricia Tzortzopoulos<sup>2</sup>, Joao Soliman-Junior<sup>3</sup>, Mike Kagioglou<sup>4</sup>, and Morolake-Ayo-Adejuyigbe<sup>5</sup>

### INTRODUCTION

Upgrading the existing social housing stock provides an opportunity for innovation and can help resolve housing deficits (Jensen et al., 2018). Upgrades, or social housing retrofits, are complex projects (Carvalho et al., 2019). Furthermore, upgrading is often ineffective in incorporating social and technological change (Blomsterberg & Pedersen, 2015), which results in overlooking value generation in the process. Upgrading can offer positive health benefits for social housing end-users (Healy, 2003). However, end-users sometimes do not gain benefits (Chaves et al., 2017) as their views and needs are seldom taken into account during the upgrade design. Also, there can be conflicting views and needs across the diverse stakeholders involved in upgrades. Communication through graphic representation can play an important role in managing such conflicts, but the process is costly and time-consuming, especially during early design (Wang et al., 2014).

Technologies such as BIM (Building Information Modelling), AR (Augmented Reality) and VR (Virtual Reality) can support overcome these problems (Nørkjaer Gade et al., 2019). BIM can be a quick and efficient tool to support end-users understanding of the upgrading design through accurate 3D visualization (Azhar et al., 2011). Thus, this research aims to generate a BIM protocol to support incorporating end-users' participation in the upgrading process within a living lab setting. Living Labs are user valued innovations to support decision making and collaboration (Leminen, 2015) through effective mediating strategies. Some researchers (e.g., Liedtke et al., 2015, Sharp & Salter, 2017, Claude et al., 2017, Lockton et al., 2017) define living labs as a series of workshop sessions that allow the development of relationships amongst stakeholders. This research adopts the living lab as a series of workshops where the protocol will be implemented and tested, to resolve conflicting understanding of problems and needs of stakeholders. The initial findings highlight synergies between living labs and lean, focussing on users' needs and values, the use of participatory approaches and the early inclusion of stakeholders in the decision-making process.

#### Research Method

Design science research is the methodological approach adopted, aiming to develop a solution that solves a practical problem and provides contributions to the associated theoretical knowledge (Holmström et al., 2009). The research design includes:(i) Understanding of the problem, (ii) development of the solution and (iii) analysis and reflection (Holmström, et al., 2009). The research will be conducted using the living lab, a social innovation (Leminen,2015), to support the user's value identification in the upgrading process.

The research is currently focused on the use of living labs during the retrofit of 8 social housing dwellings in West Yorkshire, UK, including the local council, architects, retrofit coordinator, construction company, and tenants. The living lab proposes one pilot and four workshops to understand users' requirements and values, experiment through an immersive environment, evaluate design versus users' values and needs, and evaluate the Living Lab. The process is iterative in nature, allowing refinements in the method. The following diagram (refer to Figure 1) shows the activities that will be explored in the workshops at various stages of the living lab.

---

*1 Innovative Design Lab (IDL), School of Arts and Humanities, University of Huddersfield, UK. ORCID 0000-0001-7771-1511*

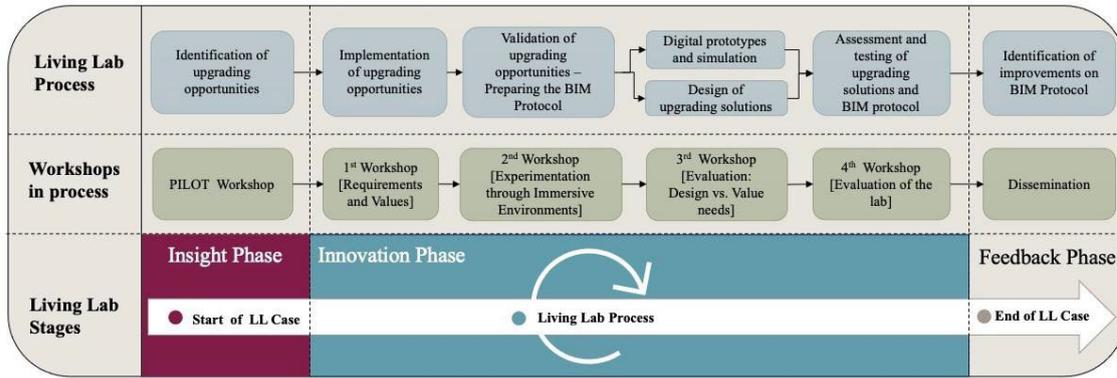
*2 Innovative Design Lab (IDL), School of Arts and Humanities, University of Huddersfield, UK. ORCID 0000-0002-8740-6753*

*3 Innovative Design Lab (IDL), School of Arts and Humanities, University of Huddersfield, UK. ORCID 0000-0002-8740-6753*

*4 School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0003-3521-1484*

*5 Innovative Design Lab (IDL), School of Arts and Humanities, University of Huddersfield, UK. ORCID 0000-0002-9600-7746*

*\* Corresponding author Email: samira.awwal@hud.ac.uk*



**Figure 1 The Living Lab Process**

At this stage, two workshops have been conducted, where the BIM models are explored as a tool to elicit and capture user value. The pilot workshop included four members of the council and four researchers, targeting to better understand how the tool will capture values and increase end-user participation. The 1st workshop included three end-users (tenants) and four researchers, aiming to understand the requirements for upgrading. The 2nd workshop focuses on experimentation through immersive experience including all stakeholders and the 3rd, and 4th workshops will be focused on evaluation and dissemination.

**PRELIMINARY FINDINGS**

In the ongoing living lab, value cards and real-time rendering software linked to BIM and VR Cave were explored. It is observed that some participants faced difficulties using the VR cave, as there were issues in moving around the model, and the graphic quality of the model could be improved. The stakeholders preferred the real-time rendering as it offered clearer and more effective visualisation to elicit participants’ choice in design requirements, providing evidence to understand their emerging needs more efficiently. This process is iterative and allows feedback options to users.

On the other hand, the value cards were straightforward and clear to use with the stakeholders, but it has been pointed out that this tool should be used at the preliminary stage of the upgrading process. The real-time rendering software linked with BIM provided the opportunity to improve understanding of requirements at multiple stages (e.g., preliminary design, development, and construction phase) of the upgrading process, enabling problems to be addressed transparently and facilitating better communication. During the process, synergies between living labs and lean (refer to Table 1) are observed in the decision-making process.

**Table 1 Synergies between living lab process and lean**

Living Lab Process (Observations from workshops)	Lean Principle (Koskela 1992)
-Elicit participants’ choice in design requirements -Participatory approach using co-creation	Increase Value
-Early stakeholder involvement -Experimentation environment in real-life context,	Increase transparency
-Allowing iterative processes with multiple feedback points	Continuous improvement & Reduce cycle times

**CONCLUSION AND FUTURE WORK**

The research is ongoing and further work to gather empirical data to test and evaluate the living lab protocol is ongoing. The initial protocol developed from the pilot upgrading project at West Yorkshire will provide a base for developing the first version of the protocol, which will be implemented and tested in another upgrading project. The living lab will be observed and outcomes will be analysed to measure value generation using social innovation in social housing upgrading.

**REFERENCES**

Azhar, S., Hein, M., & Sketo, B. (2011). Building Information Modeling (BIM): Benefits, Risks and Challenges. *Leadership and Management in Engineering* 11(3):241-252, 11(03), 11  
Blomsterberg, Å., & Pedersen, E. (2015). Tenants Acceptance or Rejection of Major Energy Renovation of

Block of Flats – IEA Annex 56. *Energy Procedia*, 78, 2346–2351.

Carvalho, J. P., Bragança, L., & Mateus, R. (2019). Optimising building sustainability assessment using BIM. *Automation in Construction*, 102, 170–182.

Chaves, F. J., Tzortzopoulos, P., Formoso, C. T. & Biotto, C. N. (2017). Building information modelling to cut disruption in housing retrofit. *Proceedings of the Institution of Civil Engineers - Engineering Sustainability*, 170(6), 322–333.

Claude, S.; Ginestet, S.; Bonhomme, M.; Moul ne, N.; Escadeillas, G. The Living Lab Methodology for Complex Environments: Insights from the Thermal Refurbishment of a Historical District in the City of Cahors, France. *Energy Res. Soc. Sci.* 2017, 32,121–130.

Healy, J. D. (2003). Excess winter mortality in Europe: A cross country analysis identifying key risk factors. *Journal of Epidemiology & Community Health*, 57(10), 784–789.

Holmström, J., Ketokivi, M., & Hameri, A.-P. (2009). Bridging Practice and Theory: A Design Science Approach. *Decision Sciences*, 40(1), 65–87.

Jensen, P. A., Maslesa, E., Berg, J. B., & Thuesen, C. (2018). 10 questions concerning sustainable building renovation. *Building and Environment*, 143, 130–137.

Koskela, L. (1992). "Application of the new production philosophy to construction" (Vol. 72). Stanford: Stanford University.

Leminen, S. (2015). Q&A. What Are Living Labs? *Technology Innovation Management Review*, 5(9), 7.

Liedtke, C.; Baedeker, C.; Hasselku , M.; Rohn, H.; Grinewitschus, V. User-Integrated Innovation in Sustainable LivingLabs:An Experimental Infrastructure for Researching and Developing Sustainable Product Service Systems. *J. Clean. Prod.* 2015, 97,106–116.

Lockton, D.; Bowden, F.; Matthews, C. Powerchord: Exploring Ambient Audio Feedback on Energy Use. In *Living Labs: Design and Assessment of Sustainable Living*; Keyson, D.V., Guerra-Santin, O., Lockton, D., Eds.; Springer International Publishing: Cham, Switzerland, 2017; pp. 297–308. ISBN 978-3-319-33527-8

Nørkjaer Gade, P., Nørkjaer Gade, A., Otrell-Cass, K., & Svidt, K. (2019). A holistic analysis of a BIM-mediated building design process using activity theory. *Construction Management and Economics*, 37(6), 336–350.

Sharp, D.; Salter, R. Direct Impacts of an Urban Living Lab from the Participants' Perspective: Livewell Yarra. *Sustainability* 2017,9, 1699

Wang, X., Wang, J., Xu, B., & Shou, W. (2014). Integrating BIM and augmented reality for interactive architectural visualisation. *Construction Innovation*, 14(4), 453–476.

# THE CHALLENGES OF SOCIAL HOUSING UPGRADING FROM A SOCIAL SCIENCE PERSPECTIVE

Janine Pöbneck<sup>1\*</sup>

## INTRODUCTION

In 2020, the European Commission published a 'Renovation Wave Strategy' aiming at increasing the annual energy renovation rate and reducing energy poverty by focusing on the worst-performing buildings. This is one step on the road to achieve climate neutrality in the EU by 2050 (European Commission, 2020). However, a deficit regarding upgrading is observed in the existing social housing stock.

Despite the recognised need and urgency of upgrading measures, there are a variety of obstacles, such as complex ownership structures, lack of political pressure and funding, and historic building preservation issues. A particular challenge of upgrading the existing social housing stock is that it is occupied. Refurbishment processes have a major social impact on the residents' everyday lives (Gee & Chiapetta, 2013). Therefore, their needs, interests and values require special attention. Residents are often only informed about upcoming refurbishment of their homes when the decisions have already been made (Gustavsson & Elander, 2016; Stenberg, 2018; Golic et al., 2020). Intensive resident participation from the very beginning, however, is necessary to meet the residents' needs in social housing upgrading.

Upgrading measures usually concentrate on specific buildings or blocks or flats, but are ultimately embedded in a larger context within a particular neighbourhood. We focus on a refurbishment project of the municipal housing company in a large panel housing estate. Four nine-storey buildings with around 100 apartments each have been gradually refurbished since 2020. Our research is part of the interdisciplinary and international project u-VITAL<sup>2</sup> with partners from four different countries: Brazil, the United Kingdom, the Netherlands, and Germany. The central objective of the German case study is to analyse resident participation in social housing upgrading using a social science approach.

## METHODOLOGY

Our German u-VITAL research approach on the challenges of social housing upgrading is embedded in a long-term study on residential satisfaction in the Leipzig-Grünau large panel housing estate. Its focus is on the residents' perceptions of the housing and living conditions. From 1979 until 2020, eleven surveys have been conducted. Questionnaires were distributed in each survey to the same fixed addresses that are spread over the entire estate. The repeated questionnaire surveys as key method were always complemented by interviews with local stakeholders, observations, analyses of planning documents and photo documentations to get a comprehensive picture of the estate. In order to guarantee the comparability of the results over time, the same core questions were used in each questionnaire. Additionally, new pressing topics were included. By doing so, we can comprehend the development of the estate and identify both potentials and problems from the perspective of the inhabitants.

For the u-VITAL project, we selected a specific case study area within the estate. We conducted in-depth interviews with different stakeholders that are involved in a refurbishment project. We met with representatives of the housing company, representatives of different construction companies and with residents. The interviews took place in-person in July and August 2021 during the COVID-19 pandemic, respecting social distancing requirements at all times. The residents belonged in most cases to vulnerable population groups (elderly people with health issues).

## RESULTS AND DISCUSSION

The long-term data provides evidence for a wave-like pattern of satisfaction among residents with their apartment, with consistently high values (Kabisch et al., 2021). Nevertheless, there are differences within

---

<sup>1</sup> Department of Urban and Environmental Sociology, Helmholtz-Centre for Environmental Research, Leipzig, Germany

\* Corresponding author [janine.poessneck@ufz.de](mailto:janine.poessneck@ufz.de)

<sup>2</sup> uVITAL stands for 'User-Valued Innovations for Social Housing Upgrading through Trans-Atlantic Living Labs', 01/2020-12/2022, Trans-Atlantic platform, BMBF (DLR-PT): 01UG2025.

subspaces of the large housing estate regarding socio-demographic characteristics and depending on the landlord's rental strategy. Residents of apartments owned by housing cooperatives tend to be more satisfied than those in apartments of private companies and the municipal housing company. In the latter case, a high demand for housing upgrading was expressed.

The housing stock under investigation is owned by the municipal housing company. Based on the qualitative approach in our refurbishment project, time and money were identified as two decisive factors. The entire process has a tight schedule that does not leave much room for intensive resident participation, which is indeed time-consuming. Furthermore, decisions for upgrading measures have to take into account the financial budget of the company as well as the residents to guarantee adequate upgrading, but at the same time avoid strong rent increases for the tenants. This results in a dilemma for the municipal housing company. On the one hand, large investments are required for energy-efficient retrofitting and age-appropriate renovation according to the residents' needs on site. On the other hand, housing must remain affordable, in particular for low-income households and vulnerable population groups.

## CONCLUSION

Social housing upgrading faces specific conditions and restrictions. Due to limited financial resources, the municipal housing company can only partially pursue the ambitious goals of energy-efficient retrofitting and age-appropriate renovation. Nevertheless, our interview results provide evidence that the residents, in general, appreciate the improvements (e.g. pipework renovation, replacing doors and windows, installing new balcony balustrades, lowering the thresholds to balconies), although they were not involved in the selection of technologies and materials. These decisions were made by the housing company. From the perspective of low-income households, however, the moderate rent increase is very important. It enables them to stay in their homes after upgrading. Thus, the dilemma presented above cannot be resolved as long as the housing sector functions according to a neoliberal market logic. There is a lack of adequate state subsidies allowing for extensive and high-quality upgrading measures in the social housing stock. Consequently, the dilemma impedes the achievement of climate neutrality.

## REFERENCES

- European Commission. (2020). A Renovation Wave for Europe – greening our buildings, creating jobs, improving lives. [https://eur-lex.europa.eu/resource.html?uri=cellar:0638aa1d-0f02-11eb-bc07-01aa75ed71a1.0003.02/DOC\\_1&format=PDF](https://eur-lex.europa.eu/resource.html?uri=cellar:0638aa1d-0f02-11eb-bc07-01aa75ed71a1.0003.02/DOC_1&format=PDF)
- Gee, P., & Chiapetta, L. (2013). Engaging residents in multifamily building retrofits: Reducing energy consumption and enhancing resident satisfaction. In: W. Swan, W. & P. Brown (Eds.), *Retrofitting the Built Environment* (pp. 155-169). Wiley Blackwell. <https://doi.org/10.1002/9781118273463.ch12>
- Golic, K., Kosoric, V., & Lau, S-K. (2020). A Framework for Early Stages of Socially Sustainable Renovation of Multifamily Buildings with Occupants' Participation. *Sustainability*, 12(21), 8832. <https://doi.org/10.3390/su12218823>
- Gustavsson, E., & Elander, G. (2016). Sustainability potential of a redevelopment initiative in Swedish public housing: The ambiguous role of residents' participation and place identity. *Progress in Planning*, 103, 1-25. <https://doi.org/10.1016/j.progress.2014.10.003>
- Kabisch, S., Poessneck, J., Soeding, M., & Schlink, U. (2021). Measuring residential satisfaction over time: results from a unique long-term study of a large housing estate. *Housing Studies*. <https://doi.org/10.1080/02673037.2020.1867083>
- Stenberg, J. (2018). Dilemmas associated with tenant participation in renovation of housing in marginalized areas may lead to system change. *Cogent Social Sciences*, 4(1), article 1528710. <https://doi.org/10.1080/23311886.2018.1528710>

# EVALUATION OF TOOLS FOR IDENTIFYING USER VALUES IN SOCIAL HOUSING UPGRADING

Morolake Ayo-Adejuyigbe<sup>1\*</sup>, Patricia Tzortzopoulos<sup>2</sup>, Mike Kagioglou<sup>3</sup>, Joao Soliman-Junior<sup>4</sup> and Samira Awwal<sup>5</sup>

## INTRODUCTION

There is a high demand for social housing globally (Gagliano et al., 2013). There is also a need to improve users' standard of living and provide a sustainable environment through social housing upgrading (or retrofit) (Jensen et al., 2018; Kowaltowski et al., 2019; Tzortzopoulos et al., 2019). User value is an essential concept in projects relating to users' requirements, priorities, needs, and preferences in their homes.

Problems associated with identifying user values include inadequate tools to engage and communicate with users, leading to information loss in the project (Blokpoel, 2003; Jensen & Maslesa, 2015). The introduction of better and more effective communication tools can improve participation problems and enhance the decision-making process, supporting collaborative multidisciplinary design (Woksepp et., 2005; Sherman & Craig, 2018; Orihuela et al., 2019).

This abstract discusses initial findings on the evaluation of tools used in two workshops to aid in understanding the requirements and needs of users in social housing upgrading. In the context of this research, the workshop serves as a Living Lab platform. The Living Lab is a platform to engage stakeholders (Cardullo et al., 2018; Chroner et al., 2019) to deliver sustainable improvement in social housing upgrading. Living Labs has other features such as activating a link to enhance stakeholders' relations and understand users' needs through experimentation, evaluating design solutions, and co-creation to understand user preferences (Leminen et al., 2012; Leminen & Westerlund, 2017; Van Geenhuizen, 2019). The main output of this research is to develop a protocol that can support stakeholders in understanding user value and the tools that can be used to engage users at the different stages of decision making in social housing upgrading.

## RESEARCH DESIGN

The Evaluation stage of Design Science Research (DSR) has been employed for this study. The evaluation allows for rigorous demonstration of the design artefact's utility, quality, and efficacy (Hevner et al., 2004; Da Rocha et al., 2012; Brady et al., 2013). The stages in evaluating tools for this study involve (i) identifying practical tools to engage stakeholders, (ii) developing evaluation criteria for the tools, (iii) Engaging stakeholders with the tools in a workshop, (iv) analysing the result from tool evaluation.

The study's focuses on stakeholders of 8 social housing upgrade in West Yorkshire, UK, including the local authority, architects, retrofit coordinator, construction company, and tenants (occupants of the houses to be upgraded). The two workshop sessions employed Value Card, BIM models and immersive virtualisation using Virtual Reality (VR) as tools to elicit the requirements and value of stakeholders.

## INITIAL FINDINGS

The initial findings report on the two workshop sessions conducted with professionals working on the project (Project Manager, Construction Manager, Quantity surveyor) and two residents, respectively. The criteria for assessing the tools include clarity on the use of the tool, ease of understanding, application of the tool, effectiveness in capturing requirements, and the relevance of each tool in capturing requirements in different project stages.

---

<sup>1</sup> Innovative Design Lab (IDL), School of Arts and Humanities, University of Huddersfield, UK. ORCID 0000-0002-9600-7746

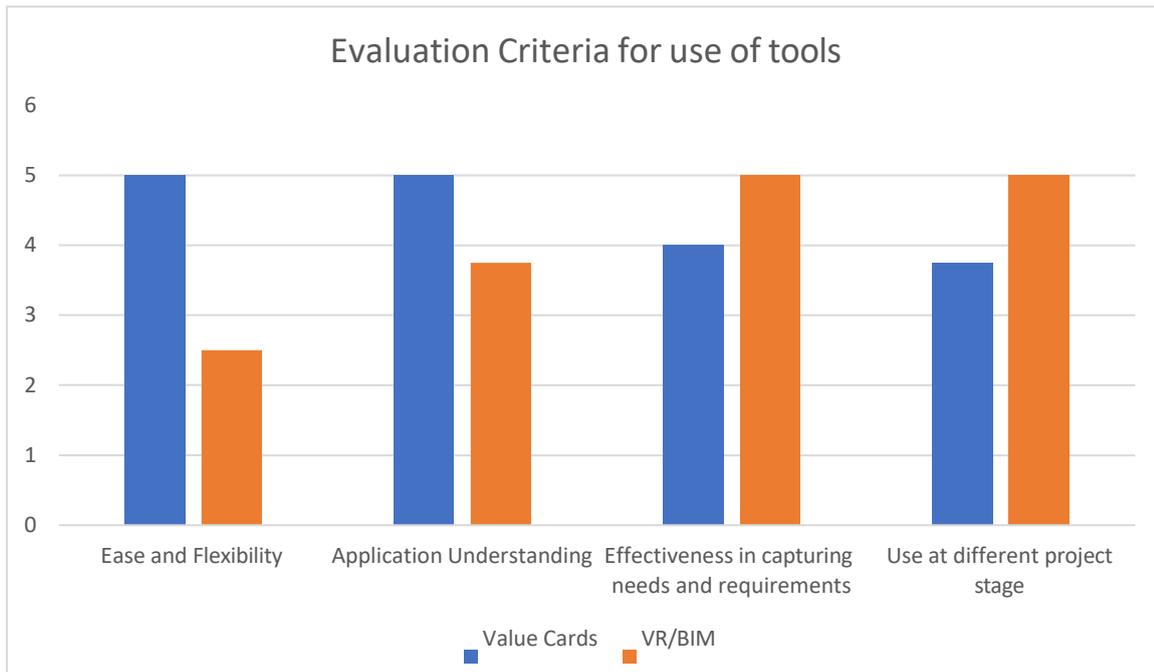
<sup>2</sup> Innovative Design Lab (IDL), School of Arts and Humanities, University of Huddersfield, UK. ORCID 0000-0002-8740-6753

<sup>3</sup> School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0003-3521-1484

<sup>4</sup> Innovative Design Lab (IDL), School of Arts and Humanities, University of Huddersfield, UK. ORCID 0000-0002-8089-8628

<sup>5</sup> Innovative Design Lab (IDL), School of Arts and Humanities, University of Huddersfield, UK. ORCID 0000-0001-7771-1511

\* Corresponding author Email: Morolake.ayoadejuyigbe@hud.ac.uk



The preliminary results indicate that Value Card, BIM and VR can serve as complementary tools for identifying user value in social housing upgrading and can be used at different stages of the project to support the process of identifying users’ values and eliciting users requirements.

**VALUE CARDS**

Results of using the value card indicate its appropriateness at the initial stage of the project to better understand users’ requirements and may potentially not be required on completion of the design stage. A participant suggested that the Value cards used require remodelling to improve the tool’s relevance in capturing requirements. Using blank or wild cards can assist users in indicating any need not represented in the card.

**VIRTUAL REALITY (VR)/ BUILDING INFORMATION MODELLING (BIM)**

Using VR indicated difficulty with the tool’s ease of use and flexibility. Some limitations during the workshop were associated with software compatibility with the VR cave. Using VR indicates the requirement of training for less computer literate persons to understand how to apply the tool. Other results show VR and BIM can be helpful at different project stages.

**CONCLUSION/FURTHER WORK**

The research is ongoing, and the evaluation criteria will be further refined based on five criteria: relevance, effectiveness, efficiency, impact, and sustainability of the tools in capturing user value which will be explored in two subsequent workshops. The results will further help establish how the tool identifies user value, the benefit of the tools, and the application in determining user value.

**REFERENCES**

Blokpoel, S. (2003). "Cooperation and Product Modelling Systems—The Application of Product Modelling Systems in the Building Process." Luleå University of Technology, Luleå, Sweden

Brady, D. A., Tzortzopoulos, P. & Rooke, J. (2013). The Development of an Evaluation Framework based on the Design Science Approach. Proceedings of the 21st Annual Conference of the International Group for Lean Construction, 579-588.

Cardullo, P., Kitchin, R., & Di Feliciano, C. (2018). Living labs and vacancy in the neoliberal city. *Cities*, 73(October 2017), 44–50. <https://doi.org/10.1016/j.cities.2017.10.008>.

Chroner, D., Stahlbrost, A., & Habibipour, A. (2019). Urban living labs: Towards an integrated

understanding of their key components. *Technology Innovation Management Review*, 9(3), 50–62. <https://doi.org/10.22215/TIMREVIEW/1224>.

Da Rocha, C. G., Formoso, C., Tzortzopoulos, P., Koskela, L. and Tezel, A. (2012). Design Science Research in Lean Construction: Process and Outcomes. <http://eprints.hud.ac.uk/id/eprint/21072/>

Diaz, E., Patino, L., & Siegel, A. (2018). Indoor environmental quality in social housing : A literature review. 131(November 2017), 231–241. <https://doi.org/10.1016/j.buildenv.2018.01.013>

Gagliano, A., Nocera, F., Patania, F., & Capizzi, G. (2013). A case study of Energy Efficiency Retrofit in social housing units. *Energy Procedia*, 42, 289–298. <https://doi.org/10.1016/j.egypro.2013.11.029>.

Hevner, R. A., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Research. *MIS Quarterly*, 28(1), 75– 105.

Jensen, P. A., & Maslesa, E. (2015). Value based building renovation - A tool for decision-making and evaluation. *Building and Environment*, 92(September 2011), 1–9.

<https://doi.org/10.1016/j.buildenv.2015.04.008>

Jensen, P. A., Maslesa, E., Berg, J. B., & Thuesen, C. (2018). 10 Questions Concerning Sustainable Building Renovation.

*Building and Environment*, 143(May), 130–137. <https://doi.org/10.1016/j.buildenv.2018.06.051>

Kowaltowski, D. C. C. K., Muianga, E. A. D., Granja, A. D., Moreira, D. de C., Bernardini, S. P., & Castro, M. R. (2019). A critical analysis of research of a mass-housing programme. *Building Research and Information*, 47(6), 716–733.

Lukka, K. (2003). The constructive research approach. In *Case Study Research in Logistics*; Ojala, L., Hilmola, O.-P., Eds.; Publications of the Turku School of Economics and Business Administration: Turku, Finland, pp. 83–101.

Moghimi, V., Bin, M., Jusan, M., Izadpanahi, P., & Mahdinejad, J. (2017). Incorporating user values into housing design through indirect user participation using MEC-QFD model. *Journal of Building Engineering*, 9(November 2016), 76– 83. <https://doi.org/10.1016/j.jobe.2016.11.012>

Orihuela, P., Noel, M., Pacheco, S., Orihuela, J., Yaya, C., & Aguilar, R. (2019). "Application of Virtual and Augmented Reality Techniques During Design and Construction Process of Building Projects. Proceedings of the 27th Annual Conference of the International Group for Lean Construction, 1105-1116.

<https://doi.org/10.24928/2019/0220>.

Sherman, W., & Craig, A. (2018). *Understanding virtual reality: Interface, application, and design*. 2nd Ed Indiana, United States. Morgan Kaufmann. ISBN 978-0-12-818399-1

Tzortzopoulos, P., Ma, L., Soliman Junior, J., & Koskela, L. (2019). Evaluating social housing retrofit options to support clients' decision Making-SIMPLER BIM protocol. *Sustainability (Switzerland)*, 11(9), 1–21.

<https://doi.org/10.3390/su1109250>

Woksepp, S., Olofsson, T., & Jongeling, R. (2005). Design Reviews and Decision-Making Using Collaborative Virtual Reality Prototypes ; A Case Study of the Large-Scale MK3 Project. Proceedings of the 13th Annual Conference of the International Group for Lean Construction, 145-152.

## UPGRADING SOCIAL HOUSING FROM "WHAT IS" TO "WHAT MIGHT BE". ARE ROADMAPS ENOUGH?

Ariovaldo D. Granja<sup>1\*</sup>, Doris C. C. K. Kowaltowski<sup>2</sup>, Vanessa G. da Silva<sup>3</sup>, Daniel de Carvalho Moreira<sup>4</sup>, Regina C. Ruschel<sup>5</sup>, Marcelle E. Bridi<sup>6</sup>, Elisa A. D. Muianga<sup>7</sup>, and Clara H. B. Pereira<sup>8</sup>

### INTRODUCTION

Existing constructions need upgrading periodically in the form of refurbishments that go beyond maintenance work. Social Housing (SH) is no exception and demands design processes that reflect new social norms and cultural and individual desires. New construction and information technology trends play a significant role in upgrading projects. In developed countries, top-down legislation demands refurbishment to attain energy efficiency. In developing countries, upgrading pressures are expressed through bottom-up transformations of homes (Kowaltowski et al., 2021). In both cases, participatory design processes are considered essential for political, social and economic reasons, and user values need assessment for upgrading processes (Stenberg, 2018).

Methods that underpin design processes have gone through changes, as has industrial production. This evolution tends towards softer approaches, as users are valued through increased participation in decision-making. Now, we embark on the fifth generation. After phases influenced by technology, the trend is towards a softer model emphasising creativity, human-machine interactions, problem-solving, collaboration in human-technology systems, co-creation, commitment and trust. The hope is for processes to be increasingly valuable for solving human problems. However, are these processes sufficient to make a real difference? Living Labs (LLs) have been suggested as essential practices to enable collaboration between stakeholders involved in problem-solving activities (Bridi et al., 2022).

This abstract describes experiences of an international research project focussing on SH upgrading in four countries: Brazil, Germany, the Netherlands and the UK. The project is called u-VITAL - "User-Valued Innovations for Social Housing Upgrading through Trans-Atlantic Living Labs". LLs are developed in different contexts using various tools. Users are actively engaged in ongoing refurbishment processes in the three European countries. In Brazil, no official policies exist for SH upgrading so far. However, users in single-family houses substantially transform their homes without technical support, and this process needs support. The pandemic affected the research project, and user engagement was a significant challenge for all case studies. Techniques and tools were modified to respond to restricted conditions. Our primary research goals for the u-VITAL project are to evaluate the applicability of the LL concept in diverse contexts (BR, DE, NL, UK). As a result, a protocol should be developed to solve dilemmas and conflicts in participatory processes within LL settings as a social innovation.

### RESEARCH METHOD & PRELIMINARY RESULTS

---

<sup>1</sup> Department of Architecture and Building, School of Civil Engineering, Architecture and Urban Design, University of Campinas, UNICAMP, Brazil. ORCID 0000-0002-2964-5609

<sup>2</sup> Department of Architecture and Building, School of Civil Engineering, Architecture and Urban Design, University of Campinas, UNICAMP, Brazil. ORCID 0000-0003-3088-6124

<sup>3</sup> Department of Architecture and Building, School of Civil Engineering, Architecture and Urban Design, University of Campinas, UNICAMP, Brazil

<sup>4</sup> Department of Architecture and Building, School of Civil Engineering, Architecture and Urban Design, University of Campinas, UNICAMP, Brazil. ORCID 0000-0002-7219-4006

<sup>5</sup> Department of Architecture and Building, School of Civil Engineering, Architecture and Urban Design, University of Campinas, UNICAMP, Brazil. ORCID 0000-0002-2796-1667

<sup>6</sup> Department of Architecture and Building, School of Civil Engineering, Architecture and Urban Design, University of Campinas, UNICAMP, Brazil. ORCID 0000-0003-4317-5938

<sup>7</sup> Department of Architecture and Building, School of Civil Engineering, Architecture and Urban Design, University of Campinas, UNICAMP, Brazil. ORCID 0000-0002-7070-3903

<sup>8</sup> Department of Architecture and Building, School of Civil Engineering, Architecture and Urban Design, University of Campinas, UNICAMP. ORCID 0000-0002-0804-8717

\*Corresponding author Email: [adgranja@unicamp.br](mailto:adgranja@unicamp.br)

We concentrate on the Brazilian case in the city of Campinas. A small SH project called Quilombo, was chosen to test the LL concept with low-income families. Specific tools and activities were developed to involve residents through discussions, walkthroughs, and co-design based on a design charrette of open public areas. Activities were specific for the understanding, co-design and analysis LL phases. Reflexive meetings were conducted, and upgrading priorities were established through questionnaires and user value assessment. Co-design will use maps and models guided by design parameters. Events will give feedback and ample opportunities for co-design. As a result of the reflexive meetings, community characteristics and conflicts were identified. A list of upgrading priorities indicated that child safety and public area upkeep were major concerns, with solid waste management a critical problem. A specific family house post-occupancy evaluation (POE) is supporting a renovation project.

As a set of directions for future action, a roadmap should be prepared to assist the Quilombo community from this case study. Achievable actions to reach desired outcomes are essential in such a context. The roadmap's success will depend on the participation of users, the public administration and private enterprise stakeholders, and the research team in the LL.

## CONCLUDING REMARKS

Some questions remain regarding the concept of LLs and how to develop viable solutions to upgrade existing SH in practice: Is a roadmap enough to achieve real actions that benefit end-users? What are the pitfalls of LL activities if public and private resources are scarce? In Europe, upgrading programs are funded with climate change in mind. In the case of Brazil, the political will is missing, and the question is: How can roadmap goals be achieved under restricted funding conditions?

To develop such a roadmap, the concept of Social Costs (SCs) should be explored in-depth in the case of a lack of political will and funds for upgrading. The concept of SCs can be applied to the issue of SH, and exist in the form of health problems and social unrest. Investments in upgrading mitigate the impacts of SCs on society of less than adequate living conditions provided by many mass and public housing developments around the world. The quality of SH, its location, design, and upkeep should positively impact employment, education, and health, among other factors. However, many SH developments do not reach desired standards. Public investments in upgrading projects can avoid SCs in the form of increased spending on health and social services and policing. For such projects, well-designed roadmaps to pave the way are essential. We believe that roadmaps can be built through LLs that explore co-design activities and the creativity of stakeholders, the local community and end-users. To build such roadmaps, other steps are necessary that we hope this workshop may help us to develop, propose and explore.

## REFERENCES

- Bridi, M. E., Soliman-Junior, J., Granja, A. D., Tzortzopoulos, P., Gomes, V., & Kowaltowski, D. C. C. K. (2022). Living Labs in Social Housing Upgrades: Process, Challenges and Recommendations. *Sustainability*, 14(5), 2595.
- Kowaltowski, D. C. C. K., Muianga, E. A. D., Ruschel, R. C., Gomes da Silva, V., Granja, A. D., MOREIRA, D. de C., Moreira, J., Augusto, da Silva, R., Ferreira, & de Vasconcellos, L., H. S. C. (2021). Housing Transformation in Search of Well-Being. *Even3*, 1947–1956.
- Martinussen, E., Sneve, Hill, D., Mathews, T., & Fischer, A. (2021). The Oslo Futures Catalogue [AHO the Oslo School of Architecture and Design].
- Stenberg, J. (2018). Dilemmas associated with tenant participation in renovation of housing in marginalized areas may lead to system change. *Cogent Social Sciences*, 4(1), 1–22.

# USER-VALUED INNOVATIONS FOR SOCIAL HOUSING UPGRADING THROUGH TRANS-ATLANTIC LIVING LABS (U-VITAL): RESEARCH DEVELOPMENT IN THE UNITED KINGDOM

Joao Soliman-Junior<sup>1\*</sup>, Patricia Tzortzopoulos<sup>2</sup> Mike Kagioglou<sup>3</sup>, Samira Awwal<sup>4</sup> and Morolake-Ayo-Adejuyigbe<sup>5</sup>

## INTRODUCTION

There is a need to improve the energy efficiency and thermal performance of the existing social housing stock through upgrades or retrofits (Swan et al., 2017). In the UK, this process tends to be driven by top-down initiatives (Karvonen, 2013) typically led by governmental organisations (such as local authorities) and housing associations, with poor participation and collaboration with end-users and other stakeholders.

There are considerable challenges associated with social housing retrofit, as they generally do not address end-users needs appropriately (Crawford et al., 2014; Chaves et al., 2017). This can generate user dissatisfaction and, ultimately, impacts the value generated to users through retrofits or upgrades (Kowaltowski & Granja, 2011). This abstract presents preliminary findings from the UK research team on the development of a research project entitled *User-Valued Innovations for Social Housing Upgrading through Trans-Atlantic Living Labs* (u-VITAL). This international collaborative research project involves institutions from four countries (Brazil, Germany, The Netherlands, and the United Kingdom) focuses on user-valued innovations for social housing upgrades via Living labs. Living Labs (LLs) consist of user-centred initiatives focused on the collaborative development of creative solutions in a real-world context (Leminen & Westerlund, 2017).

In the UK, the focus has been on a pilot social housing retrofit project consisting of 8 dwellings, aiming to improve energy and thermal efficiency. A living lab has been proposed and multiple workshop sessions supported the exploration of different tools to aid requirements' capture and user's value elicitation.

## RESEARCH DESIGN

Living labs can be understood as a concept-methodology (Tang & Hämmäläinen, 2014) in which different stakeholders (and especially end-users) collaborate, co-creating solutions (Eriksson & Kulkki, 2005). They are generally structured around the key stages of definition, ideation, co-creation and evaluation (Bridi et al., 2022). The overarching research design for the initiative developed in the UK is illustrated in Figure 1. In the figure, the blue-coded activities relate to the definition stage, and their focus is to understand the context in which the Living Lab is developed as well as the specific problems that can be addressed; the red-coded activities relate to ideation and co-creation stages, in which all participants collaborate to develop and propose a solution, developing shared understanding resolving potential conflicts. The grey-coded activities relate to the evaluation of the solution itself, as well as the evaluation of the Living lab process itself.

The activities developed up to date are: (i) 11 semi-structured interviews with end-users (in person) and 4 with project stakeholders (remote); (ii) development of two living lab workshops, including end-users, council members and researchers; (iii) 3 site visits; (iv) exploration of value cards; (v) development of BIM models and exploration of immersive visualisation through Virtual Reality (VR); and (vi) preliminary evaluation of tools used to elicit and capture users' requirements and values.

## PRELIMINARY FINDINGS

At the outset of the living lab process, the difficulties associated with its initiation were remarkable, as

---

<sup>1</sup> Innovative Design Lab, School of Arts and Humanities, University of Huddersfield, UK. ORCID 0000-0002-8089-8628

<sup>2</sup> Innovative Design Lab, School of Arts and Humanities, University of Huddersfield, UK. ORCID 0000-0002-8740-6753

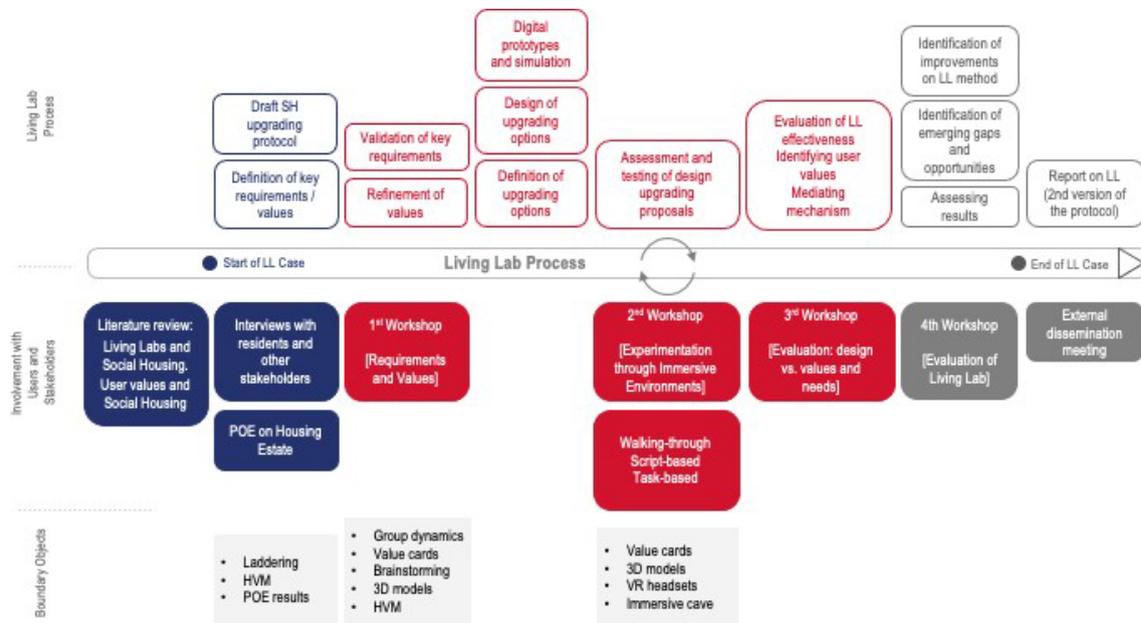
<sup>3</sup> School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0003-3521-1484

<sup>4</sup> Innovative Design Lab, School of Arts and Humanities, University of Huddersfield, UK. ORCID 0000-0001-7771-1511

<sup>5</sup> Innovative Design Lab, School of Arts and Humanities, University of Huddersfield, UK. ORCID 0000-0002-9600-7746

\* Corresponding author Email: joao.solimanjunior@hud.ac.uk

there were multiple Covid-19 restrictions in place that limited face to face interactions in workshops. During the living lab setup, there were also difficulties associated with data access, confidentiality and data sharing agreements. The interviews with stakeholders highlighted the difficulties associated with retrofit projects and, in this case, revealed that some of these challenges observed in the living lab initiation were typical characteristics of social housing retrofit construction projects, and not necessarily related to the living lab itself.



**Figure 1: Living lab process (UK). Blue (Definition), Red (Ideation + Co-creation), Grey (Evaluation).**

During the workshops developed so far, all participants acknowledged that different tools and approaches are needed to improve communication, understandability, collaboration, and transparency in social housing retrofit projects. The activities developed in the workshops (i.e. value cards and BIM-enabled VR exploration) helped demonstrate how stakeholders’ requirements and values can be better used to steer the retrofit project and elicit requirements and values. The value cards supported different participants to prioritise requirements according to their preference, triggering new insights and values in this process; the BIM-enabled VR explorations fostered discussion on different topics of the project (e.g. disruption due to scaffolding), as well as prompted design optioneering. There are benefits to be achieved in practice by using Living Labs as demonstrated through these preliminary findings. It is believed that Living Labs can improve shared understanding and foster collaborative decision-making, by enabling a transparent environment in which all participants can more easily express their needs and discuss potential conflicts towards the development of an innovation.

It is important to highlight the project is currently still under development and further living lab workshops are planned. Therefore, emerging findings will be added to the presentation on the workshop and will be used to discuss research updates on that topic.

## REFERENCES

- Bridi, M. E., Soliman-Junior, J., Granja, A. D., Tzortzopoulos, P., Gomes, V. & Kowaltowski, D. C. C. K. (2022). Living Labs in Social Housing Upgrades: Process, Challenges and Recommendations. *Sustainability*, 14(5), 2595. <https://doi.org/10.3390/su14052595>
- Chaves, F. J., Tzortzopoulos, P., Formoso, C. T. & Biotto, C. N. (2017). Building information modelling to cut disruption in housing retrofit. *Proceedings of the Institution of Civil Engineers - Engineering Sustainability*, 170(6), 322–333. <https://doi.org/10.1680/jensu.16.00063>
- Crawford, K., Johnson, C. E., Davies, F., Joo, S. & Bell, S. (2014). Demolition or Refurbishment of Social Housing? A review of the evidence. UCL Urban Lab and Engineering Exchange.
- Eriksson, M. & Kulkki, S. (2005). State-of-the-art in Utilizing Living Labs Approach to User-centric ICT Innovation - A European Approach. *State-of-the-Art in Utilizing Living Labs Approach to User-Centric ICT*

Innovation, 15.

Karvonen, A. (2013). Towards systemic domestic retrofit: a social practices approach. *Building Research & Information*, 41(5), 563–574. <https://doi.org/10.1080/09613218.2013.805298>

Kowaltowski, D. C. C. K. & Granja, A. D. (2011). The concept of desired value as a stimulus for change in social housing in Brazil. *Habitat International*, 35(3), 435–446. <https://doi.org/https://doi.org/10.1016/j.habitatint.2010.12.002>

Leminen, S. & Westerlund, M. (2017). Categorization of Innovation Tools in Living Labs. *Technology Innovation Management Review*, 7, 15–25. <https://doi.org/http://doi.org/10.22215/timreview/1046>

Swan, W., Fitton, R., Smith, L., Abbott, C., & Smith, L. (2017). Adoption of sustainable retrofit in UK social housing 2010-2015. *International Journal of Building Pathology and Adaptation*, 35(5), 456–469. <https://doi.org/10.1108/IJBPA-04-2017-0019>

## **URBAN SUSTAINABILITY**

## SUSTAINABLE CITIES: URBAN TRANSITION LABS AS INNOVATION CATALYSTS

Yreilyn Cartagena<sup>1\*</sup>

Which is the city's role in the future? How to create a sustainable city? The involvement and empowerment of communities are essential to respond to the challenges of sustainable urban development (Nastran, 2019). A well-known urgent global need to find innovative and sustainable solutions to protect the environment and prevent climate change has spread to different groups involved in urban planning. Therefore, in recent years, the concept of the urban laboratory has become popular. According to Loorbach (2009), it is about platforms and organisations that help municipalities and governments find innovative solutions to the different problems and challenges in cities, inspiring cities to innovate in the search for answers to complex issues and demonstrating the potential of urban laboratories catalysts for innovation.

Although each laboratory and city are different, their main characteristics are focused on working with the community as protagonists, both to identify the problem and the solution. The laboratories put the citizen at the centre of decision-making; they work together with the same purpose and function as their representatives in public administration. Consequently, the objective is to find long-term and far-reaching solutions. The laboratories test small-scale and low-cost pilots to identify what works and thus incorporate the learning more quickly, promoting a cultural change in how a municipality works towards a more creative, flexible, collaborative paradigm with greater tolerance for failure (Bulkeley and Betsill, 2005).

Cities are changing, tourism is growing, commercial activity is growing, and the aesthetics of squares and neighbourhoods are changing, but differences and conflicts are also increasing (Ecosistema Urbano, 2021). Currently, spaces do characterise by the concentration of people; these are environments where there are certain economic activities and social exchanges. The dehumanisation of processes reflects in the speed at which our cities are growing and stop considering the human or a person's experience (Del Caz Enjuto, 2013). For this reason, there are many simplistic solutions around the world, increasing the chaos or degrading the environment (Zipperer et al., 2020).

Responding to current global issues, urban living labs enter the scene, becoming more and more common in our cities. It is an open digital platform for urban innovation dedicated to researching, exploring, reflecting on, and disseminating knowledge and experiences related to the territory and its urban environments. In general, Bulkeley (2016) says that the Urban Living Labs (ULL) come from the traditional "Living Labs" from diverse fields. It also includes observation through various tools, working in an open and global network synchronously and asynchronously to get closer to the local reality.

As a case study, the research seeks to renew observational traditional methodological perspectives as tools to build this urban analysis in Bologna town centre and understand it as a conceptual vision, weaknesses, and strengths. As "situations" occur, sounds, silences, and behaviours have been addressed through external lenses and walks. The mirror process is the university environment, which has always been at the centre of the debate, crossed by that variety of souls that have made it unique and representative of Bologna. (Cartagena, 2022)

An exploration by a psychogeography walk and ethnography as a strategy describes the town in a socio-cultural sense, looking into the local community. The methodology used in this research follows these criteria; Psychogeography and ethnography as methods to map temporary interventions in the town centre by the development of the drifts, preparation of the Psychogeography and ethnography maps with the collected data, writing, analysis of results, conclusions, and presentation of the study. It focuses on the interventions by "Innovazione Urbana Lab/Laboratory of Urban Innovation" & ROCK Bologna; both centres for analysis, communication, elaboration and co-production on urban transformations. Whose activities intend to arise with the cooperation between the Bologna City Council, the University, and other city partners, to develop strategic projects for Bologna.

---

<sup>1</sup> Centre for Urban Design, Architecture and Sustainability, School of Arts and Humanities, University of Huddersfield, UK.  
ORCID 0000-0002-1962-3350

\* Corresponding author Email: [Y.DV.CartagenaDelgado@hud.ac.uk](mailto:Y.DV.CartagenaDelgado@hud.ac.uk)

These Labs implement different techniques for citizen innovation with the necessary public policies, such as:

the exploration of the city to analyse the problems to be dealt with;

experimenting by putting ideas into practice and testing them temporarily for evaluation and redesign with the review, analyse the impacts, effects, and profitability of the pilot projects.

The connection of diverse sectors of Bologna with technical organisations through creative financial solutions leads to the communication and presentation of the results of each intervention (Foundation for Urban Innovation, 2018). However, cities have undergone significant changes after the pandemic, adjusting the changing demand to new contexts. It reveals that experimentation spaces must continually question their objectives and tools to develop solutions to urban challenges and create future visions about which to build regenerate cities (ISPRA, 2021).

With the arrival of COVID-19, the world population had to abruptly face the freezing of public life and the urban, economic, and social havoc that the pandemic would detonate. After the first confirmed local case in March 2020, confinement measures and general mobility restrictions began to be implemented (Newman, Hargroves, Desha & Izadpanahi, 2021). However, for a large part of the population, it was not a possibility to cope with prolonged/total confinement. After the first semester of the pandemic, various urban innovations and public policies began to emerge globally that positioned public space as an ally for the reactivation of cities: emerging bike lanes, widening sidewalks, pop-up markets, the readaptation of streets, parks, and squares for the use of outdoor space, among others (Andreucci, 2021).

During the lockdown, COVID-19 tested the functioning of governments globally. Quickly responding to the challenges of the pandemic became a priority. Here is where the innovative culture, resilience and adaptability played a fundamental role in the opportunity to improve the quality of public spaces to direct them to be allies of post-pandemic recovery (D'Onofrio & Trusiani, 2022). One of the most important characteristics of urban laboratories to support sustainable development is participatory methodologies or citizen participation. It refers to citizens' active and direct involvement in matters of public life that are of interest to them, doing so through their participation in the management of said decisions (Tricarico & De Vidovich, 2021).

To sum up, the main objective of Urban Living Labs (ULL) is to articulate the different actors involved in territorial development, such as academia, the public and private sectors, and civil society, with urban problems. What is the future of these laboratories? Moreover, how can territorial interventions be generated that enable a transformation in people's quality of life? This abstract discusses these challenges and the different social, environmental, and technological challenges that cities constantly face.

## REFERENCES

- Andreucci, M. (2021). The Role of Nature in Urban Regeneration. *Nature-Based Solutions For More Sustainable Cities – A Framework Approach For Planning And Evaluation*, 111-123. doi: 10.1108/978-1-80043-636-720211011
- Bulkeley, H., & Betsill, M. (2005). Rethinking sustainable cities: Multilevel governance and the urban politics of climate change. *Environmental politics*, 14(1), 42-63.
- Bulkeley, H., Coenen, L., Frantzeskaki, N., Hartmann, C., Kronsell, A., Mai, L., ... & Palgan, Y. V. (2016). Urban living labs: governing urban sustainability transitions. *Current Opinion in Environmental Sustainability*.
- Cartagena, Y. (2022) Temporary urbanism and community engagement: A case study of Piazza Scaravilli in Bologna
- Del Caz Enjuto, R. (2013) The dehumanization of the city: the car and the invasion of public space.
- D'Onofrio, R., & Trusiani, E. (2022). The Future of the City in the Name of Proximity: A New Perspective for the Urban Regeneration of Council Housing Suburbs in Italy after the Pandemic. *Sustainability*, 14(3), 1252. doi: 10.3390/su14031252
- Ecosistema Urbano, trend negativo per Bologna. (2021). Presentation, Ecosistema Urbano, Bologna.
- Fondazione Innovazione Urbana. (2022). Retrieved 4 April 2022, from <https://www.fondazioneinnovazioneurbana.it/>
- La pandemia e i rifiuti urbani: i dati ISPRA del 2020. (2021). Presentation, Ispra Urban Waste Report 2021 edition.
- Loorbach, D. (2009, May). Urban transitions and urban transition management. The case of Rotterdam.

In Workshop on Urban Transitions.

Nastran, M. (2019). Co-creating urban green infrastructure connecting people and nature: A guiding framework and approach. *Journal of Environmental Management*.  
<https://doi.org/10.1016/j.jenvman.2018.09.083>

Nevens, F., Frantzeskaki, N., Gorissen, L., & Loorbach, D. (2013). Urban Transition Labs: co-creating transformative action for sustainable cities. *Journal Of Cleaner Production*, 50, 111-122. doi: 10.1016/j.jclepro.2012.12.001

Newman, P., Hargroves, K., Desha, C., & Izadpanahi, P. (2021). Introducing the 21st Century Boulevard: A Post-COVID Response to Urban Regeneration of Main Road Corridors. *Current Urban Studies*, 9(4), 831-854.

Tricarico, L., & De Vidovich, L. (2021). Proximity and post-COVID-19 urban development: Reflections from Milan, Italy. *Journal Of Urban Management*, 10(3), 302-310. doi: 10.1016/j.jum.2021.03.005

Zipperer, W. C., Northrop, R., & Andreu, M. (2020). Urban development and environmental degradation. *Oxford Research Encyclopedia of Environmental Science*, 2020.

## THE QUEST FOR DEVELOPING A NEIGHBOURHOOD SUSTAINABILITY ASSESSMENT TOOLS

Benedict Okundaye<sup>1\*</sup>, Alireza Moghayedi<sup>2</sup>, Patricia Tzortzopoulos<sup>3</sup>, Yun Gao<sup>4</sup>, Kathy Michell<sup>5</sup>

Developing nations lack the technological skill, infrastructure, and ability to tackle or plan for environmental and social sustainability or resilience to emerging global adversities (UN, ND; Utoikamanu, 2018; El Hajj, Montes, & Jawad, 2021). Cities house more than 50% of the planet's population in neighbourhoods and can suffer from global and local manmade and natural catastrophes (United Nations, 2020)— with urban migration to cities expected to increase (Obebe, Kolo, Enagi, & Adamu, 2020). Rapid urbanisation and pandemics are posing a growing number of challenges to both rich and impoverished neighbourhoods globally (United Nations, 2020; C40, 2020; TDHCA, 2007; UN-Habitat,, 2018). The global neighbourhood challenges, especially in developing countries such as in South Africa, include pollution poverty, energy poverty, digital poverty, environmental degradation, and socioeconomic inequalities in the post-apartheid era (ESCAP, Chapter 9: South and South-West Asia, 2005; ESCAP, Environment and Development Series 2018, 2018; Baloch, Danish, Khan, & Ulucak, 2020; EC, ND; Lemon, 2021; UN, ND). Furthermore, 1.34 billion inhabitants migrate to African cities by 2050 (Cartwright, 2015). There is an urgent need to strengthen the environmental and socioeconomic capability of the neighbourhood to increase community engagement and the assessment framework for sustainable development. The importance of the neighbourhood scale as a recovery-point in the development of a sustainable urbanity cannot be overstated (Dawodu, Akinwolemiwa, & Cheshmehzangi, 2017).

These challenges amplify three reasons for developing an assessment tool that aid in building resilient and sustainable neighbourhoods. (1.) Because of the linked socioeconomic and environmental friction with the built environment, new conceptual ideas and technological analytical methodologies that may integrate sustainable components to tackle such environmental and socioeconomic inequities in neighbourhoods are crucial (Subramanian, Chopra, Cakin, Liu, & Xu, 2021). (2.) To determine the extent to which neighbourhoods have succeeded in achieving their economic, social, and environmental objectives (Sharifi & Murayama, 2013). (3.) To help guide neighbourhood planning— promoting inclusivity, as neighbourhood planning allows communities to have a far bigger role in determining where they live and work, also supporting new social interactive technologically enabled sustainable development initiatives. Understanding the characteristics that determine residential happiness and neighbourhood resilience to the enviro-socioeconomic climate, for example, is essential for designing a long-term rehabilitative housing strategy (Kshetrimayum, Bardhan, & Kubota, 2020). It is critical to resolve the current and strategise for future South African neighbourhood issues of pollution, poverty, healthcare, and wellness, and environmentally sustainable modernisation. There are no well-established neighbourhood sustainability assessment methodologies that can singularly and comprehensively quantify or analyse the breadth of sustainability factors that neighbourhoods face to ensure their long-term viability. At the neighbourhood scale, most mainstream techniques and frameworks focus on social, economic, and environmental aspects. It is debatable to ignore the socio-environmental and socio-political factors that impact future or existing neighbourhood sustainability— as much as not incorporating simple accessible; technological, digital, and remote-based strategies or methodologies than can help tackle the issues of sustainability and neighbourhood resilience.

However, major neighbourhood evaluation systems such as BREEAM Community, LEED-ND, Green Star-Community, and CASBEE-UD are not well suited for use outside of their respective countries of origin and local context (Hilley & Sim, 2020; Yigitcanlar, Kamruzzaman, & Teriman, 2015), needing further customisations to foreign contexts (Cheshmehzangi, Dawodu, Song, Shi, & Wang, 2020; DOUSSARD, 2017). As a result, this project aims to develop a framework for assessing and investigating sustainability of neighbourhoods and the impact on QoL in the context of the neighbourhood.

The study research methodologies (Triangulation) incorporate IBM-SPSS and BIM digital technologies in statistical computing and analysing environmental, spatial, socioeconomic, and demographic data, and spatial

<sup>1</sup> School of Arts and Humanities, University of Huddersfield, UK. ORCID 0000-0002-8794-3647

<sup>2</sup> School of Arts and Humanities, University of Huddersfield, UK. ORCID 0000-0002-4165-0777

<sup>3</sup> School of Arts and Humanities, University of Huddersfield, UK. ORCID 0000-0002-8740-6753

<sup>4</sup> School of Arts and Humanities, University of Huddersfield, UK. ORCID 0000-0001-6097-9503

<sup>5</sup> University of Cape Town, South Africa. ORCID 0000-0002-3907-7393

\* Corresponding author Email: Benedict.Okundaye@hud.ac.uk

identifications. It employs such processes as regression, validation, and reliability test. It integrates, neighbourhood, development, and past/present/future site information to contextualising project environment and contribute to a better comprehension of challenges linked to socioeconomic or enviro-political climate, the surrounding systems, and resources.

## OBJECTIVES

Develop a conceptual framework for assessing and evaluating sustainability of the neighbourhood environment, and its impact on neighbourhood quality-of-life in South Africa. To develop applicable neighbourhood assessments methods, systems, and processes.

Analyse geographic, spatial, and demographic data with the aid of BIM creating a digital picture through digital imagery and collected information data, to create outcomes. An aid in improving efficiencies in both decision-making and collaborative process. Determine which sustainability pillars and factors from the conceptual framework significantly impact the sustainability and QoL in of selected of South African neighbourhood. Which can be stored and access through a BIM data base.

## REFERENCES

- Baloch, M. A., Danish, Khan, S. U.-D., & Ulucak, Z. Ş. (2020). Poverty and vulnerability of environmental degradation in Sub-Saharan African countries: what causes what? *Structural Change and Economic Dynamics*, 54, 143-149.
- C40. (2020, November 9). 1,000 cities racing to zero emissions. Retrieved from UN Race to Zero: <https://racetozero.unfccc.int/1000-cities-racing-to-zero-emissions/>
- Cartwright, A. (2015, no date no date). Better Growth, Better Cities: Rethinking and Redirecting Urbanisation in Africa. Retrieved from New Climate Economy: Working Paper: <https://www.cisl.cam.ac.uk/about/contact/cape-town/pdfs/NCE-APP-final.pdf>
- Cheshmehzangi, A., Dawodu, A., Song, W., Shi, Y., & Wang, Y. (2020). An Introduction to Neighborhood Sustainability Assessment Tool (NSAT) Study for China from Comprehensive Analysis of Eight Asian Tools. *Sustainability*, 12(6), 1-29. doi:<https://doi.org/10.3390/su120>
- Dawodu, A., Akinwolemiwa, B., & Cheshmehzangi, A. (2017). A conceptual re-visualization of the adoption and utilization of the Pillars of Sustainability in the development of Neighbourhood Sustainability Assessment Tools. *Sustainable Cities and Society*, 398-310. doi:10.1016/j.scs.2016.11.001
- DOUSSARD, C. (2017). ASSESSMENT OF SUSTAINABLE NEIGHBOURHOODS: FROM STANDARDS TO CULTURAL PRACTICES. *International Journal of Sustainable Development and Planning*, 12(3), 368-378. doi:DOI: 10.2495/SDP-V12-N3-368-378
- EC, E. C. (ND). Environment-International Issues: International Issues Africa. (European Commission website) Retrieved February 28, 2022, from [https://ec.europa.eu/environment/international\\_issues/relations\\_africa\\_en.htm](https://ec.europa.eu/environment/international_issues/relations_africa_en.htm)
- El Hajj, C., Montes, G. M., & Jawad, D. (2021). An overview of BIM adoption barriers in the Middle East and North Africa developing countries. *Engineering, Construction and Architectural Management*, 1-25. Retrieved from <https://www.emerald.com/insight/content/doi/10.1108/ECAM-05-2021-0432/full/pdf?title=an-overview-of-bim-adoption-barriers-in-the-middle-east-and-north-africa-developing-countries>
- ESCAP. (2005). Chapter 9: South and South-West Asia. In *ESCAP, State of the Environment in Asia and the Pacific* (pp. 259-278). UN. Retrieved from [https://www.unescap.org/sites/default/d8files/Part4\\_09.pdf](https://www.unescap.org/sites/default/d8files/Part4_09.pdf)
- ESCAP. (2018). *Environment and Development Series 2018: Harnessing environmental action for sustainable development in Asia and the Pacific*. UN. Bangkok: United Nations publication. Retrieved from [https://www.unescap.org/sites/default/d8files/knowledge-products/ST2849\\_Environment%20and%20Development%20Series%202018\\_final.pdf](https://www.unescap.org/sites/default/d8files/knowledge-products/ST2849_Environment%20and%20Development%20Series%202018_final.pdf)
- Hilley, J., & Sim, S. (2020). Context-Based Neighborhood Sustainability Assessment in Birmingham, Alabama. *Sustainability*, 12(22), 1-18. doi:<https://doi.org/10.3390/su12229426>
- Kshetrimayum, B., Bardhan, R., & Kubota, T. (2020). Factors affecting residential satisfaction in slum rehabilitation housing in Mumbai. *Sustainability*, 12(6), 1-22. doi:<https://doi.org/10.3390/su12062344>
- Lemon, A. (2021). The Apartheid City. In A. Lemon, R. Donaldson, & G. Visser (Eds.), *The apartheid city*. In *South African Urban Change Three Decades After Apartheid* (pp. 1-16). Cham: Springer.
- Obebe, S. B., Kolo, A., Enagi, I. S., & Adamu, A. A. (2020). FAILURE IN CONTRACTS IN NIGERIAN CONSTRUCTION PROJECTS: CAUSES AND PROFFERED POSSIBLE SOLUTIONS. *International Journal of Engineering Applied Sciences and Technology*, 679-692.

QI, Z. (2019). A CONTEXTUAL FRAMEWORK FOR SUSTAINABLE NEIGHBOURHOOD PLANNING IN TRANSITIONAL URBAN CHINA: A CASE OF CHENGDU CITY. Thesis. Hong Kong: The Hong Kong Polytechnic University.

Sharifi, A., & Murayama, A. (2013). A critical review of seven selected neighborhood sustainability assessment tools. *Environmental Impact Assessment Review* , 38, 73–87.

Subramanian, K., Chopra, S. S., Cakin, E., Liu, J., & Xu, Z. (2021). Advancing neighbourhood sustainability assessment by accounting for sustainable development goals: A case study of Sha Tin neighbourhood in Hong Kong. *Sustainable Cities and Society*, 66, 1-18. doi:<https://doi.org/10.1016/j.scs.2020.102649>.

TDHCA. (2007). 2007 State of Texas Low Income Housing Plan and Annual Report. Austin: Texas Department of Housing and Community Affairs.

UN Habitat . (2015, May 31). Retrieved January 16, 2019, from [https://unhabitat.org/.../Habitat-III-Issue-Paper-22\\_Informal-Settlements.pdf](https://unhabitat.org/.../Habitat-III-Issue-Paper-22_Informal-Settlements.pdf)

UN. (ND). Goal 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation. (United Nations) Retrieved February 21, 2022, from <https://www.un.org/sustainabledevelopment/infrastructure-industrialization/>

UN-Habitat,. (2018, May 31). International Conference on Climate Change and Cities. Nairobi: United Nations Human Settlements Programme (UN-Habitat). Retrieved January 16, 2019, from UN Habitat: <https://unhabitat.org/sites/default/files/2021/03/Cities%20IPCC%20Proceedings%20FINAL%20for%20Email-S.pdf>

United Nations. (2020, July 7). Make cities and human settlements inclusive, safe, resilient and sustainable. Retrieved from Sustainable Development Goal: <https://unstats.un.org/sdgs/report/2020/The-Sustainable-Development-Goals-Report-2020.pdf>

Utoikamanu, F. (2018). UN Chronicle: Closing the Technology Gap in Least Developed Countries. (UN ) Retrieved April 17, 2022, from <https://www.un.org/en/chronicle/article/closing-technology-gap-least-developed-countries>

Yigitcanlar, T., Kamruzzaman, M., & Teriman, S. (2015). Neighborhood Sustainability Assessment: Evaluating Residential Development Sustainability in a Developing Country Context. *Sustainability* , 7, 2570-2602. doi:[doi:10.3390/su7032570](https://doi.org/10.3390/su7032570)

## **DIGITALISATION & AUTOMATION**

# DIGITAL BUILDING PERMIT BASED ON AUTOMATED CHECKING SYSTEMS: AN INVESTIGATION FROM THE AEC SECTOR OF A BRAZILIAN MUNICIPALITY

Douglas Malheiro de Brito<sup>1</sup>, Dayana Bastos Costa<sup>2\*</sup>, and Emerson de Andrade Marques Ferreira<sup>3</sup>

## INTRODUCTION

Digitization is currently one of the main driving forces of society and has been materialising in many fields, including building permits. In a digital society, efficient processes require exchanging and integrating digital information between actors and processes, considering technical, legal, and commercial aspects (Olsson et al., 2018). Electronic permitting systems have become popular in recent years due to this scenario and its growing global recognition (Shahi et al., 2019).

The main advantages of these systems are the increase in efficiency by promoting faster permit processing, greater transparency in the approval process, and agility in document analysis and reviews (Whitel et al., 2019). In addition to time and cost savings, tax revenue growth, citizen empowerment, the attraction of business investment, and improved coordination are also noteworthy (Messaoudi and Nawari, 2021).

According to Olsson et al. (2018), although many of the techniques developed for automated code checking should be applicable or customisable to the field of digital permitting, a vital difference is a greater dependence on geospatial data. It demands the integration of Building Information Modelling (BIM) with the Geographic Information System (GIS), called GeoBIM.

Thus, the development of the most advanced systems already includes this ability to take advantage of the latest technological advances in the industry, represented by BIM and GIS (Whitel et al., 2019). However, the semantic richness of the BIM models developed by designers and the digital geospatial data of the municipalities are still not adequately used in the permitting process (Olsson et al., 2018).

The leading international initiatives identified in the literature as pioneers in digital building permits to automate code checking are located in South Korea (Kim et al., 2020), Singapore (Hjelset, 2015), Finland (Noardo et al., 2020), United Arab Emirates / Portugal (European Spatial Data Research, 2021), Estonia (Ullah et al., 2022), Canada (Whitel et al., 2019), Norway (Hjelset, 2015), United Kingdom (Beach et al., 2020), Sweden (Olsson et al., 2018), Switzerland (Chognard et al., 2018), Chile (DOM en línea, 2022), Australia (Victorian Building Authority, 2022), and Germany (Borrmann et al., 2021). Most of the systems are still under development, expected to be completed in the coming years, especially in North America, Europe, and Asia.

In the context of developing countries, Brito et al. (2022) analysed the building permit digitization in a Brazilian municipality to identify the best practices and lessons learned. However, for Noardo et al. (2022), the topic is broad and complex, with many sub-questions and uncertainties, which prevented many of the studies of the last decade from having the expected development. Therefore, in continuity with the study of Brito et al. (2022), this research aims to analyse stakeholders' perceptions in the Architecture, Engineering and Construction (AEC) sector about the building permitting digitisation in a Brazilian municipality, including the professionals responsible for the design and the municipality team responsible for code checking. This study is part of doctoral research that proposes a model for digital building permits in municipalities using GeoBIM.

## RESEARCH METHOD

The research method adopted in this study includes four stages: literature review, data collection through surveys, data analysis, and discussion of results. The awareness stage encompasses a comprehensive review of existing initiatives and literature on digital building permits and automating code checking. In addition to evaluating scientific papers, regulations (such as ISO-19650) and technical publications, documents issued by

---

<sup>1</sup> Post-Graduation Program in Civil Engineering, Federal University of Bahia, Brazil

<sup>2</sup> Department of Structural and Construction Engineering, Federal University of Bahia, Brazil. ORCID 0000-0002-1457-6401

<sup>3</sup> Department of Structural and Construction Engineering, Federal University of Bahia, Brazil. ORCID 0000-0001-9219-5447

\* Corresponding author Email: [dayanabcosta@ufba.br](mailto:dayanabcosta@ufba.br)

the Regulatory Room of buildingSMART International, and ongoing projects by the European Network for Digital Building Permits (EUnet4DBP) were considered.

Then, the data collection to carry out the surveys occurred through digital questionnaires formed by multiple-choice questions and a five-level Likert scale. The sample of stakeholders from the AEC sector involved in the building permitting digitisation belongs to a large Brazilian municipality with around three million inhabitants. The first questionnaire was answered by professionals responsible for checking projects in the municipality. At the same time, the second was aimed at professionals involved in building permits, such as applicants and designers.

The analysis of the collected data will allow investigating the perception of internal and external professionals about the actions taken by the municipality during the internal stage for developing the automated code checking system and promoting changes in processes, policies, and organisational culture. Finally, the discussion stage of the results aims to formalize this research's theoretical and practical contributions.

## FINDINGS

Preliminary results reveal the municipal team's perception of digitalisation in aspects such as expectations and reliability in automated checks, the degree of familiarity and operability with the platform, the degree of motivation and satisfaction with organisational training actions, and with the implementation process.

The survey with external stakeholders from the local AEC sector indicates the perception of professionals about digitalisation in terms of the degree of companies' readiness to submit a design in BIM for planning approval, awareness of the requirements during the preparation of the model and classification of elements, adoption of ISO-19650, expectations regarding deadlines for obtaining permits and reliability in automated checks, the value generated for the AEC sector and the degree of satisfaction with the implementation process. A comparative analysis of the perceptions of internal and external stakeholders regarding the digitisation of the municipality was conducted to identify discrepant views and opportunities for improvements to the implementation.

One of the academic contributions is an in-depth analysis of a digitisation experience in a developing country to automate code checks and a greater understanding of municipalities' practices to accelerate the process and automate non-value adding necessary tasks. As a practical contribution, the perceptions identified can be used as inputs for improvements in digitisation and facilitate other municipalities to anticipate the alignment between the stakeholders that are part of the local AEC sector. Future research may conduct case studies and surveys in other international initiatives to investigate, in more detail, the implementation of these best practices within the organisational, procedural, and technological context of the municipalities.

## REFERENCES

- Beach, T. H, Hippolyte, J., Rezgui, Y. 2020. Towards the adoption of automated regulatory compliance checking in the built environment. *Automation in Construction*. 118, 103285.
- Borrmann, A., Forster, C., Liebich, T., König, M., Tulke, J. Germany's Governmental BIM Initiative – The BIM4INFRA2020 Project Implementing the BIM Roadmap. In: Toledo Santos E., Scheer S. (eds) *Proceedings of the 18th International Conference on Computing in Civil and Building Engineering. ICCCBE 2020. Lecture Notes in Civil Engineering*, vol 98. Springer, Cham. 2021.
- Brito, D.M.; Costa, D.B.; Ferreira, E.A.M. Code Checking using BIM for Digital Building Permit: a case study in a Brazilian municipality. In *Proceedings of the CIB World Building Congress 2022 (WBC 2022)*, Melbourne, Australia, 27–30 June 2022.
- Chognard, S., Dubois, A., Benmansour, Y., Torri, E., & Domer, B. Digital Construction Permit: A Round Trip Between GIS and IFC. *Lecture Notes in Computer Science*, 287–306. 2018.
- DOM en línea. 2022. Accessed 14 February 2022 <<https://domenlinea.minvu.cl/>>
- European Spatial Data Research. Digital Building Permit: a State of Play. 2021.
- Hjelseth, E. 2015. Public BIM-based model checking solutions: lessons learned from Singapore and Norway. *Building Information Modelling (BIM) in Design, Construction and Operations*, 149, 421–436.
- Kim, I., Choi, J., Teo, E.A.L., Sun, H. 2020. Development of KBIM e-submission prototypical system for the

openBIM-based building permit framework. *Journal of Civil Engineering and Management*. 26 (8), 744-756.

Messaoudi, M., Nawari, N. O. 2021. Virtual Permitting Framework for Off-site Construction Case Study: A Case Study of the State of Florida, In: Toledo, E., Scheer, S.S. *International Conference on Computing in Civil and Building Engineering*, São Paulo, Brazil on August 18-20. Cham: Springer, 757-771.

Noardo, F., Malacarne, G., Mastrolembo, S., Tagliabue, L.C., Ciribini, A.L.C., Ellul, C., Guler, D., Harrie, L., Senger, L., Waha, A., Stoter, J., 2020. Integrating expertises and ambitions for data-driven digital building permits – The EUNET4DBP. In: *3rd BIM/GIS Integration Workshop and 15th 3D GeoInfo Conference*, 7–11 September 2020, London, UK. XLIV-4/W1-2020, 103–110.

Noardo, F., Wu, T., Arroyo Otori, K., Krijnen, T., Stoter, J. 2022. IFC models for semi-automating common planning checks for building permits. *Automation in constructions*, 134, 104097.

Olsson, P., Axelsson, J., Hooper, M., Harrie, L. 2018. Automation of building permission by integration of BIM and geospatial data. *International Journal of Geo-Information*. 7 (8), 307.

Shahi, K., McCabe, B.Y., Shahi, A. 2019. Framework for Automated Model-Based e-Permitting System for Municipal Jurisdictions. *Journal of Management in Engineering*. 35 (6), 04019025.

Ullah, K., Witt, E., Lill, I. The BIM-Based Building Permit Process: Factors Affecting Adoption. *Buildings* 2022, 12, 45.

Victorian Building Authority. 2022. State Government of Victoria. Accessed 12 February 2022 <<https://www.vba.vic.gov.au/about/research/digital-twin-initiative-ecomply/>>

Whitel, M., Cao, Y., McCabe, B. Y., Shahi, A. 2019. Standardizing Ontario's Permitting Process for E-Permitting Implementation, In: *Construction Research Congress 2020*, March 8–10, 2020, Tempe, Arizona. 1339-134

# USING DIGITAL TECHNOLOGIS FOR AUTOMATED IDENTIFICATION OF BUILDING PATHOLOGIES: A LITERATURE REVIEW

Alisson de Souza da Silva<sup>1</sup>, Dayana Bastos Costa<sup>2\*</sup>

## INTRODUCTION

The assessment of building assets is essential for managers to assess structural integrity and operability, thus estimating maintenance or rehabilitation needs. However, this evaluation is usually based on information obtained through visual and manual inspections (Stochino et al., 2018) which are considered slow, laborious, expensive, and unsafe (Hoang, 2018; Ribeiro et al., 2020; Dais et al., 2021; Guo; Wang; Li, 2021).

According to Kumarapu, Shashi, and Keesara (2021), digital technologies, such as drones and computer vision techniques are needed to overcome these building assessment limitations, automating these processes, making them more agile, safer, and more accurate. Therefore, seeking to contribute to research in this area, this study aims to identify the trends and capabilities of digital technologies for collecting and processing data used for the automated identification of pathologies in buildings.

## RESEARCH METHOD

This study presents a Systematic Literature Review (SLR) to answer the following research questions: (1) "What digital technologies are being used for the automated identification of pathologies in construction?" (2) "How do these technologies help managers in decision-making?". The PICO (Population, Intervention, Comparison, and Outcome) strategy (Donato and Donato 2019) was applied to support the definition of search terms, as shown in figure 1.

PICO	Variables	Search Terms
Population	Construction	"Construction" OR "AEC" OR "Building" OR "Infrastructure" OR "Construction industry"
Intervention	Activity	"Inspection" OR "investigation" OR "facade" OR "roof" OR "quality control"
Comparasion	Data collection	"UAS" OR "UAV" OR "Unmanned Aerial Vehicles" OR "Unmanned Aerial Systems" OR "Unmanned Aircraft System"
	Image processing	"Crack detection" OR "Damage detection" OR "Image classification" OR "Image Captioning"
	Data analysis	"Artificial intelligence" OR "Image processing" OR "Deep learning" OR "Machine Learning" OR "Convolutional neural network" OR "CNN"

**Figure 1- PICO Strategy**

The PRISMA (Preferred Reporting Items of Systematic Reviews and Meta-Analyses) guidelines were followed to perform the SLR, limiting the searches with inclusion and exclusion criteria. Initially, the searches were carried out in the Scopus, IEEE Xplore, and Web of Science databases, identifying 132 articles. The inclusion criteria established were: (1) Articles that have the search terms at least in the title, abstract, or keywords; (2) Applications in the area of AECO (Architecture, Engineering, Construction, and Operation), buildings and infrastructure, and (3) Articles published in high impact journals. The exclusion criteria were: (1) Subarea: Engineering, Language: English and Document type: Articles, (2) Articles with duplication between the databases, and (3) Publications outside the topic. After the inclusion and exclusion filters, the final sample consisted of 29 articles.

## FINDINGS

The 29 articles selected in the sample are distributed in 17 journals. The journal with the highest number of publications is Computer-Aided Civil and Infrastructure Engineering, with four publications, followed by Automation in Construction and Sensors, with three publications each. The other journals had two and one

<sup>1</sup> Federal University of Bahia, Brazil. ORCID: 0000-0003-2218-1749

<sup>2</sup> Federal University of Bahia, Brazil. ORCID: 0000-0002-1457-6401

\* Corresponding author Email: dayanabcosta@ufba.br

publication, respectively. The articles were also grouped according to the typology of construction studied. 15 publications (51.73% of the sample) used digital technologies to automate the pathologies identification regarding infrastructures such as bridges, roads, and steel and concrete structures. Ten publications (34.48%) used digital tools in building elements such as walls, roofs, and facades, and finally, four papers (13.79%) considered both building and infrastructure. In addition, the digital technologies used were analysed.

### **DATA COLLECTION TECHNOLOGIES IN THE AUTOMATED IDENTIFICATION OF PATHOLOGIES IN BUILDINGS**

The sample shows that the primary digital technologies for data collection were drones with attached cameras. Most of them were commercial drones from Da-Jiang Innovations (DJI) like the DJI Phantom with GoPro Hero 3 attached (Ellenberg et al., 2016), the DJI F550 (Kang; Young-Jin, 2018), the DJI Matrice 100 (Ayele et al., 2020), the DJI Matrice 600 Pro (Ribeiro et al., 2020; Zhu et al., 2022), the DJI F450 Quadcopter (Oh et al., 2021), the DJI Ryze Tello (Bouzan et al., 2021), among other models (Vetrivel et al., 2018; Morgenthal et al., 2019; Kung et al., 2022). Also, proprietary models have been proposed, such as climbing drones (Jiang; Zhang, 2020; Hoskere et al., 2020).

Furthermore, Valença et al. (2017) used images collected by drones, terrestrial photographs, and laser scans. Similarly, Castagno and Atkins (2018) and Bhowmick, Satish, and Ashok (2020) used georeferenced satellite and satellite imagery point clouds from drone flights with LiDAR (Light Detection and Ranging). Some authors used high-resolution manual cameras to obtain images with depth and RGB information (Red, Green, and Blue) (Kim et al., 2021).

Other authors used images from literature databases (internet) due to the practicality, quantity, and quality of images available for training since these are crucial factors for the efficiency of the process (Vijayanandh et al., 2017; Flah et al., 2020; Ghosh Mondal et al., 2020; Liu et al., 2020; Le et al., 2021; Perry et al., 2022).

### **DATA PROCESSING TECHNOLOGIES IN THE AUTOMATED IDENTIFICATION OF PATHOLOGIES IN BUILDINGS**

The sample shows that most authors used artificial intelligence and machine learning subsets such as Convolutional Neural Networks-CNN (Kang; Young-Jin, 2018; Yeum et al., 2019; Flah et al., 2020; Bouzan et al., 2021; Zhu et al., 2022). Several studies used CNN subsets such as AlexNet (Dorafshan et al., 2018; Yeum et al., 2019), MaDnet (Hoskere et al., 2020), ImageNet (Kung et al., 2021), U-Net (Bhowmick et al., 2020; Perry et al., 2022), among others.

The system proposed by Wu et al. (2021) used RBG-Net\_LWLC + ME and could detect rail surface defects efficiently while remaining at a reasonable processing speed. Le et al. (2021) proposed a CNN model that achieved excellent classification performance, being precision (96.5%), recall (98.8%), specificity (96.6%), and score (97.7%) for the test dataset.

Moreover, some authors used more than one processing method to compare the most efficient one to machine learning subsets. Oh et al. (2021) used three contour detectors, Sobel, Laplacian, and Canny algorithms, concluding that the Canny algorithm presented the highest performance. Besides, Zhu et al. (2022) used three algorithms to train the proposed method, Faster R-CNN, YOLOv3, and YOLOv4. The algorithm with the highest performance was YOLOv3 because it is robust in recognizing cracks in different environments.

### **CONCLUSIONS**

A systematic literature review was carried out to identify trends and capabilities of digital data collection and processing technologies used for the automated identification of building pathologies. The results showed that drones with attached cameras were the most used digital technologies for data collection due to the speed and safety of this process. Machine learning subsets, mainly Convolutional Neural Networks (CNN) and their subsets, were the most used digital technologies for data processing because they present good performance, accuracy, and precision in this process.

There is an opportunity for further research in the technical and managerial areas when analysing the articles. Future research is required to improve the robustness of processing algorithms, seeking to identify problems and classify, differentiate or extract characteristics that can support managers in decision making. Furthermore, as processing performance depends on the quality of the data collected, surveys integrating more than one technology during collection can broaden the scope and capture more information about the object of interest.

The literature review shows that most studies were carried out in buildings during the use and occupation stage, creating opportunities for research during the execution stages once many pathologies arise during construction. In addition, incorporating the information obtained through automated inspections in the quality control process during execution can bring agility and effectiveness to this activity.

## REFERENCES

- Ayele, Y. Z., Aliyari, M., Griffiths, D., & Droguett, E. L. (2020). Automatic crack segmentation for UAV-assisted bridge inspection. *Energies*, 13(23), 6250.
- Bhowmick, S., Nagarajaiah, S., & Veeraraghavan, A. (2020). Vision and deep learning-based algorithms to detect and quantify cracks on concrete surfaces from UAV videos. *Sensors*, 20(21), 6299.
- Bouzan, G. B., Fazzioni, P. F., Faisca, R. G., & Soares, C. A. (2021). Building facade inspection: A system based on automated data acquisition, machine learning, and deep learning image classification methods. *ARPN Journal of Engineering and Applied Sciences*, 16(14), 1516.
- Castagno, J., & Atkins, E. (2018). Roof shape classification from LiDAR and satellite image data fusion using supervised learning. *Sensors*, 18(11), 3960.
- Dais, D., Bal, I. E., Smyrou, E., & Sarhosis, V. (2021). Automatic crack classification and segmentation on masonry surfaces using convolutional neural networks and transfer learning. *Automation in Construction*, 125, 103606.
- Donato, H., Donato, M. 2019. "Etapas na Condução de uma Revisão Sistemática." *Acta Médica Portuguesa*, 32(3), 227–235. <https://doi.org/10.20344/amp.11923>
- Dorafshan, S., Thomas, R. J., & Maguire, M. (2018). Comparison of deep convolutional neural networks and edge detectors for image-based crack detection in concrete. *Construction and Building Materials*, 186, 1031-1045.
- Ellenberg, A., Kotsos, A., Moon, F., & Bartoli, I. (2016). Bridge related damage quantification using unmanned aerial vehicle imagery. *Structural Control and Health Monitoring*, 23(9), 1168-1179.
- Flah, M., Suleiman, A. R., & Nehdi, M. L. (2020). Classification and quantification of cracks in concrete structures using deep learning image-based techniques. *Cement and Concrete Composites*, 114, 103781.
- Ghosh Mondal, T., Jahanshahi, M. R., Wu, R. T., & Wu, Z. Y. (2020). Deep learning-based multi-class damage detection for autonomous post-disaster reconnaissance. *Structural Control and Health Monitoring*, 27(4), e2507.
- Guo, J., Wang, Q., & Li, Y. (2021). Evaluation-oriented façade defects detection using rule-based deep learning method. *Automation in Construction*, 131, 103910.
- Hoang, N. D. 2018. "Image Processing-Based Recognition of Wall Defects Using Machine Learning Approaches and Steerable Filters." *Computational Intelligence and Neuroscience*.
- Hoskere, V., Narazaki, Y., Hoang, T. A., & Spencer Jr, B. F. (2020). MaDnet: multi-task semantic segmentation of multiple types of structural materials and damage in images of civil infrastructure. *Journal of Civil Structural Health Monitoring*, 10(5), 757-773.
- Jiang, S., & Zhang, J. (2020). Real-time crack assessment using deep neural networks with wall-climbing unmanned aerial system. *Computer-Aided Civil and Infrastructure Engineering*, 35(6), 549-564.
- Kang, D., & Cha, Y. J. (2018). Autonomous UAVs for structural health monitoring using deep learning and an ultrasonic beacon system with geo-tagging. *Computer-Aided Civil and Infrastructure Engineering*, 33(10), 885-902.
- Kim, H., Lee, S., Ahn, E., Shin, M., & Sim, S. H. (2021). Crack identification method for concrete structures considering angle of view using RGB-D camera-based sensor fusion. *Structural Health Monitoring*, 20(2), 500-512.
- Kumarapu, K., Shashi, M., & Keesara, V. R. (2021). UAV in Construction Site Monitoring and Concrete Strength Estimation. *Journal of the Indian Society of Remote Sensing*, 49(3), 619-627.
- Kung, R. Y., Pan, N. H., Wang, C. C., & Lee, P. C. (2021). Application of Deep Learning and Unmanned Aerial Vehicle on Building Maintenance. *Advances in Civil Engineering*.
- Le, T. T., Nguyen, V. H., & Le, M. V. (2021). Development of deep learning model for the recognition of cracks on concrete surfaces. *Applied Computational Intelligence and Soft Computing*.
- Liu, Y., Yeoh, J. K., & Chua, D. K. (2020). Deep learning-based enhancement of motion blurred UAV concrete crack images. *Journal of Computing in Civil Engineering*, 34(5), 04020028.
- Morgenthal, G., Hallermann, N., Kersten, J., Taraben, J., Debus, P., Helmrich, M., & Rodehorst, V. (2019). Framework for automated UAS-based structural condition assessment of bridges. *Automation in*

Construction, 97, 77-95.

Oh, S., Ham, S., & Lee, S. (2021). Drone-Assisted Image Processing Scheme using Frame-Based Location Identification for Crack and Energy Loss Detection in Building Envelopes. *Energies*, 14(19), 6359.

Perry, B. J., Guo, Y., & Mahmoud, H. N. (2022). Automated site-specific assessment of steel structures through integrating machine learning and fracture mechanics. *Automation in Construction*, 133, 104022.

Ribeiro, D., Santos, R., Shibasaki, A., Montenegro, P., Carvalho, H., & Calçada, R. (2020). Remote inspection of RC structures using unmanned aerial vehicles and heuristic image processing. *Engineering Failure Analysis*, 117, 104813.

Stochino, F., Fadda, M. L., & Mistretta, F. (2018). Low cost condition assessment method for existing RC bridges. *Engineering Failure Analysis*, 86, 56-71.

Valença, J., Puente, I., Júlio, E. N. B. S., González-Jorge, H., & Arias-Sánchez, P. (2017). Assessment of cracks on concrete bridges using image processing supported by laser scanning survey. *Construction and Building Materials*, 146, 668-678.

Vetrivel, A., Gerke, M., Kerle, N., Nex, F., & Vosselman, G. (2018). Disaster damage detection through synergistic use of deep learning and 3D point cloud features derived from very high resolution oblique aerial images, and multiple-kernel-learning. *ISPRS journal of photogrammetry and remote sensing*, 140, 45-59.

Vijayanandh, R., Senthil Kumar, M., Vasantharaj, C., Raj Kumar, G., & Soundarya, S. (2017). Numerical study on structural health monitoring for unmanned aerial vehicle. *Journal of Advanced Research in Dynamical and Control Systems*, 9(6), 1937-1958.

Wu, Y., Qin, Y., Qian, Y., Guo, F., Wang, Z., & Jia, L. (2021). Hybrid deep learning architecture for rail surface segmentation and surface defect detection. *Computer-Aided Civil and Infrastructure Engineering*, 37(2), 227-244.

Yeum, C. M., Choi, J., & Dyke, S. J. (2019). Automated region-of-interest localization and classification for vision-based visual assessment of civil infrastructure. *Structural Health Monitoring*, 18(3), 675-689.

Zhu, J., Zhong, J., Ma, T., Huang, X., Zhang, W., & Zhou, Y. (2022). Pavement distress detection using convolutional neural networks with images captured via UAV. *Automation in Construction*, 133, 103991.

# INSIGHTS ON THE DIGITAL TRANSFORMATION IN BRAZILIAN CONSTRUCTION COMPANIES FROM A SOCIOTECHNICAL PERSPECTIVE

Luara Lopes de Araujo Fernandes<sup>1</sup> and Dayana Bastos Costa<sup>2\*</sup>

## INTRODUCTION

The construction industry is under significant change resulting from the fourth industrial revolution, transforming it into a digitally developed trade (Alaoul et al., 2018). According to Tilson et al. (2021), digitalisation is "a sociotechnical process of applying digitising techniques to broader social and institutional contexts that render digital technologies infrastructural." In this process, organisations will need to understand how to use strategically and operationally digital technologies to access new opportunities and increase profitability (Boulton and Lamb, 2019).

However, differently from other sectors, construction has difficulties to embrace the opportunities offered by technology and advances in data management (Sawhney et al., 2020). Industry 4.0 is a significant challenge for the industry because of its low innovation culture and the demographics of its business, with a majority of small and medium enterprises with diverse technological maturity levels (Klink and Turk, 2019).

Therefore, this paper presents insights of an exploratory study that aims to analyse the digital transformation (DT) process in Brazilian construction companies from sociotechnical perspectives. In this study, the sociotechnical environment combines social, technical, and operational factors (Vlachos et al., 2021).

## RESEARCH METHOD

Case study was the research strategy adopted in this work. The data collection consisted of ten interviews carried out in six organisations. Four of the interviewed organisations are from the construction sector (A, B, C, and D), which is the focus of the analysis of this paper, and the other two are from the manufacturing industry ( $\alpha$  and  $\beta$ ). Organisations  $\alpha$ , B, and D are in a more advanced phase of the DT (follow-up and continuous improvement), and organisations  $\beta$ , A, and C are in the initial ones (awareness and digital technologies/trends implementation). A semi-structured script was developed to guide the interviews. The questions address social (workforce and business culture), technical (digital technologies/trends and work environment infrastructure), and operational factors (processes and performance measurement). All interviewed companies were either medium or large-sized.

## FINDINGS AND DISCUSSION

The **social factors** analysed address workforce and business culture. Regarding a digital transformation strategy, the results showed that organisations A and D did not have a specific strategy related to DT. Company B's strategy was related to a mindset change towards DT, and C's strategy focused on BIM (Building Information Modelling) implementation. According to Hess et al. (2016), to ensure that companies capture the business value of digital transformation, they should carefully develop a DT strategy aligned with other operational or functional strategies.

Organisations A, B, and D did not have centralised digital transformation coordination, and each department managed the digitalisation according to its needs. Organisation D specified that this practice is causing a lack of interoperability among systems, and some technologies will need to be replaced as they cannot be integrated with others. This issue can result in more costs, delays, and rework.

The new skills pointed out by interviewees as required for DT were soft skills, resilience, change management capacity, flexibility, risk appetite, integration capacity, and technical skills. The four interviewed

---

<sup>1</sup> Postgraduate Program in Civil Engineering, Federal University of Bahia, Brazil. ORCID 0000-0003-4041-8025

<sup>2</sup> Federal University of Bahia, Brazil. ORCID 0000-0002-1457-6401

\* Corresponding author Email: [dayanabcosta@ufba.br](mailto:dayanabcosta@ufba.br)

companies indicated they did not renew the staff to meet digitalization requirements but trained the existing workforce. The main barriers perceived by the interviewees were related to the new capabilities, changes in mindset, cost, and workforce resistance to digitalization.

The **technical factors** comprise digital technologies/trends and work environment infrastructure aspects. Some examples of digital technologies applied in construction are BIM, common data environment, unmanned aerial vehicle, Virtual Reality/Augmented Reality (AR/VR), Artificial Intelligence (AI), cyber security, big data and analytics, blockchain, laser scanner, sensors, Internet of Things (IoT), among others (Forcael et al., 2020). The digital technologies/trends mentioned as implemented by the four interviewed companies were tablets, BIM, cloud computing, VR/AR, and specialized platforms. Other digital technologies/trends cited were AI, 360° cameras, laser scanners, sensors, and IoT. Significant financial efforts were related to equipment acquisition and software licenses. Organisations A, C, and D involved consultants to support the implementation of some digital technologies/trends, especially BIM. Concerning changes in the work environment infrastructure, the main modification highlighted was replacing old computers with machines compatible with the new digital trends.

**Operational factors** include processes and performance measurement. The most mentioned processes impacted by DT were design, planning and control, and costs. The production process was influenced only in organisations A and C, while organisation D said it was the least affected. Regarding performance measurement, the four companies indicated that DT provided faster and more reliable data, improved information flow, and provided a quicker response, resulting in performance improvement. For organisations B and C, the indicators change and increase in number. In contrast, indicators remain the same for A and D. It is worth mentioning that the literature review has indicated updates in KPIs for the manufacturing sector in the digital context (Ante et al., 2018; Kamble et al., 2020; Frederico et al., 2020).

Compared with manufacturing companies, the main differences identified refer to the DT process itself. In construction, DT is linked with implementing and adapting technologies in traditional processes. Nevertheless, in manufacturing, it is about digitalising the entire production and management systems industry. Furthermore, manufacturing has the DT process more widespread at different hierarchical levels, while construction still focuses on the strategic and managerial levels. This issue can relate to the digital technologies/trends long time use in manufacturing, resulting in a shorter path to a more comprehensive DT. It is also worth mentioning that a large part of the operational workforce on construction had little or no formal education (some workers are not even literate), making training and adaptation to digital reality challenging. Another highlight is the development of specialised digital solutions, observed in organisations C and A. In C, the digital solutions are for internal use and external purchase, creating opportunities for new business and enabling faster payback.

In addition, some interviewees questioned the concepts of construction 4.0 and digital transformation, demonstrating a lack of knowledge about the digitalisation process and confusing it with the digitisation process. Digitisation converts information from the analog to the digital environment or automates processes through information and communication technologies (Hess et al., 2016). Digital transformation (or digitalisation) relates to changes those digital technologies provide to a company's business model, products, processes, and organisational structure (Hess et al., 2016). This differentiation has significant implications for organisational transformations because they can go on diverse paths depending on their desired final states (Ritter and Pedersen, 2020). Although there are efforts to digitalize some operations, the preliminary insights of this study suggest that the industry is still digitizing them.

Furthermore, the industry seems to be still focusing on what digital novelties are more prominent in the market rather than concentrating on how to solve or improve business problems with the support of digital technologies.

Finally, a maturity model can assist companies in the digital transformation process. Maturity models outline simplified maturity stages that measure the completeness of objects via different sets of multi-dimensional criteria (Wendler, 2012). It can enable the company's evolution monitoring, guide the establishment of goals, and promote benchmarking. Maturing systems grow their capabilities for achieving some desired future state (Schumacher et al., 2016). Moreover, according to Andersen et al. (2020), it is necessary to take maturity models as evolutionary reference models for future research and practice.

## CONCLUSIONS

This abstract presents preliminary insights of an exploratory study that aims to analyse the digital transformation (DT) process in Brazilian construction companies. The main findings refer to social issues, such

as workforce resistance and lack of capabilities and knowledge towards digitalisation, challenges in diffusing a digital environment for other hierarchical levels, absence of digital strategies, and, in some cases, the lack of a coordination department for DT. This exploratory study is part of broader research in the context of a Ph.D. thesis, which aims to propose a maturity measurement system for an intelligent construction environment.

## REFERENCES

- Adepoju, O. O., & Aigbavboa, C. O. (2020). Assessing knowledge and skills gap for construction 4.0 in a developing economy. *Journal of Public Affairs*, 21(3). <https://doi.org/10.1002/pa.2264>.
- Alaloul, W. S., Liew, M. S., Zawawi, N. A. W. A., & Mohammed, B. S. (2018). Industry Revolution IR 4.0: Future Opportunities and Challenges in Construction Industry. *MATEC Web of Conferences*, 203, 02010. <https://doi.org/10.1051/mateconf/201820302010>.
- Andersen, K. N., Lee, J., Mettler, T., & Moon, M. J. (2020). Ten Misunderstandings about Maturity Models. The 21st Annual International Conference on Digital Government Research. The 21st Annual International Conference on Digital Government Research, Seoul, Republic of Korea. <https://doi.org/10.1145/3396956.3396980>.
- Ante, G., Facchini, F., Mossa, G., & Digiesi, S. (2018). Developing a key performance indicators tree for lean and smart production systems. *IFAC-PapersOnLine*, 51(11), 13–18. <https://doi.org/10.1016/j.ifacol.2018.08.227>.
- Boulton, C., & Kirsten, L. (2019, July). Capability Framework and Research Agenda for a digital built Britain (CDBB\_REP\_25). CDBB. <https://doi.org/10.17863/CAM.41751>.
- Forcael, E., Ferrari, I., Opazo-Vega, A., & Pulido-Arcas, J. A. (2020). Construction 4.0: A Literature Review. *Sustainability*, 12(22), 9755. <https://doi.org/10.3390/su12229755>.
- Frederico, G. F., Garza-Reyes, J. A., Kumar, A., & Kumar, V. (2020). Performance measurement for supply chains in the Industry 4.0 era: a balanced scorecard approach. *International Journal of Productivity and Performance Management*, 70(4), 789–807. <https://doi.org/10.1108/ijppm-08-2019-0400>.
- Hess, T., Matt, C., Benlian, A., & Wiesböck, F. (2016). Options for Formulating a Digital Transformation Strategy. *MIS Quarterly Executive*, 15, 123-139.
- Kamble, S. S., Gunasekaran, A., Ghadge, A., & Raut, R. (2020). A performance measurement system for industry 4.0 enabled smart manufacturing system in SMEs: A review and empirical investigation. *International Journal of Production Economics*, 107853. <https://doi.org/10.1016/j.ijpe.2020.107853>.
- Klinc, R., & Turk, I. (2019). Construction 4.0 – Digital Transformation of One of the Oldest Industries. *Economic and Business Review*, 21(3), 393–410. <https://doi.org/10.15458/eb.92>.
- Ritter, T., & Pedersen, C. L. (2020). Digitization capability and the digitalization of business models in business-to-business firms: Past, present, and future. *Industrial Marketing Management*, 86, 180–190. <https://doi.org/10.1016/j.indmarman.2019.11.019>
- Sawhney, A., Riley, M., & Irizarry, J. (2020). *Construction 4.0: An Innovation Platform for the Built Environment* (1st ed.). Routledge.
- Schumacher, A., Erol, S., & Sihm, W. (2016). A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. *Procedia CIRP*, 52, 161–166. <https://doi.org/10.1016/j.procir.2016.07.040>
- Tilson, D., Lyytinen, K., & Sørensen, C. (2010). Research Commentary—Digital Infrastructures: The Missing IS Research Agenda. *Information Systems Research*, 21(4), 748–759. <https://doi.org/10.1287/isre.1100.0318>.
- Wendler, R. 2012. The maturity of maturity model research: A systematic mapping study. *Information and Software Technology*, 54: 1317-1339. <http://dx.doi.org/10.1016/j.infsof.2012.07.007>.

# DEVELOPING A BLOCKCHAIN-BASED POST-CONTRACT WORK AND PAYMENT CERTIFICATION FRAMEWORK FOR CONSTRUCTION PROJECTS

G. Thilini Weerasuriya<sup>1\*</sup>, Srinath Perera<sup>2</sup>, Rodrigo N. Calheiros<sup>3</sup>

## INTRODUCTION

The construction industry faces significant challenges due to defects and failures occurring in buildings. Examples include cracking in the building structures in the Opal Tower and Mascot Towers in New South Wales, Australia, the London Grenfell Tower fire, and many others (Hackitt 2018; Snow, Gorrey & Chung 2019). Reasons for these failures include non-compliant construction and structural design (Hoffman, Carter & Foster 2019), unclear roles and responsibilities, and insufficient supervision by regulatory bodies (Hackitt 2018; Love et al. 2020).

Rigorous inspections, testing, and certification are required to identify non-compliance to standards and design (Velikova, Baker & Smith 2018), which should be properly traceable so that responsible parties can be identified and future failures are deterred (Hackitt 2018; Hoffman, Carter & Foster 2019; Shergold & Weir 2018). Recommendations for improving compliance in the construction industry include collecting and sharing building information and intelligence, and maintaining sufficient documentation and record-keeping where stakeholders can view all certifications (Hoffman, Carter & Foster 2019; Shergold & Weir 2018).

Accurate certification requires tracking complex information, including the quantity and quality of work executed by the construction contractors and numerous subcontractors. However, the literature has not revealed comprehensive systems for industry-wide traceability of certifications. Furthermore, the fragmented nature of the construction industry negatively impacts the effective interchange of data among various organisations and leads to low trust and traceability of certification data (Hewavitharana, Nanayakkara & Perera 2019). Therefore, the research question is to identify what measures can be implemented to ensure trusted and traceable certification of quality and progress of work and their related payments, enable acceptance of ownership of work, and deter disputes and fraudulent activities to ensure compliance in the built environment.

## BLOCKCHAIN TECHNOLOGY AND SMART CONTRACTS

Blockchain technology provides a method of ensuring trusted and traceable data related to construction projects. A blockchain is a decentralised digital ledger that maintains a copy of the data on all nodes (computers) on a peer-to-peer network (Nanayakkara et al. 2019). Executed transactions will be stored as "blocks", which are cryptographically linked digital records that require consensus from other nodes to be newly added to the blockchain. Once a block is added, it cannot be modified by a lone user. This ensures data immutability (Belotti et al. 2019). Records can be traced through any node in the network, which enables traceability and auditability of data.

Other features of the blockchain include enhanced trust, transparency, integrity, and data security. These allow collaboration among users in a trust less environment (Perera et al. 2020). Therefore, data can be reliably stored in a blockchain to impart trust and traceability to construction certifications. Blockchain smart contracts are automatically-executed programs that enforce contract rules in a blockchain (Cong & He 2019). Smart contracts replace third parties by enforcing contract terms without human involvement, saving time and cost (Belotti et al. 2019; Nawari & Ravindran 2019; Shojaei et al. 2019). Smart contracts can enforce compliance requirements and payment terms to increase the likelihood of performance (Nanayakkara et al. 2021a).

---

<sup>1</sup> Centre for Smart Modern Construction, School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0003-1087-5575

<sup>2</sup> Centre for Smart Modern Construction, School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0001-9218-9282

<sup>3</sup> School of Computer, Data and Mathematical Sciences, Western Sydney University, Australia. ORCID 0000-0001-7435-2445

\* Corresponding author Email: 19876535@student.westernsydney.edu.au

## RESEARCH METHOD

This research proposes a blockchain framework to track certifications of quality, progress, and related payments, and details of stakeholders, defects, and issues. The scope of the research will be within the construction industry in New South Wales, Australia.

The research follows a hybrid methodology combining qualitative methods of data collection and software development methodologies. Primary data was gathered through expert forum interviews with construction consultants, including project managers, quantity surveyors, architects, engineers, and registered certifiers. The current process of certification of quality and progress of work and related payments, and its inefficiencies and limitations have been identified through the expert interviews.

An integrated data model that enables data sharing among all stakeholders, and an integrated process model for a lean, streamlined, comprehensive certification process in construction projects has been designed. This is a major contribution to knowledge of the research. Hyperledger Fabric was identified as the most suitable blockchain platform to develop the system by following a systematic process protocol proposed by Nanayakkara et al. (2021b).

The proposed models are being validated by a Delphi-based expert forum, and will be revised based on the interview inputs. Comprehensive software designs for a blockchain prototype will be created to reflect the revised integrated data and process models. A blockchain prototype will be developed based on the software designs, which will include smart contracts that automatically execute after necessary conditions are fulfilled, increasing the lean dimension of the framework. The blockchain prototype will contain distributed applications for stakeholders to access the stored data and interact with the blockchain. The final framework that consists of the revised data and process models and blockchain prototype will be validated through another expert forum.

## CONCLUSION

The performance of projects, contractors, and consultants can be tracked over time in an immutable, transparent, and trustworthy manner within the blockchain system. Responsible parties for defects or incorrect certifications would be clearly identifiable as the blockchain provides traceability of data. This is expected to ensure contractors' compliance of work and consultants' ownership of certifications, leading to reduced building defects and failures. Reliable contractors and consultants could also be identified and the performance history of unreliable parties would be exposed through the blockchain. Providing a common platform for all stakeholders to interact on will increase communication and collaboration within construction projects. Ultimately, this would lead to enhanced performance within the construction industry.

## REFERENCES

- Belotti, M, Božić, N, Pujolle, G & Secci, S 2019, 'A Vademecum on Blockchain Technologies: When, Which, and How', IEEE Communications Surveys & Tutorials, vol. 21, no. 4, pp. 3796-838, DOI 10.1109/COMST.2019.2928178.
- Cong, LW & He, Z 2019, 'Blockchain disruption and smart contracts', The Review of Financial Studies, vol. 32, no. 5, pp. 1754-97.
- Hackitt, J 2018, Building a safer future - Independent review of building regulations and fire safety: final report, United Kingdom.
- Hewavitharana, T, Nanayakkara, S & Perera, S 2019, 'Blockchain as a project management platform', 8th World Construction Symposium. DOI doi.org/10.31705/WCS.2019.14.
- Hoffman, M, Carter, J & Foster, S 2019, Opal Tower investigation: final report, Department of Planning and Environment (NSW), <<https://apo.org.au/node/221431>>.
- Love, PED, Ika, L, Luo, H, Zhou, Y, Zhong, B & Fang, W 2020, 'Rework, Failures, and Unsafe Behavior: Moving Toward an Error Management Mindset in Construction', IEEE Transactions on Engineering Management, pp. 1-13, DOI 10.1109/TEM.2020.2982463.
- Nanayakkara, S, Perera, S, Bandara, HMND, Weerasuriya, GT & Ayoub, J 2019, 'Blockchain Technology and its Potential for the Construction Industry', Proceedings of the 43rd Australasian Universities Building Education Association (AUBEA) Conference: Built to Thrive: Creating Buildings and Cities that Support Individual Well-being and Community Prosperity.
- Nanayakkara, S, Perera, S, Senaratne, S, Weerasuriya, GT & Bandara, HMND 2021a, 'Blockchain and Smart Contracts: A Solution for Payment Issues in Construction Supply Chains', Informatics, vol. 8, no. 2, p. 36,

<<https://www.mdpi.com/2227-9709/8/2/36>>.

Nanayakkara, S, Rodrigo, MNN, Perera, S, Weerasuriya, GT & Hijazi, AA 2021b, 'A Methodology for Selection of a Blockchain Platform to Develop an Enterprise System', *Journal of Industrial Information Integration*, p. 100215.

Nawari, NO & Ravindran, S 2019, 'Blockchain and the built environment: Potentials and limitations', *Journal of Building Engineering*, vol. 25, DOI <https://doi.org/10.1016/j.jobe.2019.100832>.

Perera, S, Nanayakkara, S, Rodrigo, MNN, Senaratne, S & Weinand, R 2020, 'Blockchain Technology: Is it Hype or Real in the Construction Industry?', *Journal of Industrial Information Integration*, vol. 17, p. 100125, DOI 10.1016/j.jii.2020.100125.

Shergold, P & Weir, B 2018, *Building confidence. Improving the effectiveness of compliance and enforcement systems for the building and construction industry across Australia*, Department of Industry, Innovation and Science, Australia, viewed 10-09-2019, <<https://apo.org.au/node/171286>>.

Shojaei, A, Flood, I, Moud, HI, Hatami, M & Zhang, X 2019, 'An Implementation of Smart Contracts by Integrating BIM and Blockchain', *Proceedings of the Future Technologies Conference*. Springer.

Snow, D, Gorrey, M & Chung, L 2019, 'No effective oversight': why the Opal and Mascot Towers cases may be the tip of a very large iceberg', *The Sydney Morning Herald*, viewed 15-08-2019, <<https://www.smh.com.au/national/nsw/no-effective-oversight-why-the-opal-and-mascot-towers-cases-may-be-the-tip-of-a-very-large-iceberg-20190621-p52017.html>>.

Velikova, M, Baker, H & Smith, SD 2018, 'The Meaning of Failure: Establishing a Taxonomy of Failure in the Construction Industry to Improve Organisational Learning', 34th Annual ARCOM Conference. Association of Researchers in Construction Management, Belfast, UK.

## MANAGING RISK IN PROJECTS WITH DIGITAL TWINS: A RISK SCIENCE PERSPECTIVE

Irem Dikmen<sup>1\*</sup>

A digital twin is a virtual representation that serves as the real-time digital counterpart of a physical object or process. A closed-loop digital twin technology (DT) integrates BIM, IoT, and data mining techniques where IoT connects the physical and cyber world to capture real-time data for modelling, analysis and simulation to discover hidden knowledge (Pan and Zhang, 2021). DTs are aware of their own context, capable of autonomous decision-making and adapting themselves to the systems within which they operate (Hribernik et al., 2021). DT's value is related with the knowledge it delivers for improved decision-making.

In this abstract, reflections on the role of DTs for risk-informed decision-making in construction projects are discussed utilising a risk science (RS) perspective. RS, studied in fields as diverse as mathematics, engineering and social sciences such as sociology and philosophy, aims to provide guidance on concepts, principles, methods and models on how to understand, characterise, assess, communicate and manage risk (Aven, 2016).

The Society of Risk Analysis, established by the international RS community in 1980s, aimed to establish a common scientific platform and developed a risk glossary (2015) as well as core subjects of risk (2017). Different schools within RS, such as technical, cognitive, socio-cultural and constructivist schools concentrate on different epistemological dimensions, assessment methods and recommend different policies for managing risk, which are also applicable for project management.

Project Risk management (PRM) is focused on understanding risks in a project, assessing their impacts and devising strategies to reduce them to a tolerable level. Although PRM in construction research is very rich in terms of quantitative assessment methods assuming risk as an objective fact (Taroun, 2014), there are limited studies that conceptualise risk from social construction perspective (Willumsen et al., 2019). Technical school that considers risk as a quantifiable factor based on probability and impact values dominates the literature whereas RS schools such as constructivist and socio-cultural schools have been rarely investigated. From the technical perspective, availability, quality and structure of information that can be used to quantify risk are conceived as critical success factors for risk analysis. From this perspective, with the increased number and quality of data about the past, present and future conditions of projects, DT can lead to several changes and improvements in PRM such as;

**Better prediction:** Anticipating the future is about applying some model of the project that connects the past and present to the future by a set of data. Predictive models have their own uncertainty. With increased number and quality of data, epistemic uncertainty is decreased and reliability of probabilistic models can be increased. On the other hand, it has to be noted that digitalisation is imposing new risks of security, underperformance and create deep uncertainty due to technological novelty and complexity. Moreover, Thamhain (2013) argues that industry is efficient in analysing known risk factors, but weak in dealing with unknown risks. Whether DT can make reliable predictions for unknown risks (black swans) is not clear yet.

**Revealing hidden knowledge:** Causation is a foundational issue of risk and the challenge of including causally relevant knowledge from the local context has been stressed by various authors (Anjum and Rocca, 2018). Hidden knowledge on context and causation can be revealed by data analytics and AI. DT may unhide the causal emergence paths of risk events resulting in better informed decisions on risk mitigation as well as improving learning from risks.

**Lower contingency:** Precautionary principle widely used in RS is a broad epistemological approach to innovations/actions with potential for causing harm when extensive scientific knowledge on the matter is lacking. In the engineering context, it manifests itself as the factor of safety and project management context as contingency. Debate exists over how to define and apply it to complex scenarios. Data analytics may reveal patterns and decrease uncertainty, thus theoretically, it may lead to lower contingencies on project time and cost.

---

<sup>1</sup> School of the Built Environment, University of Reading, UK. ORCID 0000-0002-6988-7557

\*Corresponding author Email: i.dikmen@reading.ac.uk

Automation of PRM processes: All stages of PRM require human input with some expertise. RS is very rich in developing expert knowledge elicitation (EKE) methods. On the other hand, humans use mental shortcuts or heuristics that can result in bias in both predictions and assessment of uncertainty surrounding predictions (Kahneman and Tversky, 1984). With DT, less human involvement will be possible, decreasing bias. Major tasks of risk managers are setting up the project risk management system and running the processes with data/knowledge mainly gathered from EKE sessions. Thus, the role of a risk manager may change with DT technology. RM will be more about defining data requirements and models, whereas processes can be automatically carried out by a virtual risk manager.

In this abstract, reflections on how PRM and the role of a risk manager may change with DT technology will be presented and research ideas will be depicted considering different schools in RS. Positivist research methods such as simulation can be used to test the impact of big data and automation on PRM processes for inductive theory building. On the other hand, from a sociological perspective, risks involving social interaction are not necessarily better assessed by more information. PRM is about making sense of complex project systems. A shift from technical towards social processes in RM is proposed to cope with complex governance regimes where different interests of stakeholders need to be considered, balanced and negotiated. Interpretive data collection methods from social sciences such as case studies can be used to make sense of the behaviour of stakeholders during risk-informed decision-making and how DT can be used to simulate and support related processes. DT has a potential to unify different schools in RS if it can connect the physical, social and cyber world, and simulate projects as complex adaptive socio-technical systems.

## REFERENCES

- Anjum, R. L., and Rocca, E. (2018). "From Ideal to Real Risk: Philosophy of Causation Meets Risk Analysis". *Risk Analysis.*, 39:729–740. <https://doi.org/10.1111/risa.13187>
- Aven, T. (2016), "Risk Assessment and Risk Management: Review of Recent Advances On their Foundation", *European Journal of Operational Research*, 253, 1-13. <https://doi.org/10.1016/j.ejor.2015.12.023>
- Hribernik, K., Cabri, G., Mandreoli, F. and Mentzas, G. (2021). "Autonomous, context-aware, adaptive Digital Twins – State of the Art and Roadmap", *Computers in Industry*, 133, 1023508, [10.1016/j.compind.2021.103508](https://doi.org/10.1016/j.compind.2021.103508)
- Kahneman, D., and Tversky, A. (1984). "Choices, values, and frames" *American Psychologist*, 39(4), 341–350. <https://doi.org/10.1037/0003-066X.39.4.341>
- Pan, Y. and Zhang, L. (2021) "A BIM-data mining integrated digital twin framework for advanced project management", Volume 124, 103564, ISSN 0926-5805, <https://doi.org/10.1016/j.autcon.2021.103564>.
- Thamhain, H. (2013), "Managing Risks in Complex Projects", *Project Management Journal*, 44(2), 20-35. [10.1002/pmj.21325](https://doi.org/10.1002/pmj.21325).
- Willumsen, P., Oehmen, J., Stingl, V., and Geraldi, J. (2019). "Value Creation through Project Risk Management". *International Journal of Project Management*, 37(5), 731-749. <https://doi.org/10.1016/j.ijproman.2019.01.007>.

# OBSTACLES TO THE IMPLEMENTATION OF DIGITAL TWINS: A REVIEW IN THE CONSTRUCTION INDUSTRY

De-Graft Joe Opoku<sup>1\*</sup>, Srinath Perera<sup>2</sup>, Robert Osei-Kyei<sup>3</sup>, Maria Rashidi<sup>4</sup>, Keivan Bamdad<sup>5</sup>

## INTRODUCTION

The advent of industry 4.0 gave rise to an array of digital technologies, including digital twins (DTs). DTs present the opportunity to develop digital models, which can be continually updated using several data sources to predict physical assets' current and future conditions. These models can be simulated for real-time predictions, optimisation, monitoring, controlling and enhanced decision making regarding the status of a physical asset. In addition, DTs utilise other technologies, including artificial intelligence (AI), machine learning and data analytics. Due to the prowess of DTs, the construction industry, with its numerous challenges, have started DTs applications. Technologies such as building information modelling (BIM), Wireless Sensor Networks (WSNs), data analytics, and machine learning are currently supporting the adoption of DTs in the construction industry.

Several studies (Boje et al. 2020; Sacks et al. 2020; Opoku, DGJ et al. 2021) have studied DTs in construction and established their relevance. For instance, Opoku, DGJ et al. (2021) indicated that DTs are necessary for facility management since they can be employed in 'what-if' analysis in decision making regarding the operation and maintenance of the building. Researchers and practitioners are currently discovering the numerous potentials of DTs in the construction industry. There is, however, a misconception in the construction industry where DTs are likened to BIM due to their similarities (Khajavi et al. 2019). Opoku, D-GJ et al. (2022) and Khajavi et al. (2019) reported their differences based on their purposes, technologies, and end-users.

Notwithstanding the advancement of DTs in the construction industry, it is essential to answer the question, "What barriers impede the prompt adoption of DTs in the construction industry?". Unfortunately, little attention has been geared toward the barriers hindering DTs adoption in the construction industry. Though there have been several reviews (Alshammari et al. 2021; Deng et al. 2021; Opoku, D-GJ et al. 2022; Opoku, DGJ et al. 2021) on DTs in the construction industry, they did not pay enough attention to the barriers to DTs adoption. Thus, there is yet to be a study that comprehensively reviews the literature on the barriers to adopting DTs in the construction industry. This hinders the preparedness to fully embrace DTs in the construction industry. Therefore, this research aims to identify and rank the barriers to adopting DTs in the construction industry to support a roadmap for its adoption in the construction industry.

## RESEARCH METHODS

Using a systematic literature review (SLR), the study utilised three databases including Scopus, Web of Science and ScienceDirect to identify the barriers to the adoption of DTs in the construction industry. Firstly, a search for the literature was conducted using Scopus database where a comprehensive search was carried-out using the keywords with appropriate Boolean operators: ("digital twin" OR "virtual counterpart" OR "digital replica" OR "virtual twin") AND ("barriers" OR "challenges" OR "obstacles" AND ("construction" OR "construction industry")), with no limitation in terms of the year (search on February 27, 2022). However,

---

<sup>1</sup> Centre for Smart Modern Construction (c4SMC), School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0003-2557-5268

<sup>2</sup> Centre for Smart Modern Construction (c4SMC), School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0001-9218-9282

<sup>3</sup> Centre for Smart Modern Construction (c4SMC), School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0003-4121-1958

<sup>4</sup> Centre for Infrastructure Engineering (CIE), School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0003-2847-3806

<sup>5</sup> Centre for Smart Modern Construction (c4SMC), School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0002-6091-2736

\* Corresponding author Email: [d.opoku@westernsydney.edu.au](mailto:d.opoku@westernsydney.edu.au)

“article” or “review” was selected for the type of document since they provide the most reputable and influential sources of knowledge (Santos et al. 2017).

The initial search resulted in 54 papers, whilst an additional search carried out using Web of Science and ScienceDirect added to the initial search yielded 86 papers. This was done to ensure that an acceptable number of papers were captured for the study. After a more critical and comprehensive examination of the 86 papers, 43 academic publications relevant to the study were identified. A content analysis of the 43 papers resulted in identifying 38 barriers to adopting DTs in the construction industry. Whilst some publications listed some of the barriers in tables and charts, other papers required detailed content analysis to discover the barriers. The identified barriers were then ranked based on the number of publications mentioning the identified barriers. Future studies are planned to empirically test the identified barriers among construction stakeholders to draw a quantitative analysis of the identified barriers.

## RESULTS AND DISCUSSION

The findings from the systematic review disclosed the top five barriers to the adoption of DTs in construction: *low level of technology acceptance, low level of knowledge, lack of competence, lack of trust in data security, and legal and ethical issues*. The “low level of technology acceptance” was identified by 21 out of 43 different papers constituting 49% of the total number of reviewed papers. This barrier was ranked first out of the 38 identified barriers to adopting DTs in the construction industry. It is worthy to note that this finding has been a significant challenge within the construction industry, as confirmed by several studies (Li et al. 2019; Oettinghaus 2019; Opoku, D-GJ et al. 2022). Opoku, DGJ et al. (2021) mentioned that the ambiguities regarding DTs and BIM had hindered their smooth acceptance due to their similarities. The “low level of knowledge” barrier was ranked second out of the 38 identified barriers. Twelve out of 43 publications reviewed confirmed this barrier. Several individuals and organisations have misconceptions about the potential of advanced technologies like DTs, BIM, blockchain and the like in tackling challenges of the construction industry, and this has resulted in their abandonment and lack of knowledge and understanding of these technologies (Perera et al. 2022; Winfield & Rock 2018).

Further, “lack of competence” was ranked third out of 38 identified barriers, and it is a crucial aspect for consideration if DTs are to be successful within the construction industry. Competency is always one of the most potent criteria for success. However, a lack of competency may hinder the successful adoption of DTs in the construction industry (Perera et al. 2022). The “lack of trust in data security” barrier was the fourth-ranked barrier to adopting DTs in the construction industry. Since DTs operate by connecting the physical and the digital model using large volumes of data, data becomes a significant component in a DT (Tao et al. 2018). For this reason, industry practitioners and players are highly concerned about the security and trustworthiness of data in DTs. Finally, the fifth-ranked barrier to adopting DTs in the construction industry was “legal and ethical issues”. As stated earlier regarding data in DTs, legal and ethical issues relating to data breaches hinder the smooth adoption of DTs and other technologies like BIM in the construction industry (Winfield 2018).

## CONCLUSIONS

The findings from this study can help propel DTs adoption in construction and aid stakeholders to identify adequate strategies to overcome these barriers. In addition, this study will broaden the knowledge base on the application of DTs and their associated barriers, which is essential for the successful utilisation of DTs in the construction industry.

## REFERENCES

- Alshammari, K, Beach, T & Rezgui, Y 2021, 'Cybersecurity for digital twins in the built environment: Current research and future directions', *Journal of Information Technology in Construction*, vol. 26, pp. 159-73, Scopus, DOI 10.36680/j.itcon.2021.010, <[https://www.scopus.com/inward/record.uri?eid=2-s2.0-85105588737&doi=10.36680%2fj.itcon.2021.010&partnerID=40&md5=f06a66611e234f9353bada0107f980b0https://www.itcon.org/papers/2021\\_10-ITcon-Alshammari.pdf](https://www.scopus.com/inward/record.uri?eid=2-s2.0-85105588737&doi=10.36680%2fj.itcon.2021.010&partnerID=40&md5=f06a66611e234f9353bada0107f980b0https://www.itcon.org/papers/2021_10-ITcon-Alshammari.pdf)>.
- Boje, C, Guerriero, A, Kubicki, S & Rezgui, Y 2020, 'Towards a semantic Construction Digital Twin: Directions for future research', *Automation in Construction*, vol. 114, Scopus, DOI 10.1016/j.autcon.2020.103179, <<https://www.scopus.com/inward/record.uri?eid=2-s2.0-85082386834&doi=10.1016%2fj.autcon.2020.103179&partnerID=40&md5=914efcd6c064d6a97299f00d812bb8fc>>.
- Deng, M, Menassa, CC & Kamat, VR 2021, 'From BIM to digital twins: A systematic review of the evolution of intelligent building representations in the AEC-FM industry', *Journal of Information Technology in*

- Construction, vol. 26, pp. 58-83, Scopus, DOI 10.36680/J.ITCON.2021.005, <<https://www.scopus.com/inward/record.uri?eid=2-s2.0-85103484819&doi=10.36680%2fJ.ITCON.2021.005&partnerID=40&md5=35720c65ebda4e06cc3240abfe8d01d7>>.
- [https://www.itcon.org/papers/2021\\_05-SI-ITcon-Deng.pdf](https://www.itcon.org/papers/2021_05-SI-ITcon-Deng.pdf).
- Khajavi, SH, Motlagh, NH, Jaribion, A, Werner, LC & Holmström, J 2019, 'Digital twin: vision, benefits, boundaries, and creation for buildings', IEEE Access, vol. 7, pp. 147406-19.
- Li, J, Greenwood, D & Kassem, M 2019, 'Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases', Automation in Construction, vol. 102, pp. 288-307.
- Oettinghaus, S 2019, 'Digital construction with Building Information Modeling - The digital twin', WasserWirtschaft, vol. 109, no. 5, pp. 86-9.
- Opoku, D-GJ, Perera, S, Osei-Kyei, R, Rashidi, M, Famakinwa, T & Bamdad, K 2022, 'Drivers for Digital Twin Adoption in the Construction Industry: A Systematic Literature Review', Buildings, vol. 12, no. 2, p. 113.
- Opoku, DGJ, Perera, S, Osei-Kyei, R & Rashidi, M 2021, 'Digital twin application in the construction industry: A literature review', Journal of Building Engineering, vol. 40, Scopus, DOI 10.1016/j.jobe.2021.102726, <<https://www.scopus.com/inward/record.uri?eid=2-s2.0-85107846403&doi=10.1016%2fj.jobe.2021.102726&partnerID=40&md5=b4c1ceb0ac9fe55de15a4b8bbb67b9ac>>.
- Perera, S, Opoku, D-GJ & Rodrigo, N 2022, 'Technological advancements in green and sustainable construction', The Construction Industry: Global Trends, Job Burnout and Safety Issues, pp. 51-74.
- Sacks, R, Brilakis, I, Pikas, E, Xie, HS & Girolami, M 2020, 'Construction with digital twin information systems', Data-Centric Engineering, vol. 1, DOI 10.1017/dce.2020.16, <<https://dx.doi.org/10.1017/dce.2020.16>>.
- Santos, R, Costa, AA & Grilo, A 2017, 'Bibliometric analysis and review of Building Information Modelling literature published between 2005 and 2015', Automation in Construction, vol. 80, pp. 118-36.
- Tao, F, Zhang, H, Liu, A & Nee, AYC 2018, 'Digital twin in industry: State-of-the-art', IEEE Transactions on Industrial Informatics, vol. 15, no. 4, pp. 2405-15.
- Winfield, M 2018, 'The winfield rock report: Overcoming the legal and contractual barriers of BIM', pp. 1-60.
- Winfield, M & Rock, S 2018, 'The winfield rock report: Overcoming the legal and contractual barriers of BIM', pp. 1-60.

# **THE ROLE OF TECHNOLOGY AND HUMAN INTERACTION IN INDUSTRY 5.0**

# MANAGEMENT OF CUSTOMER COMPLAINTS IN RESIDENTIAL BUILDING PROJECTS USING SPATIAL ANALYSIS AND BUILDING INFORMATION MODELS

Jordana Bazzan<sup>1\*</sup>, Carlos Torres Formoso<sup>2</sup>, and Márcia Echeveste<sup>3</sup>

## INTRODUCTION

Customer complaints have negative consequences in the construction industry, such as reduction of profits and negative impact on the companies' image (Fauzi et al., 2012; Pan and Thomas, 2015). Therefore, complaint records must be managed and used to understand the causes of defects as well as to implement improvements in future projects (Brito et al., 2011; Forcada et al., 2016). According to El-Adaway (2017), successful projects are not those that attain a minimal number of claims, but rather those with the best handling of claims. Complaint management is a major challenge that real estate companies face in the business environment (Kululanga et al., 2001), as records are often incomplete and unstructured (Brito et al., 2011; Cupertino and Brandstetter, 2015).

Some studies have explored the analysis of large complaint databases, but the majority are from non-residential building projects that have a company in charge of facilities management. Those research studies are not usually concerned with the identification of improvement opportunities at the design and production phases, but with improving maintenance plans (Peng et al., 2017; Gunay et al., 2018; Bortolini and Forcada, 2019; Gómez-Chaparro et al., 2019). Moreover, existing databases often have limitations due to poor data collection, and there is a lack of academic studies exploring improvements in data collection and analysis of customer complaints. Some investigations have attempted to use Building Information Models (BIM) to visualise work orders (Motamedi et al., 2014; MacArthur et al., 2018) and extract information from building components (Chen et al., 2018), indicating that BIM can be used to communicate problems to maintenance teams, and can potentially be used to error detection.

Therefore, there is a knowledge gap on how to manage customer complaints to improve building quality in future projects. This paper reports the preliminary results of an ongoing doctoral research that aims to propose a customer complaint management model in house-building companies to provide feedback to quality management systems. Some components of this model include improvements to data collection, procedures for data analysis based on Spatial Statistics, and communication of results using BIM. Spatial Statistics can be used to explain an event, considering data distribution over space and time (Bailey and Gatrell, 1995), variables that must be considered in building defect analysis. Moreover, BIM will be used to support and communicate the Spatial Statistic results, as it allows a spatial geometric representation of building parts and different types of simulations, considering the time dimension. The potential users of the complaint management model are house-building companies that want to improve the quality of their projects by making the most out of customer complaint data.

## RESEARCH METHOD

Design Science Research (DSR) is the methodological approach adopted in this investigation. It aims to devise solution concepts, named artefacts, to solve classes of problems or improve performance (Van Aken, 2004). The artefact to be devised in this investigation is a model to manage customer complaints in house-building companies to provide feedback to quality systems. The target audience for the use of the artefact are warranty service departments that need to use information systems for properly managing customer complaints. This study has been developed in partnership with a large Brazilian real estate market company.

---

<sup>1</sup> Postgraduate Program in Civil Engineering, Federal University of Rio Grande do Sul, Porto Alegre, Brazil. ORCID 0000-0003-0743-8630

<sup>2</sup> Postgraduate Program in Civil Engineering, Federal University of Rio Grande do Sul, Porto Alegre, Brazil. ORCID 0000-0002-4772-3746

<sup>3</sup> Postgraduate Program in Industrial Engineering, University of Rio Grande do Sul, Porto Alegre, Brazil. ORCID 0000-0003-1084-0495

\* Corresponding author Email: [jordanabazzan@gmail.com](mailto:jordanabazzan@gmail.com)

It has a warranty service department, in charge of dealing with complaints and providing repair services.

The research includes three stages. First, an assessment of the warranty service process was made based on interviews with the company's warranty service team members, participant observations of twenty customer services, and the analysis of an existing database. Based on that assessment, improvements to data collection of customer complaints were proposed. Second, some improvements have been tested and implemented, according to improvements identified in three workshops involving different sectors of the company. In those workshops, the focus of discussions were how defects should be recorded in the database (e.g., the most appropriate category) and which are the possible causes of the most important defects. Finally, the third stage, to be developed, refers to the use of spatial statistics for data analysis and integrating the data in the BIM product model. As a DSR project has refinement cycles, this last step will involve using the insights from previous steps to improve both data collection and the warranty service process.

This abstract presents initial research results, which consist of the descriptive analysis of a database with 11.513 records from 35 projects. The analysis was carried out using the R software, and focused on temporal and spatial features of defects to support the development of the model. In addition, an exploratory case study on the use of BIM was carried out, using a specific project with one year of occupation. The defect data were included in the model by adding parameters in BIM objects. Colour filters were used to visualise the information.

## **FINDINGS**

As this is an ongoing investigation, some preliminary findings are presented in this section.

**Spatial descriptive analysis of data:** data analysis indicated that some projects had a number of complaints significantly higher than the average, despite the project being considered as medium to high standard. This set of projects had similar design features that can contribute to identifying the causes of building defects. Most problems refer to bathrooms, bedrooms, and living rooms. The most frequent problems were leaks from water piping, leaks from windows, and cracks on vertical partitions. Solar orientation and design features will be further investigated to better understand the causes.

The floor level also has a relationship with the occurrence of some defects. For instance, leaks from pipes can occur more in the first levels due to the high piezometric head. However, this feature was not identified due to data problems. For example, customer complaints usually describe the effect of leaks (e.g., moisture stains on the ceiling) and not the origin of the problem. The company does not systematically investigate and record the origin appropriately. Therefore, data on problems that depend on the level floor can be inconsistent. This problem was regarded in this investigation as an improvement opportunity in data collection.

Regarding the time variable, in general, the number of defects tends to increase until the second year of warranty and, then, reduces until the end of this period. However, the electrical service problems had a different pattern, reducing the number of complaints from the first year.

**BIM Study:** an interesting opportunity found in this investigation was the visualisation of leak patterns located on the corners of the building tower. According to the company, this problem occurred due to the detachment of components on the building's facade, resulting in water leaks into the building. However, some challenges were observed: (i) the records did not have the necessary precision to store data in the model. For instance, it was not possible to identify which window among several ones had the problem. Precision is essential for considering solar orientation analysis, and this improvement in data collection should be implemented; (ii) Even with a rigorous data collection, it is a challenge to record the defect position in communal areas because they are large areas and usually do not have internal walls; (iii) BIM objects should be modelled according to the type of space as this is an important information. For instance, floor objects should be modelled for each space and housing unit, instead of the entire floor level; (iv) when an object or building part have more than one defect, it is challenging to visualise both information by using colours. Then, a possible alternative is to use the time simulation together to analyse them over space.

## **CONCLUSION**

The research is expected to contribute to the improvement of warranty services in residential building companies and the development of more effective quality management systems in terms of providing feedback. These changes can turn the warranty service department into a sector closer to the engineering area and with a more strategic role in terms of business goals, by providing systematic feedback.

As further steps, this study intends to develop a spatial statistics model to find patterns and understand

defect occurrence. Also, only the geometric visualisation of BIM models was used, and the time simulation will be implemented in the future. Finally, data inputs were carried out manually, and this study intends to automate this process.

## REFERENCES

- Bailey T. C. and Gatrell, A. C. (1995). *Interactive Spatial Data Analysis*. New York: Longman Harlow.
- Brito, J. N. D. S., Formoso, C. T., and Echeveste, M. E. S. (2011). Complaint data analysis of low-income projects: study on the rental housing programme. *Ambiente Construído*, 11(4), 151–166. doi: 10.1590/S1678-86212011000400011.
- Bortolini, R. and Forcada, N. (2019). Analysis of building maintenance requests using a text mining approach: building services evaluation. *Building Research and Information*, 1466–4321. doi: 10.1080/09613218.2019.1609291.
- Chen, W., Chen, K., Cheng, J. C. P., Wang, Q., and Gan, V. J. L. (2018). BIM-based framework for automatic scheduling of facility maintenance work orders. *Automation in Construction*, 91(February), 15–30. <https://doi.org/10.1016/j.autcon.2018.03.007>
- Cupertino, D. and Brandstetter, M. C. G. (2015). Proposition of occupancy management tool from data of Technical Assistance. *Ambiente Construído*, 15(4), 243–65. doi: 10.1590/s1678-86212015000400049.
- El-adaway, I. (2017). Review of construction contract claims, changes, and dispute resolution. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*. 9(4), 1-3.
- Fauzi, S. N. F. M., Yusof, N., and Abidin, N. Z. (2012). The relationship of housing defects, occupants' satisfaction and loyalty behavior in build-then-sell houses. *Procedia - Social and Behavioral Sciences*, 62, 75–86. doi: 10.1016/j.sbspro.2012.09.014.
- Forcada, N., Macarulla, M., Gangolells, M., and Casals, M. (2016). Handover defects: Comparison of construction and post-handover housing defects. *Building Research and Information*, 44(3), 279–288. doi: 10.1080/09613218.2015.1039284.
- Gómez-Chaparro, M., García-Sanz-Calcedo, J., and Aunió-Villa, J. (2019). Maintenance in hospitals with less than 200 beds: efficiency indicators. *Building Research and Information*, 48(5), 526–537. doi: 10.1080/09613218.2019.1678007.
- Gunay, H. B., Shen, W. and Yang, C. (2019). Text-Mining Building Maintenance Work Orders for Component Fault Frequency. *Building Research and Information*, 47(5), 518–33.
- Kululanga, G.K., Kuotcha, W., McCaffer, R. and Edum-Fotwe, F. (2001), Construction contractors' claim process framework. *Journal of Construction Engineering and Management*, 127(4), 309-314. doi: 10.1061/(ASCE)0733-9364(2001)127:4(309), 309-314.
- McArthur, J. J., Shahbazi, N., Fok, R., Raghobar, C., Bortoluzzi, B., and An, A. (2018). Machine learning and BIM visualization for maintenance issue classification and enhanced data collection. *Advanced Engineering Informatics*, 38(June), 101–112.
- Motamedi, A., Hammad, A., and Asen, Y. (2014). Knowledge-assisted BIM-based visual analytics for failure root cause detection in facilities management. *Automation in Construction*, 43, 73–83. doi: g/10.1016/j.autcon.2014.03.012.
- Pan, W. and Thomas, R. (2015). Defects and Their Influencing Factors of Posthandover New-Build Homes. *Journal of Performance of Constructed Facilities*, 29(4), 1–19. doi: 10.1061/(ASCE)CF.1943-5509.0000618.
- Peng, Y., Lin, J. R., Zhang, J. P., and Hu, Z. Z. (2017). A hybrid data mining approach on BIM-based building operation and maintenance. *Building and Environment*, 126, 483–495. doi: 10.1016/j.buildenv.2017.09.030.
- Van Aken, J. E. (2004). Management Research Based on the Paradigm of the Design Sciences: The Quest for Field-Tested and Grounded Technological Rules. *Journal of Management Studies*, 41(2), 219–246. <https://doi.org/0022-2380>.

## INDUSTRY 5.0: IMPROVING CONSTRUCTION SAFETY USING WORKER-CENTRIC TECHNOLOGY

Matt Stevens<sup>1\*</sup>

### INTRODUCTION

Industry 5.0 emphasises collaboration between technology and humans, enabling workplace resilience while following social values (Sindhvani et al. 2022). However, technology has not been fully integrated into the construction industry by any measure, most of it by choice. Moreover, the cost of time and money to adopt digitalisation is often prohibitive for most construction organisations. However, there are incremental improvements that most builders and subcontractors can implement and maintain that do not only improve the safety process but also their organisational culture. Safety results in the built environment have been unsatisfactory in many Western countries. The next significant increase in built environment investment will attract less experienced worker who as a group behave unsafely on a construction site.

Presently, projects are constructed with more intensity and complexity. Advancements are needed to match this change. Industry 5.0 offers an integration framework of worker involvement who is the most plentiful observer with technology with speed, power, and confidentiality to minimise or eliminate most hazards. This paper asserts that understanding the social dynamics of the construction job site combined with practical technology can give measurable improvement to a core industry concern: workplace safety.

Workers are the largest cohort on any job site, closest to hazards and safety focused. Main contractors and their subcontractors have a significant moral, ethical and economic motivation to reduce safety incidents and accidents to zero. Smartphone technology represents the most powerful and plentiful tool available to workers in capturing and communicating information. However, young people state they feel less influence in the workplace because of their age and work experience. Powerlessness is a word used to describe their feelings. Their hesitancy to voice safety concerns is a product of their sense of their supervisor's indifference, their lack of established competency, or that they might be fired. (Tucker and Turner 2013) Workers born two decades ago prioritise practicality and possess the confidence that could boost our built environment industry improvement further. It is an underperforming sector due to several factors, further hampered by COVID-19 dynamics (Cook 2021) It is critical to note that most projects have a single safety manager due to their size and scope. This safety manager has multiple overwhelming duties, including walking the project, observing, and interpreting many possible hazards, including behaviours. The risk to workers is direct for a failure. Even though the workers should report more often and safety walks help, more worker messages with evidence can significantly assist and eliminate a step to keeping a project safe.

This abstract introduces a safety process and straightforward mobile computing technology for construction safety management. A WSU team created a safety app to approach construction job site safety from an Industry 5.0 perspective. The result is a practical system that attempts to balance technology, reporting accuracy and worker confidentiality to increase job site safety.

### PRELIMINARY DEVELOPMENT

Each invention proceeds through three phases linearly to create a product or service and bring it to reality: 1) ideation 2) development in the lab and marketplace, 3) commercial integration, including deal-making (Isaacson 2014).

The Agile Method was used in a construction-centric innovation incubator to develop this safety innovation idea. Few construction-centric innovation incubator experiences have been explored within the Agile framework in literature. Innovation incubators facilitate and direct creative thinking toward an identified problem.

The WSU incubator team interviewed dozens of construction field and office personnel, deriving their insights, wants and needs. These interviewees represented both subcontractors and main contractors,

---

<sup>1</sup> Western Sydney University, Australia. ORCID 0000-0003-2301-1311

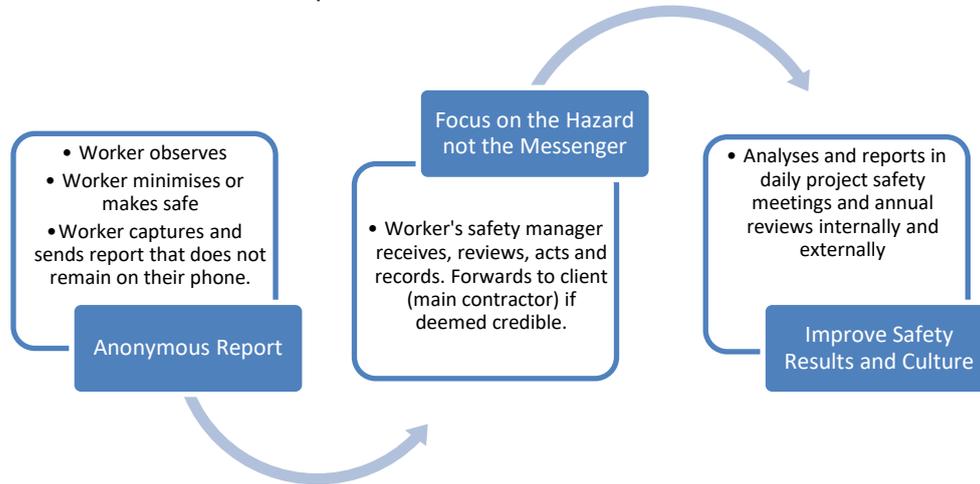
\* Corresponding author Email: Matt.Stevens@westernsydney.edu.au

providing a view of the industry's safety process and information technology gaps. Furthermore, six sponsors took part in the incubator process requiring face-to-face reports during the 6-week term. Each of these meetings was a status presentation and a value assessment of the idea's current development. Iterative development resulted in improved processes and financial projections.

### CURRENT PROCESS AND TECHNOLOGY PLATFORM

A beta version has been developed but not yet placed into the hands of the worker and their supervisor to prompt feedback and improvement. It has been published as "Good Day Safety" on the Google Play Console© but is going through review and programming before seeking practitioner review.

The process is linear and structures the worker-generated electronic statement to be transmitted only to one person - their internal company responsible safety person (see Figure 1). Observing a hazardous condition begins a series of steps. The first - anonymous reporting – is shown in the literature to encourage more information to be shared than estimated. Next, the message is sent to the worker's safety leader on the project. This intermediary acts as a filter and expediter depending on the severity, probability, and duration of harm. The safety leader can quickly seek the facts about the hazard. In all, there are a dozen or more of these responsible safety persons acting in this way since a dozen or more subcontractors typically construct the work. Notably, the worker is not punished nor criticised for reporting due to anonymity. The app utilises standard encryption technology – an accepted method to assure confidentiality. Also, the system does not allow any data to remain on the smartphone.



**Figure 1: A proposed process of Worker-Centric Anonymous Hazard Reporting.**

The long-term value of this reporting process and equipment choice appears high. Workers will feel less exposed to the risk of being seen as a "trouble-maker" due to encryption. Safety managers will receive increased hazard notifications and data, providing real opportunities to increase job site safety. Furthermore, critical metrics can be created and standardised. This information can produce a complete picture across projects and companies, such as safety rankings, hazard categories, sources, and elimination/minimisation cycles. Data and its analysis can be shared with external partners such as insurers, clients, and governments.

### REFERENCES

- Cook, L.L. 2021, "Insight into the millennial mindset: Impact of 4IR and Society 5.0 on the real estate, construction and other industries", IOP Conference Series. Earth and Environmental Science, vol. 654, no. 1.
- Isaacson, W. 2014. The Innovators: how a group of hackers, geniuses and geeks created the digital revolution, vol. 1, Simon and Schuster UK, London.
- Lee, H., Lee, K., Park, M., Baek, Y., and Lee S. 2012 "RFID-based real-time locating system for construction safety management," Journal of Computing in Civil Engineering, vol. 26 no. 3, pp. 366-377.
- Sindhvani, R., Afridi, S., Kumar, A., Banaitis, A., Luthra, S., & Singh, P. 2022, 'Can industry 5.0 revolutionise the wave of resilience and social value creation? A multi-criteria framework to analyse enablers', Technology in Society, vol. 68.
- Tucker, S. & Turner, N. 2013, Waiting for safety: Responses by young Canadian workers to unsafe work, National Safety Council.

# DISRUPTIVE TECHNOLOGIES AND HUMAN INVOLVEMENT IN AUTOMATING CONSTRUCTION INDUSTRY TOWARDS INDUSTRY 5.0: A NEW ZEALAND PERSPECTIVE

Azam Zavvari<sup>1</sup>, Wajiha Shahzad<sup>2</sup> and Monty Sutrisna<sup>3\*</sup>

## INTRODUCTION: A BACKGROUND ON INDUSTRY 5.0:

Industry 5.0 leads the way to bring human involvement back to the automation process, so humans work collaboratively, better and faster with robots. Various works of academic literature and industry reports have been published on the concept of 'Industry 5.0' since 2015, which introduced it as a transformation from virtual to physical, return of the human involvement by using collaborative robots that help personalise autonomous manufacturing (Özdemir & Hekim, 2018; Nahavandi, 2019; Javaid et al., 2020; Yuqian Lu et al., 2022). Industry 5.0 can also be explained as a human-centric transformation from Industry 4.0.

A recent report on Industry 5.0 by the European Union investigated the need and drivers of these notions and documented three drivers of industry 5.0: a human-centric approach, sustainable development, and resilience for the next industrial transformation (Breque, De Nul, & Petridis, 2021). The industry 5.0 approach puts human interest, wellbeing, and needs at the centre of the production process. It is believed that industry 5.0 will change the current technology-centric approach to the human-centric approach (Yuqian Lu et al., 2022). "European Union Report" called it a transformative model considering and learning from the Covid pandemic (Stride, Renukappa, Suresh, & Egbu, 2021). Like other industries, the construction industry (Darlow, Rotimi, & Shahzad, 2021) has become more critical than before, and professionals work collaboratively with robots.

## THE CURRENT STATE OF INDUSTRY 4.0, INCLUDING NZ

The main goal of industry 4.0 is to achieve automation and reduce human involvement in industrial processes while adding more intelligence between the devices and applications. Industry 4.0 connects advanced disruptive technologies such as Cloud Computing, Big Data Analysis, Artificial Intelligence (AI), the Internet of Things (IoT) / Industrial Internet of Things (IIoT), and Blockchain into a higher degree of automation. Cloud computing allows a significant amount of data storage in the cloud, and it is accessible in real-time at different locations (Yang Lu, 2021; Maddikunta et al., 2021). The large storage of data brings the construction to the era of big data analysis and the use of powerful Artificial Intelligence (AI) techniques to mine useful information. AI techniques and major development of its Machine Learning (ML) apply pattern recognition, feature recognition, and future prediction on construction and manufacturing data (Darlow et al., 2021).

IoT, for example, is an important technology that uses Radio Frequency Identification (RFID) and sensors or controllers that sense and monitor to send the data to the data bank on the internet for analysis and decision-making. IIoT is a subcategory of IoT that refer to the IoT technologies applied in the industrial and manufacturing concepts, which provide a deep insight into knowledge for companies. Blockchain technology from digital currency gets adopted in industry accounting and production activities (Haghnegahdar, Joshi, & Dahotre, 2022; Yang Lu, 2021). The New Zealand construction industry benefits from industry 4.0 for digitalization by discovering, adopting, and investigating more modern and intelligent technologies (Parente, Silva, Junior, & Uhlmann, 2022).

## THE NEED FOR CONSTRUCTION IN NZ TO MOVE TO INDUSTRY 5.0

New Zealand is a relatively small and a micro-businesses oriented nation. A report by "New Zealand Small Business Council - 2019" published an estimation of the size of the companies listed as follows (1) companies with no employees 70.5%, (2) companies with 1-5 employees 19 %, (3) and companies with 5+ employees

<sup>1</sup> School of Built Environment, Massey University, New Zealand. ORCID: 0000-0003-4023-4787

<sup>2</sup> School of Built Environment, Massey University, New Zealand. ORCID: 0000-0002-7683-287X

<sup>3</sup> School of Built Environment, Massey University, New Zealand. ORCID: 0000-0001-7265-6373

\* Corresponding author Email: A.Zavvari@massey.ac.nz

10.5%. The micro-size companies give a unique environment to New Zealand, which applies in many of its industries, including the construction industry. Similar to other businesses, construction companies in New Zealand have their unique challenges.

Amid the move through digitalisation for industry 4.0, the construction industry is currently still struggling for skilled workers, including up-skilling the current workers. Whilst industry 5.0 will apply a high degree of automation, there will still be a need for humans to upskill to the high technical level required to interface with this automation. Industry 5.0 introduces various novel concepts, for example, collaborative robots known as "Cobot," which can help businesses to carry out their work faster and better (Kim, 2022). Thus, industry 5.0, will likely provide solutions to overcome the New Zealand's skill shortage in its construction industry as long as the industry is able to adopt its skills, knowledge, and working practises.

New Zealand construction industry is also taking quick leaps towards its transformation to a Net Carbon Zero industry. The sustainability focus of Industry 5.0 holds the real potential to enable the construction industry to achieve its sustainability targets. New Zealand legislation like Resource Management Act 1991 emphasises sustainable development of the built environment and puts people and communities at the heart of the development process. More recently, New Zealand Government passed the Zero Carbon Amendment Act 2019 and agreed to make ambitious cuts in greenhouse gas emissions in the country (Bui, et al., 2021). The human-centric, sustainable, and resilient approaches are at the heart of Industry 5.0, which has the potential to transform the New Zealand construction industry so it can flourish for the benefit of the whole country.

## **AIM AND OBJECTIVES**

This abstract reports the progress of a current research project aiming to devise a way forward for the New Zealand construction industry to fully embrace Industry 5.0. To achieve this aim, the objectives are: 1) to assess and evaluate the New Zealand construction industry based on applied technologies and where it stands based on digitalisation; 2) to identify the factors that may facilitate and accelerate the adoption of industry 5.0, and 3) to develop a framework for New Zealand construction industry to be ready for and fully benefit from Industry 5.0.

The developed framework is envisaged to help construction professionals and clients to plan for advancing their technological capability and capacity to remain competitive in the construction industry in the future. One of the most important drivers of economic transformation is optimising future technology. In terms of contributions to knowledge, this research is expected to contribute to the continuous shaping and refinement of Industry 5.0 characteristics. The research method applied in this research can also be used as a valid method to conduct similar research in the future.

## **RESEARCH METHOD**

In this study, a triangulation method is carried out using bibliographic analysis, literature review, and semi-structured interviews with relevant companies and manufacturers in New Zealand's construction industry. The bibliometric analysis is performed to identify a comprehensive range of articles on digitalisation in the construction industry 4.0 and 5.0 (Donthu, Kumar, Mukherjee, Pandey, & Lim, 2021). Then an in-depth study provided by literature review assisted the authors in the second stage to find out the challenges and opportunities towards industry 5.0 in New Zealand (Webster & Watson, 2002). Moreover, semi-structured interviews with industry experts will be conducted; the interview data will be analysed through qualitative content analysis. The authors will be able to increase the study's reliability and validity by using the supplementary datasets offered by interview findings (Barriball & While, 1994; Kallio, Pietilä, Johnson, & Kangasniemi, 2016).

For this study, as of now, we have completed the bibliographic analysis and literature review. Semi-structured interviews with construction industry practitioners, involved with implementation of technology in their companies will be carried out to the point of saturation (Strauss & Corbin, 1998; Sutrisna & Setiawan, 2016). The list of interview questions are currently being finalised with the aim to understand the perspectives of industry 5.0 and its potential benefits as well as challenges, existing tools and standard practices to determine the way forward for New Zealand's construction industry to arrive at Industry 5.0.

## **EXPECTED OUTCOMES**

The study is expected to enhance the understanding of industry 5.0, optimising its prospects for the New

Zealand construction industry. The outcomes from bibliographic analysis and literature review have been utilised to contextualise and design the semi-structured interviews, with the final outcomes envisaged to be a proposed framework to enable the New Zealand Construction industry to be fully prepared for adoption of industry 5.0.

## REFERENCES

- Barriball, K. L., & While, A. (1994). Collecting data using a semi-structured interview: a discussion paper. *Journal of Advanced Nursing-Institutional Subscription*, 19(2), 328-335.
- Breque, M., De Nul, L., & Petridis, A. (2021). Industry 5.0: towards a sustainable, human-centric and resilient European industry. Luxembourg, LU: European Commission, Directorate-General for Research and Innovation.
- Bui, T. T. P., Wilkinson, S., Domingo, N., & MacGregor, C. (2021). Zero Carbon Building Practices in Aotearoa New Zealand. *Energies*, 14(15), 4455.
- Darlow, G., Rotimi, J. O., & Shahzad, W. M. (2021). Automation in New Zealand's offsite construction (OSC): a status update. *Built Environment Project and Asset Management*.
- Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, 133, 285-296.
- Haghnegahdar, L., Joshi, S. S., & Dahotre, N. B. (2022). From IoT-based cloud manufacturing approach to intelligent additive manufacturing: Industrial Internet of Things—An overview. *The International Journal of Advanced Manufacturing Technology*, 1-18.
- Harden, A., & Thomas, J. (2010). Mixed methods and systematic reviews: Examples and emerging issues. *Sage handbook of mixed methods in social & behavioral research*, 2, 749-774.
- Javaid, M., Haleem, A., Singh, R. P., Haq, M. I. U., Raina, A., & Suman, R. (2020). Industry 5.0: Potential applications in COVID-19. *Journal of Industrial Integration and Management*, 5(04), 507-530.
- Kallio, H., Pietilä, A. M., Johnson, M., & Kangasniemi, M. (2016). Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. *Journal of advanced nursing*, 72(12), 2954-2965.
- Kim, S. (2022). Working With Robots: Human Resource Development Considerations in Human–Robot Interaction. *Human Resource Development Review*, 15344843211068810.
- Lu, Y. (2021). The Current Status and Developing Trends of Industry 4.0: a Review. *Information Systems Frontiers*, 1-20.
- Lu, Y., Zheng, H., Chand, S., Xia, W., Liu, Z., Xu, X., . . . Bao, J. (2022). Outlook on human-centric manufacturing towards Industry 5.0. *Journal of Manufacturing Systems*, 62, 612-627.
- Maddikunta, P. K. R., Pham, Q.-V., Prabadevi, B., Deepa, N., Dev, K., Gadekallu, T. R., . . . Liyanage, M. (2021). Industry 5.0: A survey on enabling technologies and potential applications. *Journal of Industrial Information Integration*, 100257.
- Nahavandi, S. (2019). Industry 5.0—A human-centric solution. *Sustainability*, 11(16), 4371.
- Özdemir, V., & Hekim, N. (2018). Birth of industry 5.0: Making sense of big data with artificial intelligence, "the internet of things" and next-generation technology policy. *Omics: a journal of integrative biology*, 22(1), 65-76.
- Parente, R. S., Silva, I. R. S., Junior, P. O. S., & Uhlmann, I. R. (2022). Digital technologies review for manufacturing processes. *Independent Journal of Management & Production*, 13(1), 321-349.
- Strauss, A., & Corbin, J. (1998). *Basics of qualitative research techniques*.
- Stride, M., Renukappa, S., Suresh, S., & Egbu, C. (2021). The effects of COVID-19 pandemic on the UK construction industry and the process of future-proofing business. *Construction Innovation*.
- Sutrisna, M., & Setiawan, W. (2016). 14 the application of grounded theory methodology in built environment research. *Research methodology in the built environment: A selection of case studies*, 231.
- Webster, J., & Watson, R. T. (2002). Analyzing the past to prepare for the future: Writing a literature review. *MIS quarterly*, xiii-xxiii.

# THE IMPORTANCE OF OCCUPANT BEHAVIOUR WITHIN INDUSTRY 5.0

Laura Almeida<sup>1\*</sup>, Vivian Tam<sup>2</sup>, Matt Stevens<sup>3</sup>, Alan Todhunter<sup>4</sup> and Peng Zhang<sup>5</sup>

## INTRODUCTION

Occupant behaviour is one of the most complex variables impacting energy use in buildings. Its unpredictability and the different factors affecting how occupants perceive energy and building systems are highly relevant to driving modern societies toward sustainable developments (Hong et al. 2016). As Industry 5.0 takes a more societal approach and considers the human-machine interaction a critical leveraging point for process optimisation, occupant behaviour is detrimental to the rational and optimal use of energy in buildings from a building sector perspective (Xu et al. 2021). Attaining the desired outcomes conceived by the United Nations with the 17 Sustainable Development Goals (SDGs) will be facilitated with a complete understanding of the variability of human behaviour. Moreover, minimising energy waste and increasing occupants' value on energy use decision making in buildings is supported by the Lean philosophy on waste minimisation and improving resource efficiency (Francis and Thomas 2020). This research aims to promote awareness among building occupants on energy use and create an occupant behaviour database.

## BACKGROUND

After Industry 4.0, defined as integrating smart technologies in Industry, Industry 5.0 emerges as the next logical step (Xu et al. 2021). With the focus on human-centric, sustainability and resilience approaches, Industry 5.0 incorporates the human interaction with the technologies implemented in Industry 4.0 (Østergaard 2018). The human-centric approach sees people as the real value of any industry. Aligned with Lean Construction principles of generating value, people are no longer seen as mere costs but as new investments. Technology only makes sense if it is perfectly adapted and used by humans (Østergaard 2018, Xu et al. 2021, Francis and Thomas 2020).

Moreover, the resilience and sustainable approaches focus not only on environmental impacts but also on preventing possible disruptions that may compromise modern societies' well-being and normal "functioning" (Xu et al. 2021). Energy is one of the key elements of modern societies and one of the major concerns of governments (World Energy Council 2022). Energy is subjected to resource availability, type, and geopolitical influences that impact its availability and prices.

Recently, with the Ukraine crisis, significant increase in gas and oil prices was experienced. This affected not only transportation but also electricity production (World Energy Council 2022). Therefore, the urge to promote more energy-efficient systems and drive the world to decarbonised societies is more urgent than ever! The use of tools that incorporate Lean principles, such as the 'Lean Energy Climate', created by the US EPA in 2013, can be an excellent energy-efficient solution—promoting the efficient use of energy, and reduction in costs and impact on the environment, by encouraging users to identify areas with a waste of energy and implement Lean practices to improve them (Francis and Thomas 2020).

## RESEARCH PROBLEM

Buildings represent 40% of the primary energy uses in a western country (IEA 2013). From a Lean Construction perspective, buildings are inefficient systems that 'waste' energy, incurring in high costs. Lean Construction focuses on reducing any 'waste' (Francis and Thomas 2020). The literature has identified that there is a gap between the energy predicted in the design and operational stages in buildings. According to Stazi et al. (2017) and Khashe et al. (2015), this gap may vary between 150 - 300 %. Increasing the energy performance in buildings and reducing their use is crucial to sustainable development.

---

<sup>1</sup> Western Sydney University, Australia. ORCID: 0000-0002-4228-2187

<sup>2</sup> Western Sydney University, Australia. ORCID: 0000-0002-1074-8018

<sup>3</sup> Western Sydney University, Australia. ORCID: 0000-0003-2301-1311

<sup>4</sup> Western Sydney University, Australia. ORCID: 0000-0003-2218-1749

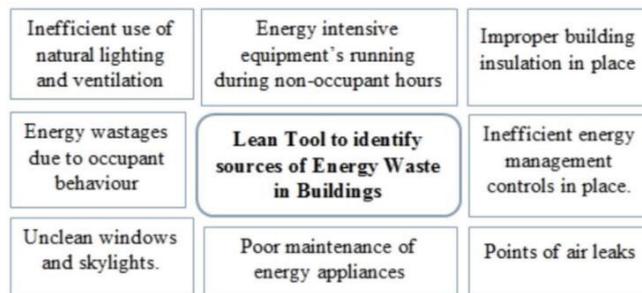
<sup>5</sup> Western Sydney University, Australia. ORCID: 0000-0002-6855-3395

\* Corresponding author Email: L.Almeida@westernsydney.edu.au

There are several variables impacting the energy performance in buildings, being occupant behaviour one of the critical elements. Occupants affect energy use by more than 50% (Stazi et al. 2017). The difference between a good energy user and an intensive one may go up to 72% (Almeida et al. 2020a). Occupant behaviour is complex and needs a more profound understanding. It is impacted by several aspects such as social and psychological aspects, background, motivation, and demography (Hong et al. 2016).

Moreover, the lack of awareness, misunderstanding and misinformation about the systems in buildings are some of the key elements that impact energy use in buildings. Past studies show that 81% of occupants lack awareness of how to efficiently use the systems in a building (Almeida et al. 2020a,b, Almeida et al. 2021). Promoting awareness to occupants is crucial in the new Industry 5.0 paradigm. Industry 5.0 highlights the collaboration between machines and humans. It prioritises the optimisation of machinery and people aligned with the environment (Demir and Cicibas 2017). Therefore, there is a need to align buildings toward a User-Centred approach and demystify the 'intelligent' user because most occupants using technology in buildings have limited technical background. For example, only approximately 4 % of the population in Australia attests to some technical knowledge (ABS 2021).

According to Francis and Thomas (2020), Lean Construction is a tool that can be used to identify several sources of wasted energy in buildings, existing and new. It can be used to estimate energy use and align with the prediction of energy during the design stage of a building. According to the previous authors, the following figure shows the different sources of energy waste that can be identified with Lean Construction in buildings.



**Figure 1 - Sources of energy waste that can be identified with Lean Construction (Francis and Thomas 2020)**

**AIM AND OBJECTIVES**

This research aims to provide a practical contribution to knowledge on promoting awareness among building occupants. It is intended to change occupants' behaviours and attitudes to match their behaviours on energy use. The main objectives are to reduce energy use in buildings and their environmental impact on climate change; understand the different types of energy users, how energy is used and where; and understand all subjective components of occupant behaviour. In the first stage, residential and university buildings will be targeted. However, it is intended to cover all different building classes.

**METHODOLOGICAL APPROACH TAKEN**

This research suggests implementing a mobile computing application (app) to increase occupants' energy awareness by providing customised advice and real-time information related to energy uses and carbon emissions, aligned with the concepts of Industry 5.0. According to Xu et al. (2021), technology only makes sense if used to serve people and societies. With a human-centric approach, Industry 5.0 focuses on technologies that promote data storage, analysis and transmission; and efficient energy use and storage that may lead to a nation's energy autonomy.

In this research, the app is seen as the 'machine' mechanism with which humans will be interacting. It will receive real-time information from a platform connected to the building management system. The platform is the data storage and transmission element. Energy uses will be measured instantaneously and sent to occupants for their monitoring. The analysis, in this case, is performed by the occupants. Occupants will receive the information and analyse and act upon it. This system will enable an understanding of different types of occupants/users, how energy is used, and where by collecting and creating an occupant behaviour database, storing all the information collected during the research period. In addition, subjective aspects such as social, psychological, physiological and economic will be analysed and scrutinised. Similar to a Value stream

mapping (VSM), by understanding all the previous factors, a mapping of all the information related to occupant behaviour and different causes for waste of energy will be created (Francis and Thomas 2020).

Additionally, the information collected and compiled in this research will be made available to be incorporated by designers during the design process of buildings. Francis and Thomas (2020) highlight the use of the Lean tool to understand the patterns in energy use and track the critical areas for energy loss, recommending improvement measures aligned with the aims and objectives of this research.

## PREDICTED RESULTS

In Australia, there are approximately 7,760,000 households (ABS 2021). A typical household uses between 19 kWh to 50 kWh per day, emitting an average of 12 tCO<sub>2</sub> per year (ABS 2021).

Considering the potential 96 % of the Australian population without technical background and 81 % lacking awareness, with a conservative approach of 50 % success, the potential impact of this research is avoidance of around 34 GtCO<sub>2</sub> (34 TCO<sub>2</sub>)<sup>1</sup> per year for the residential sector only. It is expected in this research a change in occupant behaviours and, consequently, a reduction in energy use, which will lead to the avoided greenhouse gas emissions referred to previously.

## REFERENCES

- Almeida, L., Tam Vivian, W.Y., Le Khoa, N., She, Y., 2020a, Effects of occupant behaviour on energy performance in buildings: a green and non-green building comparison, *Engineering Construction Architectural Management*, 27 (8), 1939–1962, <https://doi.org/10.1108/ECAM-11-2019-0653>
- Almeida, L.M.M.C.E., Tam, V.W.Y., Le, K.N., 2020b, Quantification of the energy use due to occupant behaviour collected in surveys: a case study of a green and non-green building, *J. Build. Perfor. Simulat.*, 13 (6), 777–803, <https://doi.org/10.1080/19401493.2020.1825529>
- Almeida, L., Tam Vivian, W.Y., Le Khoa, N., She, Y., 2021, Users1 building optimal performance manual, *Cleaner and Responsible Consumption*, 2, 100009, <https://doi.org/10.1016/j.clrc.2021.100009>
- Appleby, P. 2022, We need to talk about and engage each other on energy – In the face of two "once in a lifetime" Energy Shocks, in World Energy Council, viewed 18 March 2022, <  
<https://www.worldenergy.org/news-views/entry/we-need-to-talk-about-and-engage-each-other-on-energy>>
- Commonwealth\_Of\_Australia 2021, National greenhouse accounts factors 2021, Australian National Greenhouse Accounts, National greenhouse accounts factors, Australian Government Department of Industry, Science, Energy and Resources: Commonwealth of Australia.
- Demir KA and Cicibas H 2017, Industry 5.0 and a Critique of Industry 4.0, In Proceedings of the 4th international management information systems conference, Istanbul, Turkey (pp. 17-20).
- Francis A and Thomas, A 2020, Exploring the relationship between lean construction and environmental sustainability: A review of existing literature to decipher broader dimensions, *Journal of cleaner production*, 252, p.119913.
- Hong T, Taylor-Lange SC, D'oca S, Yan D & Corgnati S P 2016, Advances in research and applications of energy-related occupant behavior in buildings, *Energy and Buildings*, 116, 694-702.
- IEA, I. E. A. 2013. Modernising Building Energy Codes to Secure our Global Energy Future. International Energy Agency, Policy Pathway, 8.
- Hong, T., Taylor-Lange, S. C., D'Oca, S., Yan, D., & Corgnati, S. P. (2016). Advances in research and applications of energy-related occupant behavior in buildings. *Energy and Buildings*, 116, 694-702. doi:10.1016/j.enbuild.2015.11.052
- Khashe, S., et al., Influence of LEED branding on building occupants' pro-environmental behavior. *Build. Environ.*, 2015. 94: p. 477-488
- Norford, L. K., Socolow, R. H., Hsieh, E. S., & Spadaro, G. V., 1994, Two-to-one discrepancy between measured and predicted performance of a 'low-energy' office building: insights from reconciliation based on the DOE-2model, *Energy and Buildings*, 21, 121-131.
- Østergaard, E.H., 2018. Welcome to industry 5.0. Retrieved Febr, 5, p.2020.
- Stazi, F., F. Naspì, and M. D'Orazio, A literature review on driving factors and contextual events influencing

<sup>1</sup> The GHG emissions were calculated for electricity use based on the report by the COMMONWEALTH\_OF\_AUSTRALIA 2021. National greenhouse accounts factors 2021, Australian National Greenhouse Accounts. National greenhouse accounts factors. Australian Government Department of Industry, Science, Energy and Resources: Commonwealth of Australia

occupants' behaviours in buildings. *Building and Environment*, 2017. 118: p. 40-66

Xu, X., Lu, Y., Vogel-Heuser, B. and Wang, L., 2021. Industry 4.0 and Industry 5.0—Inception, conception and perception. *Journal of Manufacturing Systems*, 61, pp.530-535.

## **DESIGN**

# A CONCEPTUAL MODEL FOR UNDERSTANDING THE VALUE HIERARCHY OF HEALTHCARE BUILT ENVIRONMENTS AND SERVICES

Giulie Anna Baldissera<sup>1\*</sup>, Carlos Torres Formoso<sup>2</sup>, and Patricia Tzortzopoulos<sup>3</sup>

## INTRODUCTION

Value generation is one of the main purposes of the Lean Philosophy and it is achieved by the fulfilment of user's requirements (Koskela, 2000). In the particular context of healthcare built environments (BE), value generation is concerned with service efficiency, as well as the quality of care throughout the healing process (Tzortzopoulos, et. al., 2009). Despite value-based healthcare being a growing field of research (Colldén, et al., 2017), the value concept is still a buzzword for the healthcare sector (Colldén, et al., 2017; Fredriksson et al., 2015). Due to the complexity, multidimensional character, and interrelated dimensions of the value construct, it requires further understanding (Sánchez-Fernández, Iniesta-Bonillo, 2007).

The Means-End Chain (MEC) conceptual model, proposed by Gutman (1982), is a multidimensional perspective of value. In this approach, three levels of hierarchy are set: attributes (the most concrete level), consequences, and value (the most abstract level) (Reynolds & Gutman, 2001). The MEC approach is usually explored by using an interview method, named laddering technique, for the identification of each level of hierarchy (Leppard, et. al., 2003). As a result, a diagram, named Hierarchical Value Map (HVM) is produced, which represents the connections between these levels (Reynolds & Gutman, 2001). Kumar, et. al. (2020) carried out a systematic literature review to identify papers concerning laddering interviews and hierarchical value maps in healthcare. However, they found a scant number (only 3) of eligible studies concerning patient's values. Despite the contribution to those specific studies, further research is necessary, especially regarding the adoption of a multidimensional approach for value generation in healthcare built environments, considering that existing knowledge is highly fragmented. Moreover, considering the intangibility of the healthcare services (Zeithaml, et. al., 1985), and its inseparability from the BE (Hutton, Richardson, 1995), it is important to understand the interdependences between services and BE and their impact on value generation.

Another useful conceptual framework for understanding value generation in healthcare is *Healthscape* (Hutton, Richardson, 1995), which has its roots on Bitner (1992)'s proposal for the retail market, named *Servicescape*. *Healthscape* is the influence perceived by different users of healthcare services brought about by the BE, analysing tangible elements (Hutton, Richardson, 1995). The main contributions of studies on this topic refer to the identification of a variety of concrete and abstract characteristics of healthcare BE (Codinhoto, et. al., 2009; Ulrich, et. al., 2010; Suess, Mody, 2018; Han, et. al., 2018). As there is a trend of users to reuse healthcare services, many studies explore cause-effect relationships. However, there is a gap of knowledge concerned with understanding the relationships between attributes, consequences and values.

Against this background, the emerging research problem is "how to establish relation among main constructs regarding healthcare BE value generation considering an integrated approach with services and their impacts for different users?". This investigation does not attempt to provide a universal model that will fit any healthcare facility. Instead, it acknowledges that each healthcare department has its specific characteristics and that is necessary for design professionals to understand them. Therefore, this research has two broad purposes. Firstly, it aims to identify the main constructs that must be considered in the development of hierarchical value maps. Secondly, a conceptual model will be devised for structuring and connecting these categories through a value hierarchy.

## RESEARCH METHOD

The methodological approach adopted in this investigation is Design Science Research (DSR). The aim of this approach is to solve classes of real-world problems, by devising a solution concept, named artifact (Lukka,

---

<sup>1</sup> Building Innovation Research Unit (NORIE), Federal University of Rio Grande do Sul (UFRGS), Brazil. ORCID 0000-0002-2094-7731

<sup>2</sup> Building Innovation Research Unit (NORIE), Federal University of Rio Grande do Sul (UFRGS), Brazil. ORCID 0000-0002-4772-3746

<sup>3</sup> School of Art, Design and Architecture, University of Huddersfield, UK. ORCID 0000-0002-8740-6753

\* Corresponding author Email: giuliebaldissera@gmail.com

2003). This research work is based on two empirical studies. The first one was carried out in an Intensive Care Unit of a hospital (hospital A) and the second was held at an Emergency Department of another hospital (hospital B), both in Southern Brazil.

The research design was divided into (Van Aken, 2004): (i) problem understanding, (ii) development and application of the solution; and (iii) evaluation and reflection about the solution. The first phase began by understanding the real-world problem, regarding healthcare BE, services provided, and the profile of the different users. Then a HVM was devised in both empirical studies. The second phase comprised development of the conceptual model, that arose from a set of analysis of the HVMs. So, the main constructs and possible interconnections were defined. The third phase consists of an evaluation of the artifact in terms of utility and applicability, and a reflection regarding the artifact's practical and theoretical contributions. The main sources of evidence were: (i) document analysis, to understand the project design; (ii) non-participant observations regarding service routine; (iii) semi-structured interviews, based on the laddering technique with different users; and (iv) meetings with key-stakeholders to discuss partial results. This research is still under development, currently on the second phase of the investigation. Therefore, the conceptual model is still being devised. The following step consists of undertaken a focus group to discuss the research results. After that, the conceptual model will be tested and evaluated.

## CONCLUSIONS

The main contribution of this research consists of a conceptual model for developing HVM for healthcare BE and its interdependences with services. The main theoretical contribution of this research lies on the definition of main constructs for understanding value generation and the relationship between healthcare BE and services.

Regarding the practical contributions, this research intends to enlighten design teams with insights on the multiple factors to be considered in healthcare design. Once decision-makers understand the main relationships between healthcare facilities and services, this will facilitate decision making. Therefore, this conceptual model can be used either during the design process or for evaluating healthcare facilities along its occupation.

## REFERENCES

- Bitner, M. J. (1992). Servicescapes: The impact of physical surroundings on customers and employees. *Journal of marketing*, 56(2), 57-71.
- Codinhoto, R., Aouad, G., Kagioglou, M., Tzortzopoulos, P., & Cooper, R. (2009). Evidence-based design of health care facilities. *Journal of health services research & policy*, 14(4), 194-196.
- Colldén, Christian; Gremyr, Ida; Hellström, Andreas; Sporræus, Daniella (2017). A value-based taxonomy of improvement approaches in healthcare, *Journal of Health Organization and Management*, Vol. 31 Issue: 4, pp.445-458, doi: 10.1108/JHOM-08-2016-0162
- Fredriksson JJ, Ebbevi D, Savage C (2015). *BMJ Qual Saf* 2015;24:451–457. doi: 10.1136/bmjqs-2014-003803
- Gutman, J. (1982). A means-end chain model based on consumer categorization processes. *Journal of marketing*, 46(2), 60-72.
- Han, J., Kang, H. J., & Kwon, G. H. (2018). A systematic underpinning and framing of the servicescape: Reflections on future challenges in healthcare services. *International journal of environmental research and public health*, 15(3), 509.
- Hutton, J. D., & Richardson, L. D. (1995). Healthscapes: The role of the facility and physical environment on consumer attitudes, satisfaction, quality assessments, and behaviors. *Health care management review*, 48-61.
- Koskela L. (2000). An exploration towards a production theory and its application to construction. Ph.D. Diss, University of Technology, Espoo-Finland.
- Kumar, P., Follen, M., Huang, C.-C., and Cathey, A., 2020. Using Laddering Interviews and Hierarchical Value Mapping to Gain Insights Into Improving Patient Experience in the Hospital: A Systematic Literature Review. *Journal of Patient Experience*, 7 (6), 1740–1747.
- Leppard, P., Russell, C. G., & Cox, D. N. (2004). Improving means-end-chain studies by using a ranking method to construct hierarchical value maps. *Food quality and preference*, 15(5), 489-497.
- Reynolds, T. J., & Gutman, J. (2001). Laddering theory, method, analysis, and interpretation. In *Understanding consumer decision making* (pp. 40-79). Psychology Press.

- Sánchez-Fernández, R., & Iniesta-Bonillo, M. Á. (2007). The concept of perceived value: a systematic review of the research. *Marketing theory*, 7(4), 427-451.
- Suess, C., & Mody, M. (2018). The influence of hospitable design and service on patient responses. *The Service Industries Journal*, 38(1-2), 127-147.
- Tzortzopoulos, P., Codinhoto, R., Kagioglou, M., Rooke, J., and Koskela, L., 2009. The gaps between healthcare service and building design: a state of the art review. *Ambiente Construído*, 9 (2), 47–55.
- Ulrich, R. S., Berry, L. L., Quan, X., & Parish, J. T. (2010). A conceptual framework for the domain of evidence-based design. *HERD: Health Environments Research & Design Journal*, 4(1), 95-114.
- Van Aken, J. E. (2004). Management research based on the paradigm of the design sciences: the quest for field-tested and grounded technological rules. *Journal of management studies*, 41(2), 219-246.
- Zeithaml, V. A., Parasuraman, A., & Berry, L. L. (1985). A conceptual model of service quality and its implications for future research. *Journal of marketing*, 49(4), 41-50.v. 49, n. 4, p. 41-50, 1985.

## DESIGN PLANNING AND CONTROL OF FAST COMMERCIAL REFURBISHMENT BUILDING PROJECTS

Douglas C. Hamerski<sup>1\*</sup>, Carlos Torres Formoso<sup>2</sup>, and Eduardo L. Isatto<sup>3</sup>

### INTRODUCTION

Traditional project management approaches tend to be ineffective for design management in construction (Fosse and Ballard, 2016). The techniques based on those approaches are not able to cope with the complexity involved in construction projects and with the nature of design tasks (Fosse and Ballard, 2016). Design processes have high levels of uncertainty and often involve non-linear chains of interaction between different parties (Hamzeh et al., 2009).

This study is focused on the context of fast commercial refurbishment building projects, in which client organisations need to manage multiple simultaneous projects carried out by suppliers. These projects have high levels of complexity (Egbu, 1995; Bryde and Schulmeister, 2012; Kemmer and Koskela, 2020): (i) a large number of stakeholders typically work together, and some resources are shared among different projects; (ii) a high level of uncertainty usually exists as some information are made available just after dismantling and stripping work have started; (iii) project scope can be unclear (design changes are demanded by clients and designers after the beginning of the production stage); and (iv) projects need to be developed within a short time frame.

Some studies have reported successful implementations of the Last Planner System (LPS) in the design process (Hamzeh et al., 2009; Kerosuo et al., 2012; Fosse and Ballard, 2016). This planning and control model is strongly based on Lean Production, and to some extent is able to cope with the level of complexity that exists in design. However, there seem to be some gaps in the implementation of LPS in design, such as limited success in constraints identification and removal (Wesz et al., 2018) and the lack of metrics for assessing the impacts of LPS (Hamzeh et al., 2009), especially at the long-term planning level. These are specific design planning problems that are expected to be tackled by this study.

In addition, the application of LPS has not been explored in the context of fast commercial refurbishment building projects. This is important as construction projects may have different types of complexity (Luo et al., 2016), which establish different requirements for planning and control systems. This can provide additional insights into how to adapt the LPS (originally developed for production) into the design process.

Resilience Engineering (RE) is a theoretical framework that has been used as a reference for designing and managing complex socio-technical systems (Hollnagel et al., 2006). RE is concerned with the study and application of the concept of resilience, which is the intrinsic ability of a system to adjust its functioning prior to, during, or following events so that it can sustain required operations under both expected and unexpected conditions (Hollnagel et al., 2015). The concept of resilience has been explored mostly for safety management in several knowledge areas, such as healthcare, aviation, and construction. Mark and Semaan (2008) studied the role of resilience in collaboration in which they conducted an empirical study of people that experienced prolonged disruption through a war in their work and personal lives. The authors describe how technology played an important role in providing people with alternative resources to reconstruct, modify, and develop new routines, or patterns of action, for work and socializing. RE has not been explored much in other managerial process, such as planning and control in construction projects. The benefit of looking at design planning from an RE perspective is that new ways of dealing with complexity can be added or emphasised in the LPS.

This research proposes a set of requirements for design planning and control systems focused on dealing with the complexity of fast commercial refurbishment building projects based on LP and RE. This research work is based on an empirical study that has been carried out in a department store company from Brazil (hereinafter referred to as Company A), which has a large portfolio of projects every year. This document

<sup>1</sup> Federal University of Rio Grande do Sul (UFRGS), Brazil. ORCID 0000-0002-3804-4047

<sup>2</sup> Federal University of Rio Grande do Sul (UFRGS), Brazil. ORCID 0000-0002-4772-3746

<sup>3</sup> Federal University of Rio Grande do Sul (UFRGS), Brazil. ORCID 0000-0002-0851-8790

\* Corresponding author Email: douglas\_hamerski@hotmail.com

presents some initial results of this investigation.

## RESEARCH METHOD

Design Science Research (DSR) is the methodological approach adopted in this investigation. The research process has been carried out in close collaboration and engagement of the professionals from Company A and suppliers, through a strategy similar to Action Research.

The main activities developed to date are: (i) assessing the existing planning and control system; (ii) devising the first version of the new planning and control system; and (iii) implementing this first version in two different projects. Activity (i) involved 4 semi-structured interviews with Company A representatives, 3 semi-structured interviews with different suppliers and the analysis of a large set of documents (eg., project charters, list of deliverables, long-term plans, design drawings, etc.). Activity (ii) involved 5 meetings with Company A representatives. Finally, activity (iii) involved participant observation in all design planning meetings of the two projects (13 meetings in Project 1 and 17 meetings in Project 2) and document analysis (especially the look-ahead and short-term plans of each project). The upcoming activities are: (i) to refine the first version of the planning and control system, including the creation of a new long-term planning tool based on the idea of reducing design batch size; (ii) to implement the refined version of the system in Project 3; and (iii) analyse the practical and theoretical contributions of this investigation.

Project 1 (75 days of duration) is a store located in a shopping centre and Project 2 (90 days of duration) is a stand-alone street store. Design planning and control was implemented in a virtual environment using digital technologies, including video conferencing and the use of BIM. All meetings of the implementation process were carried out virtually through the Microsoft Teams® communication and collaboration platform. The design of each project was developed using Autodesk Revit®.

## RESULTS

The design phase of Company A's projects is divided into five stages: preparation (collecting data about the existing building), outline design, scheme design, design for legal requirements, and detail design. The duration of each stage lasts between 15 and 20 days. Before the beginning of this study, Company A had a standard planning and control system that was applied to all projects. This system was strongly based on a long-term plan produced at the beginning of each project in a CPM-based software.

The first version of the new planning and control system was focused on look-ahead and short-term planning routines. The look-ahead efforts began before the beginning of the projects, in which a meeting was held with a planning horizon of the entire design duration. After that, look-ahead meetings were held at the end of each stage of the design process with a planning horizon of two stages ahead. Short-term planning meetings were held weekly. Part of these meetings was dedicated to the follow-up of the look-ahead plans and the identification and removal of emerging constraints.

The implementation of the first version of the new system increased the effectiveness of the planning and control process of these projects: the projects were delivered on time, and the Constraint Removal Index (CRI) and the Percentage of Plans Completed (PPC) remained very close to 80% and stable. Both design managers and designers were very engaged in the quick removal of constraints. Participants highlighted decentralization and collaboration as the main benefits of the implemented practices.

## DISCUSSION

From a practical point of view, it is expected that this work will bring insights regarding the development of a long-term planning tool and the proposition of innovative indicators for this level of planning and recommendations to improve constraints management. From a theoretical point of view, it is expected that this work will bring insights into how RE can be used to improve the implementation of LPS in design.

## REFERENCES

- Ballard, G. The last planner system of production control. 2000. PhD Thesis. University of Birmingham.
- Ballard, G.; Tommelein, I. 2020 Current Process Benchmark for the Last Planner (R) System of Project Planning and Control. 2021.
- Bryde, D. J.; Schulmeister, R. Applying Lean principles to a building refurbishment project: experiences of key stakeholders. *Construction Management and Economics*, v. 30, n. 9, p. 777-794, 2012.
- Egbu, C. O. Perceived degree of difficulty of management tasks in construction refurbishment work: Record

of a survey of 32 large refurbishment organizations and 142 practising refurbishment managers showing that forecasting and planning, analysis of risks, uncertainty and competitive tendering are the most difficult management tasks in refurbishment. *Building research and information*, v. 23, n. 6, p. 340-344, 1995.

Fosse, R.; Ballard, G. Lean design management in practice with the last planner system. In: *Proceedings of the 24th Annual Conference of the International Group for Lean Construction*. Boston: IGLC, 2016.

Habibi Rad, M.; Mojtahedi, M.; Ostwald, M. J. The integration of lean and resilience paradigms: A systematic review identifying current and future research directions. *Sustainability*, v. 13, n. 16, p. 8893, 2021.

Hamzeh, F. R.; Ballard, G.; Tommelein, I. D. Is the Last Planner System applicable to design? A case study. In: *Proceedings of the 17th Annual Conference of the International Group for Lean Construction*. Taipei: IGLC, 2009.

Hollnagel, E. How resilient is your organisation? An introduction to the resilience analysis grid (RAG). In: *Sustainable transformation: Building a resilient organization*. 2010.

Hollnagel, E.; Woods, D. D.; Leveson, N. (Ed.). *Resilience engineering: Concepts and precepts*. Ashgate Publishing, Ltd., 2006.

Kemmer, S.; Koskela, L. Lean as an appropriate approach for managing production in refurbishment projects. *Lean Construction: Core Concepts and New Frontiers*, p. 230, 2020.

Kerosuo, H. et al. In time at last: Adaption of Last Planner tools for the design phase of a building project. In: *Proceeding of the 20th Annual Conference of the International Group for Lean Construction*. San Diego: IGLC, 2012.

Mark, Gloria; Semaan, Bryan. Resilience in collaboration: Technology as a resource for new patterns of action. In: *Proceedings of the 2008 ACM conference on Computer supported cooperative work*, San Diego: ACM, 2008.

Saurin, T. A.; Rooke, J.; Koskela, L.. A complex systems theory perspective of lean production. *International Journal of Production Research*, v. 51, n. 19, p. 5824-5838, 2013.

Wesz, J. G. B.; Formoso, C. T.; Tzortzopoulos, P. Planning and controlling design in engineered-to-order prefabricated building systems. *Engineering, Construction and Architectural Management*, 2018.

# DIGITAL WHITEBOARDS AS A VISUAL MANAGEMENT STRATEGY TO SUPPORT COLLABORATIVE INTERACTIONS IN CIVIL ENGINEERING DESIGN

Bárbara Pedó<sup>1\*</sup>, Patricia Tzortzopoulos<sup>2</sup>, Lauri Koskela<sup>3</sup> and Algan Tezel<sup>4</sup>

## INTRODUCTION

The management of engineering projects requires organisational structures and information systems that encourages collaboration. Technological innovations in information management have the potential to enable interactions across physical boundaries, facilitating distributed collaboration. However, collaboration can still be considered a challenge, as well as a prerequisite for the development of digital innovations (Pershina et al. 2019). This process was accelerated during COVID-19 pandemic, in which remote work has been encouraged, and the need for real-time information sharing, communication, and coordination increased.

Visual Management (VM) can be defined as an information management strategy that supports collaborative interactions, common ground, and increased transparency (Formoso et al. 2002; Lindlöf 2014; Tezel et al. 2009). Thus, digital VM has the potential to improve communication and collaboration, nevertheless this has been poorly explored in the literature and practice. The adoption of digital VM is under accelerated development, so that there is limited knowledge on how the users adopt it. To date, the links between VM and digital solutions have been understudied in the literature (Tezel et al. 2015; Tezel and Aziz 2017), and there is still a research gap on how information is captured, recorded, shown and analysed via shared visual representations (Yusoff and Salim 2015). In addition, distributed working is often stated as a challenge because there is no support for the users who are actually collaborating with each other (Gumienny et al. 2011), and the design of the digital systems frequently ignores the coordination requirements, such as the cognitive work of coordination and the dynamic interactions (Maguire 2019). Murata (2019), however, recently explored four scenarios for improving performance of VM with digital technology, expanding visual space, considering the temporal extension, supporting the entire problem solving process, and visualising geographically different places.

The aim of this research is to devise a method for digital VM implementation, focusing on digital whiteboards, to support collaborative practices, such as the planning of activities in design. A method is described by March and Smith (1995) as a set of steps, e.g. guidelines, necessary to perform a task, based on a representation of the solution space (model) and a set of constructs. This method is meant to be a prescriptive contribution, supporting the development, refinement and use of digital visual management within design companies.

## RESEARCH METHOD

The research adopted the Design Science Research approach, connecting practice and theory (Holmström et al. 2009) by solving real-world problems and contributing to the theory with innovative solutions (Lukka 2003). There was a strong involvement of the researcher and the company in the development of the solution, with no dissociation of the solution development and evaluation (Sein et al. 2011). Thus, Action Research was the research strategy adopted. This investigation was carried out in collaboration with an infrastructure design and consultancy company from the UK through an ongoing Knowledge Transfer Partnership (KTP) project<sup>5</sup>. The research is characterised by incremental learning cycles, and the main phases (Susman and Evered 1978) are: (i) diagnosing, related to the understanding of the overall problem, existing VM devices and collaborative

---

<sup>1</sup> University of Huddersfield, UK. ORCID 0000-0002-6520-0981

<sup>2</sup> University of Huddersfield, UK. ORCID 0000-0002-8740-6753

<sup>3</sup> University of Huddersfield, UK. ORCID 0000-0003-4449-2281

<sup>4</sup> Aston University, UK. ORCID 0000-0003-3903-6126

\* Corresponding author Email: b.pedo@hud.ac.uk

<sup>5</sup> Knowledge Transfer Partnership (KTP) is a partially government-funded programme to encourage collaboration between academia and industry in the UK. This KTP project aims to explore the integration of Lean and digital design, and it is sponsored by InnovateUK.

interactions; (ii) action planning and taking, associated with the proposition and observation of new digital VM devices using collaborative digital whiteboards, such as Miro ([miro.com](https://miro.com)) and Mural ([www.mural.co](https://www.mural.co)) for different functions, allowing its comparison with manual VM practices; (iii) evaluating, through participant observation; and (iv) specifying learning, which relates to the critical analysis and theoretical contributions. The main sources of evidence were: (i) workshop with key stakeholders to develop and assess the VM interface and routines; (ii) participant observation of workshops and meetings; (iii) survey with workshop attendees; and (iv) training sessions.

## FINDINGS

The effectiveness of digital whiteboard was explored by analysing their applicability to various functions, as well as comparing digital and manual implementations. The adoption of whiteboards for the planning of activities using Last Planner System (LPS) emerged as a necessity during Covid-19 restrictions of working from home, which leveraged and valued the use of digital technologies in design to assist remote work. Nine different whiteboard functions were identified in total, however, the other eight functions, such as digital whiteboards for designing new systems and strategies, brainstorming and meeting structure, arisen after its initial use for planning implementation, without a problem identification in advance. Since the teams became familiar with the device interface and its functionalities, it enabled the whiteboard dissemination for various uses and purposes. Through participant observation, digital whiteboards were found to be flexible in adapting the devices according to the users' needs over time and requirements, so that, new problems could also be solved without a previous problem formulation, as proposed by von Hippel and von Krogh (2016).

Its adoption was described by the workshop participants as a valuable way to communicate concepts, ideas, and actions, through virtual interactions. Thus, all participants can contribute equally and support faster problem-solving at the same or different times and virtual place, allowing them to also easily access information prior and after the meetings. The human-technology interaction was considered through different types of collaboration, e.g., asynchronous and synchronous distributed collaboration as defined by Anumba et al. (2002), while the users' perception was considered to support the understanding of common ground and shared understanding. It can be adopted as means for collaboration among users with different perceptions, which corroborates with Lindlöf (2014), aiming to create a common point of view and agreement. It allows the transfer of information across time and space, but can also support the identification of abnormalities and problem solving, discussed by Murata (2019). By creating and recreating a common ground in virtual environments, it has the potential to support complex and emergent interactions in the collaborative space. Thus, the method includes the key steps: observe the process, analyse user needs, integrate in the process routine, analyse technical requirements, and define the visual attributes, adapting the model suggested by Valente et al. (2019) to the digital context. Further research should explore a substantial number of other digital collaborative VM devices, encouraging a further reflection about the benefits and barriers, as well as further understanding of how the users adopt and perceive digital VM through collaborative interactions.

## REFERENCES

- Anumba, C. J., Ugwu, O. O., Newnham, L., and Thorpe, A. (2002). "Collaborative design of structures using intelligent agents." *Automation in Construction*, 11(1), 89–103.
- Formoso, C. T., Santos, A. dos, and Powell, J. A. (2002). "An exploratory study on the applicability of process transparency in construction sites." *Journal of Construction Research*, World Scientific, 03(01), 35–54.
- Gumienny, R., Meinel, C., Gericke, L., Quasthoff, M., LoBue, P., and Willems, C. (2011). "Tele-Board: Enabling Efficient Collaboration In Digital Design Spaces Across Time and Distance." *Design Thinking*, Springer Berlin Heidelberg, Berlin, Heidelberg, 147–164.
- von Hippel, E., and von Krogh, G. (2016). "Problem solving without problem formulation." *Organization Science*, 27(1), 207–221.
- Holmström, J., Ketokivi, M., and Hameri, A.-P. (2009). "Bridging practice and theory: a design science approach." *Decision Sciences*, Wiley Online Library, 40(1), 65–87.
- Lindlöf, L. (2014). "Visual Management – on Communication in Product Development Organizations." Chalmers University of Technology.
- Lukka, K. (2003). "The constructive research approach." *Case study research in logistics*. Publications of the Turku School of Economics and Business Administration, Series B, 1(2003), 83–101.
- Maguire, L. M. D. (2019). "Managing the hidden costs of coordination." (december), 71–93.
- March, S. T., and Smith, G. F. (1995). "Design and natural science research on information technology."

Decision Support Systems, Elsevier, 15(4), 251–266.

Murata, K. (2019). "On the role of visual management in the era of digital innovation." *Procedia Manufacturing*, Elsevier B.V., 39, 117–122.

Pershina, R., Soppe, B., and Thune, T. M. (2019). "Bridging analog and digital expertise: Cross-domain collaboration and boundary-spanning tools in the creation of digital innovation." *Research Policy*, Elsevier, 48(9), 103819.

Sein, M. K., Henfridsson, O., Purao, S., Rossi, M., and Lindgren, R. (2011). "Action design research." *MIS Quarterly: Management Information Systems*, 35(1), 37–56.

Susman, G., and Evered, R. D. (1978). "An Assessment of the Scientific Merits of Action Research Author ( s ): Gerald I . Susman and Roger D . Evered Published by : Sage Publications , Inc . on behalf of the Johnson Graduate School of Management , Cornell University Stable URL : <http://www.jst>." 23(4), 582–603.

Tezel, A., and Aziz, Z. (2017). "From conventional to it based visual management: A conceptual discussion for lean construction." *Journal of Information Technology in Construction*, 22(May 2016), 220–246.

Tezel, A., Koskela, L., Tzortzopoulos, P., Formoso, C. T., and Alves, T. (2015). "Visual Management in Brazilian Construction Companies: Taxonomy and Guidelines for Implementation." *Journal of Management in Engineering*, 31(6), 05015001.

Tezel, B. A., Koskela, L. J., and Tzortzopoulos, P. (2009). "The functions of visual management." *International Research Symposium*, 201–219.

Valente, C. P., Brandalise, F. M. P., and Formoso, C. T. (2019). "Model for Devising Visual Management Systems on Construction Sites." *Journal of Construction Engineering and Management*, 145(2), 04018138.

Yusoff, N. M., and Salim, S. S. (2015). "A systematic review of shared visualisation to achieve common ground." *Journal of Visual Languages and Computing*, Elsevier, 28, 83–99.

## **BIM AND KNOWLEDGE MANAGEMENT AS A LEAN TOOL FOR THE IMPROVEMENT OF PREFABRICATED BUILDING SYSTEMS: USER-DRIVEN INNOVATION IN THE CONSTRUCTION PROCESS**

Lucianne Casasanta Garcia<sup>1\*</sup>, Simone Barbosa Villa<sup>2</sup>

Construction represents one of the activities with the greatest impact on the environment, acting throughout the life cycle of the building, from its conception to its demolition. In this respect, the use of prefabricated elements is presented as a strategy to improve production methods and to reduce environmental impacts in the construction process. In addition, there are several tools to assist in strategic decisions during all phases of the project, such as Building Information Modeling (BIM), digitalisation, Lean Construction, etc. However, compared to other industries, there is a failure to successfully implement information technology and harness the potential of new technologies to improve productivity in the construction industry.

There are few studies that concern the use of Knowledge Management (KM) in the design phase to incorporate the end-user demand into the process. KM can be seen as the means to extract and capture the available information which can be used to provide better ways of doing things regarding products and processes in a construction context. Companies are aware of situations in their organisations in which costly errors have been made because knowledge was not available when and where it was needed and because employees did not know how to interpret or use the information available to them. These results are mainly due to the project-based nature of the construction industry and the fact that knowledge is embedded in social relations. The challenge may originate from a complexity of factors, such as climatic conditions or occupant behavioural patterns. Also, its potential and its ability to adopt big data techniques have not been sufficiently studied. Therefore, KM and BIM play a key role in construction automation and corresponding management systems, and can help to automatically extract important concepts, interrelations, and models of the interest database. Systematic management of knowledge can help in a better continuous improvement, sharing tacit knowledge, faster response to customers, dissemination best practices, reduction in rework.

This research aims to present a new design analysis model with strategies for the application of the BIM methodology as a lean tool, using KM techniques, so that civil construction agents can incorporate user needs in the construction process. More specifically, it presents a research work regarding the improvement of prefabricated construction systems developed by an Argentine enterprise called Astori. This work was developed within the scope of the Post-Graduation Program in Architecture of Universidad Nacional de Rosario (Argentina) and is part of the doctoral thesis entitled "Metodología y gestión BIM en el desarrollo de sistemas constructivos en hormigón armado: el caso Astori y sus nuevas demandas desde la construcción civil". The research was funded by CONICET (Consejo Nacional de Investigaciones Científicas y Técnicas) of Argentina and by ENIT (École Nationale d'Ingénieurs de Tarbes) of Université de Toulouse (France).

The research method is based on Design Science Research, and the empirical studies were carried out as Action Research studies, considering the implementations carried out by the Astori company after the feedback of the results. In order to complement the various forms of evaluation and analysis of results, it was stipulated for this research the approach of multiple methods for data collection: (i) Walkthrough analysis in 6 study cases that use Astori's prefabricated elements, (iii) interviews with employees and managers of the Astori company in Argentina, (v) interviews with architects/builders responsible for the 6 buildings chosen as a study case. The aspects addressed were structured in: (i) Condition of the building in terms of prefabricated elements; (ii) Functional aspects of buildings; (iii) Comfort and Environmental Quality of the buildings; (iv) Satisfaction – in terms of technical-constructive, environmental, functional, and behavioral aspects. The analyzed attributes were evaluated individually (raw data) and aggregated (overlapping techniques and data crossing), in order to establish comparative and analytical patterns of the results obtained. The BIM model, along with interviews with end-users, builders, and designers, give data to support the calculation to outline goal levels for the improvement of prefabricated building systems. To facilitate automation, the data mining tool SPMF was used to model knowledge and encoded reasoning in the knowledge base. SPMF encoded

---

<sup>1</sup> *Facultad de arquitectura, planeamiento urbano y diseño, Universidad Nacional de Rosario, Argentina*

<sup>2</sup> *Faculdade de arquitetura, urbanismo e design, Universidade Federal de Uberlândia, Brasil. ORCID 0000-0002-4413-7821*

\* *Corresponding author Email: casasantag@conicet.gov.ar*

knowledge as conceptual graphs and reasoning as graph operations that can be visualized in a logically precise way based on domain ontologies. SPMF is a free French software that comprises various algorithms for data preparation, mining, and result validation. Particularly, FP- Growth Algorithm and Clustering methodologies were used to analyse occupant behaviour, in order to compare them using Revit© software. For this research, the software was optimized for the evaluation of prefabricated elements.

From the results obtained in the study, it was possible to develop a method of design analysis with strategies for the prefabricated system of the Astori company, considering the demands of end-users and how their behaviour can directly influence design decisions. The participation of end-users, builders and designers in this process not only guarantees a better service to the needs of users, but also makes it possible to establish qualitative guidelines for future constructions. The research reported here was based mainly on these considerations when outlining its methodological procedures, highlighting the approach of BIM and KM as a lean tool for the improvement of prefabricated building systems. The beneficial interaction between continuous improvements, experience feedback processes and stepwise problem-solving procedures is knowledge created from structured learning processes. It is expected that the results of this work will contribute to the design of prefabricated systems in Argentina and Latin American countries that use Astori system or similar prefabricated construction systems, by proposing design strategies suited to user demands.

## REFERENCES

- Augenbroe, G., & Park, C. (2005). Qualification methods of technical building performance. *Building Research and Information*, 159-172.
- Baldauf, J.P., Formoso, C.T., Tzortzopoulos, P., Miron, L.I.G. and Soliman-Junior, J. (2020), "Using building information modelling to manage client requirements in social housing projects", *Sustainability (Switzerland)*, Vol. 12 No. 7, pp. 1-21.
- Bonte, M.; Thellier, F.; Lartigue, B. (2014) Impact of occupant's actions on energy building performance and thermal sensation, *Energy and Buildings* 76 (0). P. 219–227.
- Carrillo, P., & Chinowsky, P. (2006). Exploiting Knowledge Management: The Engineering and Construction Perspective. *ASCE Journal of Management in Engineering*, 2-10.
- Choi, J. (2010) CoBi: bio-sensing building mechanical system controls for sustainably enhancing individual thermal comfort, in: Ph.D. Dissertation, Carnegie Mellon University, Pittsburgh, PA.
- Christiansson P., Sørensen K. B., Rødtness M., Abrahamsen M., Ostenfeld L. R., Alsdorf M. (2008) User driven innovation in the building process. *Journal of Tsinghua University-Science and Technology*. Elsevier. Volume 13. Number S1. October 2008. ISSN 1007-0214 40/67. CN 11-3745/N, CODEN TSTEF7. Elsevier, pp. 248-254.
- Christiansson, P.L., Svidt, K., Pedersen, K.B. and Dybro, U. (2011), "User participation in the building process", *Electronic Journal of Information Technology in Construction*, Vol. 16, pp. 309-334.
- Fayyad, U. M, Shapiro, G. P, E Smyth, P. (1996) *From Data Mining to Knowledge Discovery in Databases*. American Association for Artificial Intelligence. Providence.
- Goins, J.; Moezzi, M. (2013) Linking occupant complaints to building performance, *Building Research & Information* 41 (3) 361–372.
- Gu, Y. (2011) The impacts of real-time knowledge-based personal lighting control on energy consumption, user satisfaction and task performance in offices, in: Ph.D. Dissertation, Carnegie Mellon University.
- Jallow, A.K., Demian, P., Baldwin, A.N. and Anumba, C. (2014), "An empirical study of the complexity of requirements management in construction projects", *Engineering, Construction and Architectural Management*, Vol. 21 No. 5, pp. 505-531, doi: 10.1108/ECAM-09-2013-0084.
- Kamara, J.M., Anumba, C.J. and Evbuomwan, N.F.O. (2002), *Capturing Client Requirements in Construction Projects*, 1st ed., Thomas Telford Publishing, London.
- Klein, L.; Kwak, J.; Kavulya, G.; Jazizadeh, F.; Becerik-Gerber, B.; Varakantham, P.; Tambe, M. (2012) Coordinating occupant behavior for building energy and comfort management using multi-agent systems, *Automation in Construction* 22. 525–536.
- Lee, Y.; Malkawi, A. (2014) Simulating multiple occupant behaviors in buildings: an agent-based modeling approach, *Energy and Buildings* 69. P. 407–416.
- Lin, J., Hu, Z. & Zhang, J. (2013) BIM oriented intelligent data mining and representation, in *Proceedings of 30th CIB W78 International Conference on Applications of IT in the AEC Industry*, Beijing, China.
- Loftness, V.; Aziz, A., Choi, J.; Kampschroer, K.; Powell, K.; Atkinson, M., Heerwagen, J. (2009) The value of post-occupancy evaluation for building occupants and facility managers, *Intelligent Buildings International* 1

(4) 249–268.

Murakami, Y., Terano, M., Mizutani, K. Harada, M., Kuno, S. (2007) Field experiments on energy consumption and thermal comfort in the office environment controlled by occupants' requirements from PC terminal, *Building and Environment* 42. 4022–4027.

Oman, B. (2016). *Application of Data Mining and Big Data Analytics in the Construction Industry*. Ohio State University.

Park, J. (2013) Post-occupancy Evaluation for energy conservation, superior IEQ & increased occupant satisfaction, in: *World Workplace*, Ifma.

Parsanezhad, P., Tarandi, V. and Lund, R. (2016), "Formalized requirements management in the briefing and design phase, a pivotal review of literature", *Journal of Information Technology in Construction*, Vol. 21, May, pp. 272-291.

Peng, Y., Lin, J.-R., Zhang, J.-P., & Hu, Z.-Z. (2017). A hybrid data mining approach on BIM-based building operation and maintenance. *Building and Environment*.

Piatetsky-Shapiro, Gregory (1991), *Discovery, analysis, and presentation of strong rules*, in Piatetsky-Shapiro, Gregory; and Frawley, William J.; eds., *Knowledge Discovery in Databases*, AAAI/MIT Press, Cambridge, MA.

Sacks, R., Koskela, L., Dave, B.A. and Owen, R. (2009), "Interaction of lean and building information modeling in construction", *Journal of Construction Engineering and Management*, Vol. 136, September, pp. 968-980.

Shen, Q., Li, H., Chung, J. and Hui, P.-Y.Y.P.Y. (2004), "A framework for identification and representation of client requirements in the briefing process", *Construction Management and Economics*, Vol. 22 No. 2, pp. 213-221, doi: 10.1080/0144619042000201411 (accessed 30 October 2012).

Shen, W., Shen, Q., Xiaoling, Z., Zhang, X., Qiping, G. and Fernando, T. (2013), "The user preoccupancy evaluation method in designer – client communication in early design stage: a case study", *Automation in Construction*, Vol. 32 Nos 7/8, pp. 112-124, doi: 10.1016/j.autcon.2013.01. 014 (accessed 9 February 2013).

Vissotto, E. M.; Camargo, A. B. (2013) *Aplicativo de Mineração de Dados Aplicado em Base de Dados Acadêmicas*. Anais do EATI – Encontro Anual de Tecnologia da Informação e Semana Acadêmica da Tecnologia da Informação.

## **PRODUCTION**

# PROBLEMS ASSOCIATED WITH THE ADOPTION OF OFFSITE CONSTRUCTION

Kola Olayiwola<sup>1\*</sup>, Srinath Perera<sup>2</sup>, Mike Kagioglou<sup>3</sup>, Xiaohua Jin<sup>4</sup>, Pejman Sharafi<sup>5</sup>

## RESEARCH BACKGROUND

Offsite Construction (OSC) is one in which all or some components of a building are manufactured and partly assembled in a prefabrication factory and then transported to a construction site for final installation (Li, et al., 2017; Wuni & Shen 2019). Offsite construction brings onsite construction works into a climate-controlled facility where advanced machinery and manufacturing technologies can be utilised to fabricate components in a standardised and efficient manner (Yin et al. 2019).

Industry 5.0 production model is set to address the interaction between humans and machines by leveraging the collaboration in human-machine. The widespread increase in the acceptance and adoption of offsite construction (OSC) in the construction industry and use of machines and Robotic technology to manufacture large components of OSC has increased interaction between humans and machines. There is the need, therefore, to categorise the problems associated with OSC for better understanding and interaction, and therefore better product output.

## RESEARCH PROBLEM

OSC is rife with many barriers impeding its adoption. Factors militating against the use of OSC identified by many researchers are systemic, process, regulatory, logistics, resources, knowledge constraints, cost implications, dominance of conventional project process, limited market demand and lack of social acceptance. Others are government related barriers such as regulations and standard, incentive and Research & Development (R&D). Government support for OSC will have significant positive impact and increase OSC adoption (Darko et al. 2018). Company related barriers like skills and experience, industry and market culture, and tools, also have significant negative impact on OSC adoption (Blismas et al., 2005; Blismas, et al. 2009; Elnaas et al., 2013; Rahman 2014; Darko et al. 2018; Gan et al., 2018). However, these barriers are skewed to local and country conditions.

## AIM/OBJECTIVES

This abstract aggregates the barriers and categorise them in order as presented globally by many researchers. Appreciating these problems and how they impede the use of OSC is core, and it will promote strategies to influence its adoption. The classification provides a valuable source of information and better understanding of the barriers to implementing OSC. It sheds light on the barriers, and help the stakeholders create better mitigation strategies and effectively develop measures to facilitate the OSC adoption in the construction sector.

## METHOD

A detailed literature review will be carried out to aggregate barriers of offsite constructions. These barriers as presented globally by many researchers will then be classified into Political, Environmental, Social, Technological, Economic and Legal (PESTEL). Appreciating the categories of the barriers will inform the policy makers and other stakeholders to know how their policies and decisions impede the use of OSC.

## PRELIMINARY RESULTS

---

*1 Centre for Smart Modern Construction, Western Sydney University, Australia. ORCID 0000-0002-1025-6646*

*2 Centre for Smart Modern Construction, Western Sydney University, Australia. ORCID 0000-0001-9218-9282*

*3 School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0003-3521-1484*

*4 Centre for Smart Modern Construction, Western Sydney University, Australia. ORCID 0000-0003-0877-9533*

*5 Centre for Infrastructure Engineering, Western Sydney University, Australia. ORCID 0000-0002-3378-9920*

*\* Corresponding author Email: k.olayiwola@westernsydney.edu.au*

Preliminary findings revealed that several barriers are impeding the adoption of OSC which include requirement of initial high capital cost, lack of education about OSC and non-existence of regulations to support OSC and offsite logistics scheduling (Mostafa, et al., 2016; Darlow et al., 2022). Darlow et al. (2022) further noted that financial supports to the OSC sub-sector in form of subsidies, tax waivers, and enhanced leasing model could enhance the uptake of OSC.

Mostafa et al. (2016) discussed that to revolutionise OSC, logistic scheduling, and effectively support contractors and module suppliers to deliver building projects, there is need to (1) strengthen suppliers' demand responsiveness by shortening module production time; (2) enhance manufacturing flexibility by increasing factory storage utilisation; (3) improve supply chain synchronisation; and (4) capitalise on the government's role in offsite logistics enhancement.

However, Charef et al. (2021) classified the barriers into six different categories: organisational, economical, technical, social, political and environmental; and Hwang et al. (2018) identified five top significant constraints as extensive coordination required prior to and during construction, need for additional project planning and design efforts, increased transportation and logistics considerations, early commitment from stakeholders, and higher initial cost than conventional traditional construction method.

Furthermore, Abdul Nabi and El-Adaway (2021) classified the top eight critical factors militating against the adoption of OSC as (1) shortage of skilled and experienced laborers, (2) late design changes, (3) poor site attributes and logistics, (4) unsuitability of design for modularization, (5) contractual risks and disputes, (6) lack of adequate collaboration and coordination, (7) challenges related to tolerances and interfaces, and (8) poor construction activity sequencing. Gan, X. et al. (2018) claims that specific consideration should be given to government regulations and policies; as well as the development of skills and expertise needed for OSC as different from the traditional construction.

Gibb (2001) agreed that Stakeholders of OSC barely understand its process (CIRIA, 2000). The approach was wrongly viewed as expensive, unjustifiable, and can never be a solution to the many problems of traditional construction. He further argued that construction products differ from manufactured products in that they are immobile, complex, durable, costly and require a high degree of social responsibility. These characteristics limits the adoption of technologies to construction and further suggest the understanding the characteristics of constructed products will influence the potential for an increased adoption of manufacturing of the products. In conclusion, the construction industry has many problems which inhibits introduction of manufacturing process (Gibb 2001; Nam & Tatum 1988).

## REFERENCES:

- Abdul Nabi, M & El-Adaway, IH 2021, 'Understanding the Key Risks Affecting Cost and Schedule Performance of Modular Construction Projects', *Journal of management in engineering*, vol. 37, no. 4, Scopus, DOI 10.1061/(ASCE)ME.1943-5479.0000917, <<https://www.scopus.com/inward/record.uri?eid=2-s2.0-85103317399&doi=10.1061%2f%28ASCE%29ME.1943-5479.0000917&partnerID=40&md5=43df933eb94cc5112552ff0d82ffa7d8>>.
- Blismas, N & Wakefield, R 2009, 'Drivers, constraints and the future of offsite manufacture in Australia', *Construction Innovation*, vol. 9, no. 1, pp. 72-83, Emerald Group Publishing Limited, DOI 10.1108/14714170910931552, <[www.emeraldinsight.com/1471-4175.htm](http://www.emeraldinsight.com/1471-4175.htm)>.
- Blismas, NG, Pendlebury, M, Gibb, A & Pasquire, C 2005, 'Constraints to the Use of Off-site Production on Construction Projects', *Architectural engineering and design management*, vol. 1, no. 3, pp. 153-62, DOI 10.1080/17452007.2005.9684590, <<https://dpspace.lboro.ac.uk/2134/9225>>.
- Charef, R, Morel, JC & Rakhshan, K 2021, 'Barriers to implementing the circular economy in the construction industry: A critical review', *Sustainability (Switzerland)*, vol. 13, no. 23, Scopus, DOI 10.3390/su132312989, <<https://www.scopus.com/inward/record.uri?eid=2-s2.0-85120005830&doi=10.3390%2fsu132312989&partnerID=40&md5=cce96c1b75b842dd2380e6cfd286a28>>.
- Construction Industry Research and Information Association (CIRIA) (2000) *Standardisation, Pre-assembly and Modularisation – A Client's Guide*, Construction Industry Research and Information Association, London.
- Darko, A, Chan, APC, Yang, Y, Shan, M, He, B-J & Gou, Z 2018, 'Influences of barriers, drivers, and promotion strategies on green building technologies adoption in developing countries: The Ghanaian case', *Journal of Cleaner Production*, vol. 200, pp. 687-703, DOI 10.1016/j.jclepro.2018.07.318.
- Darlow, G, Rotimi, JOB & Shahzad, WM 2022, 'Automation in New Zealand's offsite construction (OSC): a status update', *Built Environment Project and Asset Management*, vol. 12, no. 1, pp. 38-52, Scopus, DOI 10.1108/BEPAM-11-2020-0174, <<https://www.scopus.com/inward/record.uri?eid=2-s2.0->

85102937735&doi=10.1108%2fBEPAM-11-2020-0174&partnerID=40&md5=6dc444cb1e04325f32ba206ce00a832a>.

Elnaas, H, Gidado, K & Ashton, P 2013, 'Factors and Drivers Effecting the Decision of Using Off-Site Manufacturing (OSM) Systems in House Building Industry.', *Journal of Engineering, Project, and Production Management*.

Gan, X, Chang, R & Wen, T 2018, 'Overcoming barriers to off-site construction through engaging stakeholders: A two-mode social network analysis', *Journal of Cleaner Production*, vol. 201, pp. 735-47, DOI 10.1016/j.jclepro.2018.07.299, <[www.elsevier.com/locate/jclepro](http://www.elsevier.com/locate/jclepro)>.

Gan, X, Chang, R, Zuo, J, Wen, T & Zillante, G 2018, 'Barriers to the transition towards off-site construction in China: An Interpretive structural modeling approach', *Journal of Cleaner Production*, vol. 197, pp. 8-18, Scopus, DOI 10.1016/j.jclepro.2018.06.184, <<https://www.scopus.com/inward/record.uri?eid=2-s2.0-85049299975&doi=10.1016%2fj.jclepro.2018.06.184&partnerID=40&md5=e20d2a6d6719c20db1b9bdf6cef437ca>>.

Gibb, AGF 2001, 'Standardization and pre-assembly- distinguishing myth from reality using case study research', *Construction Management and Economics*, vol. 19, no. 3, pp. 307-15, DOI 10.1080/01446190010020435.

Hwang, BG, Shan, M & Looi, KY 2018, 'Key constraints and mitigation strategies for prefabricated prefinished volumetric construction', *Journal of Cleaner Production*, vol. 183, pp. 183-93, Scopus, DOI 10.1016/j.jclepro.2018.02.136, <<https://www.scopus.com/inward/record.uri?eid=2-s2.0-85043581889&doi=10.1016%2fj.jclepro.2018.02.136&partnerID=40&md5=773bcb7a8a5757f9859ee847b3eda64e>>.

Li, H, Luther, M & Mills, A 2017, 'Prefabrication in the Australian Context.', *International Symposium on Industrialized Construction Technology*, no. 2, pp. 1-8.

Mostafa, S, Chileshe, N & Abdelhamid, T 2016, 'Lean and agile integration within offsite construction using discrete event simulation A systematic literature review', *Construction Innovation*, vol. 16, no. 4, pp. 483-525, Scopus, DOI 10.1108/CI-09-2014-0043, <<https://www.scopus.com/inward/record.uri?eid=2-s2.0-84995400187&doi=10.1108%2fCI-09-2014-0043&partnerID=40&md5=37fcd2b990412acee0a7b1918724730b>>.

Nam, C & Tatum, C 1988, 'Major characteristics of constructed products and resulting limitations of construction technology', *Construction Management and Economics*, vol. 6, no. 2, pp. 133-47.

Rahman, MM 2014, 'Barriers of Implementing Modern Methods of Construction', *Journal of management in engineering*, vol. 30, no. 1, pp. 69-77, DOI 10.1061/(asce)me.1943-5479.0000173, <<https://www.researchgate.net/publication/277663241>>.

Wuni, IY & Shen, GQP 2019, 'Holistic Review and Conceptual Framework for the Drivers of Offsite Construction: A Total Interpretive Structural Modelling Approach', *Buildings*, vol. 9, no. 5, DOI 10.3390/buildings9050117, <<http://creativecommons.org/licenses/by/4.0/>>.

Yin, X, Liu, H, Chen, Y & Al-Hussein, M 2019, 'Building information modelling for off-site construction: Review and future directions', *Automation in Construction*, vol. 101, pp. 72-91, DOI 10.1016/j.autcon.2019.01.010.

# REQUIREMENTS FOR OFFSITE PRODUCTION PROCESSES OF VOLUMETRIC SYSTEMS FOR MASS CUSTOMISATION

Tamiris Capellaro Ferreira<sup>1\*</sup>, José Carlos Paliari<sup>2</sup>, Patricia Tzortzopoulos<sup>3</sup>

## INTRODUCTION

It has long been argued that offsite manufacturing can reduce variability and improve flow in construction projects, as well as aspects such as safety and quality, since production takes place in a controlled environment (RICS, 2018). However, despite the benefits, over the years offsite manufacturing has seen only marginal increases in adoption. Nonetheless, the consultancy Bryden Wood (2018) believes that conditions now appear favourable for a fundamental shift in the industry.

In offsite manufacturing, as in other industries, the low unit costs of mass production can be achieved by scaling production, focusing on manufacturing large quantities of standardized goods and services. However, standardized designs do not meet the individual demands of users (Bonatto, Miron, & Formoso, 2011; Brito, Formoso & Echeveste, 2011), so mass customization (MC) is a strategy that can be adopted to satisfy both the needs for modernization, improvement, efficiency and productivity, as well as the particular needs of users (Frutos & Borenstein, 2003). MC aims to enable the production of a variety of products and still maintain competitive cost and delivery time.

On the other hand, some companies still find it difficult to implement MC, because by increasing the number of options offered to the customer, the complexity of production is also increased, due to the greater variation of materials and the greater amount of information necessary for the execution of the constructive unit, requiring more effective production control (Rocha & Kemmer, 2013; Martinez, Tommelein, & Alvear, 2017). Thus, it is important that companies use practices that facilitate the execution of customized units and production control, such as better communication of differentiated items, alteration of the product design and robust and stable process design, which allows for reuse or recombination of existing resources (Piller & Wang, 2017). Zawadzki and Żywicki (2016) state that without the perfection of the planning, product design and manufacturing preparation and control processes, the efficient fulfilment of the premises of MC and the maintenance of its positive results are not possible.

## AIM

In this context, the following research question arises: what are the requirements of the offsite production process of volumetric systems so that mass customization is viable in terms of cost and delivery time? In other words, we seek to understand how the offsite production process should be to allow the manufacture of a variety of products, keeping cost and delivery time competitive, which means minimising the trade-offs between flexibility and efficiency. Therefore, the aim of this research is to propose a set of guidelines for the development of offsite production processes of volumetric systems that enable mass customisation, minimising trade-offs between flexibility, cost and delivery time.

The specific aims are: 1) Refine a set of concepts related to MC, in order to adapt them to the specific context of the offsite production of volumetric systems; 2) Define parameters to measure the feasibility in terms of cost and delivery time, of MC of volumetric systems produced offsite; 3) Develop a conceptual framework for the definition of production strategies that allow the MC of volumetric systems produced offsite.

The outcome will be a set of guidelines (artifact) for the development of offsite production processes of volumetric systems that enable MC in terms of cost and delivery time. It will be based on practices identified in the literature and on an empirical study carried out in an offsite construction company. The guidelines should be used by companies to support the definition of production and MC strategies.

---

*1 Universidade Federal de São Carlos (Federal University of São Carlos), Brazil. ORCID 0000-0002-4563-2429*

*2 Universidade Federal de São Carlos (Federal University of São Carlos), Brazil. ORCID 0000-0002-2964-8551*

*3 University of Huddersfield, UK. ORCID 0000-0002-8740-6753*

*\* Corresponding author Email: tamiris.capellaro@gmail.com*

## JUSTIFICATION

Being able to develop customized units while maintaining acceptable costs and deadlines is the challenge for its viability, which is the relevance of the research problem. Practices that help to reduce the impact of complexity on production when adopting MC have been reported in previous research. Formoso et al. (2022), for example, explored the possibility of adopting MC ideas to offer flexibility to the customers of a company that produces social housing while keeping costs low. The main contributions of the research were related to the expansion of the understanding of the components that allow the implementation of MC in the context of the construction companies of houses that adopt traditional technologies of construction. The research of Viana et al. (2017) explored the use of engineered-to-order industrialised building systems, illustrating how modularity can reduce its complexity in companies that adopt a MC strategy. The research has shown that tolerance management plays a key role in achieving high productivity and short lead times. In addition to showing how the adoption of a limited set of modular components can be used to standardise different types of processes. However, no research was found that studies practices related to the management of offsite production of volumetric systems so that MC is made possible.

In other words, the set of practices adopted by manufacturers that produce customisable volumetric systems that allow them to maintain the balance between flexibility, cost and time have not yet been systematically analysed and have not been structured in order to be applied in different contexts, which represents the knowledge gap considered as the starting point of the present study. Therefore, we intend to explore how the offsite production planning and control system, at its different levels, can contribute to the consideration of customer requests in production, to minimize trade-offs between flexibility and efficiency. As a theoretical contribution, it is intended to advance the knowledge about the process that enables MC in offsite constructions.

## METHOD

Design Science Research (DSR) is the methodological approach adopted in this investigation. It has a prescriptive character, seeking to elaborate solution concepts, called artifacts, to solve classes of problems (Holmstrom, Ketokivi & Hameri, 2009; Van Aken, 2004). Furthermore, it fits into what has been called by Van Aken (2004) as best practice research, which aims to discover the underlying ideas of practices that have been successfully implemented in the real world.

This work was divided into steps that are in line with the DSR (Oyegoke, 2011). Initially, the production process will be mapped (considering manufacturing, logistics and assembly of the units) of a company that performs offsite production of customizable volumetric systems. After that, an evaluation of supplier and production management operations will be carried out, seeking to understand how MC influences them. Then, the best practices used by the company, the opportunities for improvement and the main challenges of the production process will be identified so that the MC can happen efficiently. Finally, improvements will be proposed in the company's production system.

## REFERENCES

- Bonatto, F. S., Miron, L. I., & Formoso, C. T. (2011, July). Evaluation of social housing projects based on user perceived value hierarchy. In Proceedings of 19th Annual Conference of the International Group for Lean Construction (IGLC), Lima, Peru (Vol. 1315).
- Brito, J. N. D. S., Formoso, C. T., & Echeveste, M. E. S. (2011). Analysis of complaint data in social house-building projects: a study in the Residential Leasing Program. *Ambiente Construído*, 11, 151-166.
- Bryden Wood (2018). *Platforms: bridging the gap between construction and manufacturing*. London.
- Formoso, C. T., Tillmann, P. A., & Hentschke, C. D. S. (2022). Guidelines for the Implementation of Mass Customization in Affordable House-Building Projects. *Sustainability*, 14(7), 4141.
- Frutos, J. D., & Borenstein, D. (2003). Object-oriented model for customer-building company interaction in mass customization environment. *Journal of Construction Engineering and Management*, 129(3), 302-313.
- Holmström, J., Ketokivi, M., & Hameri, A. P. (2009). Bridging practice and theory: A design science approach. *Decision Sciences*, 40(1), 65-87.
- Martinez, E., Tommelein, I. D., & Alvear, A. (2017, July). Integration of lean and information technology to enable a customization strategy in affordable housing. In Proceedings of the 25th annual conference of the international group for lean construction (IGLC),

Heraklion, Greece (pp. 9-12).

Oyegoke, A. (2011). The constructive research approach in project management research. *International Journal of managing projects in business*.

Piller, F. T., & Wang, N. (2017). Strategic foundations and capabilities of mass customization. In *Product Configurators* (pp. 2-29). Routledge.

Rocha, C. G., & Kemmer, S. L. (2013). Method to implement delayed product differentiation in construction of high-rise apartment building projects. *Journal of construction engineering and management*, 139(10), 05013001.

Royal Institution of Chartered Surveyors (RICS) (2018). *Modern Methods of Construction: A forward-thinking solution to the housing crisis*. London.

Van Aken, J. E. (2004). Management research based on the paradigm of the design sciences: the quest for field-tested and grounded technological rules. *Journal of management studies*, 41(2), 219-246.

Viana, D. D., Tommelein, I. D., & Formoso, C. T. (2017). Using modularity to reduce complexity of industrialized building systems for mass customization. *Energies*, 10(10), 1622.

Zawadzki, P., & Żywicki, K. (2016). Smart product design and production control for effective mass customization in the Industry 4.0 concept. *Management and production engineering review*.

# CONSTRUCTABILITY ASSESSMENT: A LEAN TOOL TO IMPROVE CONSTRUCTION PROJECTS

João Paulo Marcel de Abreu<sup>1\*</sup>, Fernanda Marchiori<sup>2</sup>, Vera Lucia Correia<sup>3</sup> and Silva, Rafael Fernandes Teixeira da Silva<sup>4</sup>

## INTRODUCTION

Koskela (1992) and Abreu et al. (2020) cited flow problems associated with traditional managerial concepts and emphasised the importance of practices that promote the best constructability in construction projects based on lean principles. In addition, these authors highlight that measures are extremely important in continuous improvement and tools to achieve lean goals like simplification, adding value, transparency, and others. Since the 2000s, constructability assessment systems are researched in some countries or regions such as Singapore (Lam and Wong 2008), Hong Kong (Lam et al. 2007), and Malaysia (Hijazi et al. 2009). These assessment systems are used as design criteria for new constructions or to define goals through data from past projects.

According to Mao et al. (2018), constructability reviews and lean construction share the common goals of benefiting the project delivery such as the increased value of the end product, and Guerriero et al. (2017) emphasise BIM as an important tool to achieve these goals. In the 2010s, new assessment systems were created and integrated with BIM technologies, becoming more easily automated analysis of constructability criteria like kind of construction systems, geometry, standardisation, temporary works, and others (Jiang and Leicht 2015, Kannan and Santhi 2018).

Most countries, including Brazil, don't have constructability assessment systems fitted to their construction methods. The copy-paste behaviour, or easily transposition of measures, leads to errors in indicators results (Van Camp and Braet 2016) and the benefits of better constructability, like improving productivity, quality, and costs (Russell and Gugel 1993; Jarkas 2010; Abreu et al 2020), couldn't be achieved. This paper presents a development of a constructability assessment system to evaluate and improve constructability focused on Brazilian popular residential condominium construction projects.

## METHOD

This research was conducted during postgraduate research (Abreu 2020) in five phases (see Figure 1). In the first phase, a bibliographic search was done (1.1) in national and international databases and defined a state-of-the-art about constructability, and after (1.2), the first definition of indicators and their characteristics.

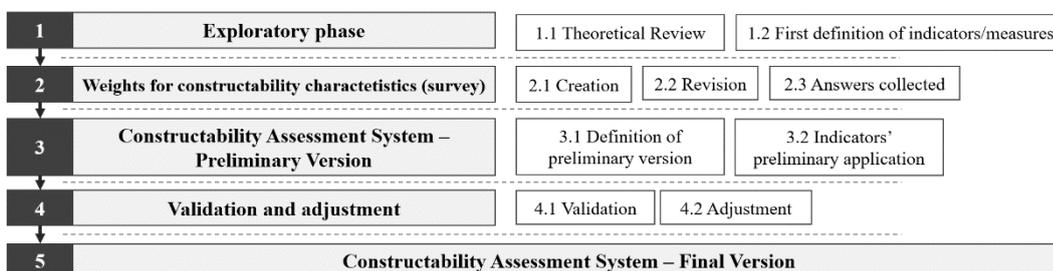


Figure 1 - Method

In the second phase, a survey was carried out (2.1-2.2) to define weights in the constructability assessment

1 Universidade Federal de Santa Catarina, Brazil. ORCID 0000-0001-5930-7486

2 Universidade Federal de Santa Catarina, Brazil. ORCID 0000-0001-9182-2541

3 Universidade Federal de Santa Catarina, Brazil. ORCID 0000-0003-1728-0160

4 Universidade Federal de Santa Catarina, Brazil. ORCID 0000-0003-2445-4034

\* Corresponding author, +55 54 98445-5844; Email: joaopaulojpma@hotmail.com

system. Answers have a Likert scale from 1 to 5 points (importance in constructability, 1:low, 5:high), from professionals who have already worked in design and construction projects (2.3). The third phase consists of the whole definition of a preliminary version of the assessment system (3.1) and the application of this version in three construction projects (CPs) named CP1, CP2, and CP3 (Fig. 2). With the preliminary version and evaluation, the fourth phase was validation and adjustment – potential users are presented with the prototype (preliminary version) and indicate their contributions from professional experience (Dos Reis and Mauri 2012). From the suggestions of these construction experts, enhancements in weights, indicators, or scales were done and the final version of the constructability assessment system was organized to explain its use to multiple construction stakeholders (fifth phase).

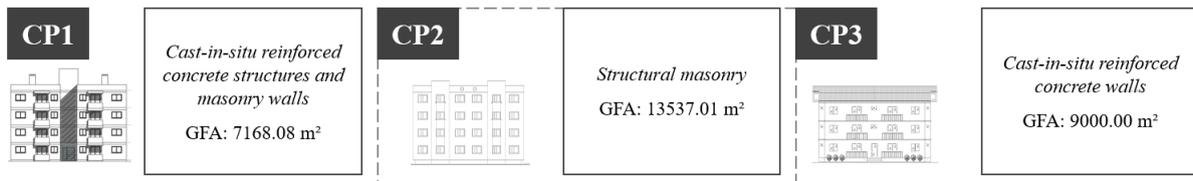


Figure 2 - Main buildings and characteristics of construction projects evaluated

## FINDINGS

The constructability assessment system generated is useful for different construction stakeholders (when construction systems are designed – of a design criterion - or about past projects – for definition on constructability goals) for evaluation of construction condominium projects in a popular pattern. Its constructability indicators were divided into three categories, according to construction life cycle: indicators of design (fifteen indicators related to geometry, standardization, architecture, constructability database), indicators of production planning (four indicators about building works site and construction restrictions), and indicators of execution (three indicators about the construction effectively). Each category has a partial indicator of constructability, and the overall constructability indicator is obtained at the end of the construction project or calculated about past projects.

According to the constructability concept (ASCE 1991; Jarkas 2010; Kifokeris and Xenidis 2017), earlier decisions are extremely important, anticipating problems and solutions. Because of this, fifteen of twenty-three indicators are related to the design phase, but the next steps in construction were considered, aligned to the "constructability" concept (when the focus is only on design constructability, it is named "buildability"). About constructability evaluations of CPs, overall indicators of CP2 and CP3 are higher than CP1, but this assessment isn't from an absolute set of higher indicators in one project, is a conjunction of characteristics, more than a structural system, walls, or single options. This result reflects the multifaceted evaluation of constructability proposed.

## CONCLUSIONS AND FUTURE WORK

The constructability assessment system generated has a format that considers several constructability criteria and the main steps of a construction project (design, production planning, and execution). It could be useful to improve the efficiency of new projects in Brazilian popular residential condominiums. Better constructability (higher indicators of constructability) means best productivity, quality, avoiding reworks, and adding value, among other benefits. In the case studies (in CPs), overall evaluations are aligned with construction experts' experience. In the continuity of this research, the potentialities of BIM to improve constructability will be considered, as well as new computational tools using BIM data collection and automatization to improve constructability analysis. Other future work also includes analysis between constructability and other variables such as costs and energy efficiency.

## REFERENCES

- Abreu, J.P.M. 2020. "Desenvolvimento de um sistema de indicadores de construtibilidade para empreendimentos residenciais multifamiliares de padrão popular" [Development of constructability assessment system of residential condominiums in popular pattern]. [In Portuguese]. MS Thesis, Federal University of Santa Catarina, Florianópolis, Brazil.
- Abreu, J.P.M, F.F. Marchiori, G.C. Cardoso and L.A. Corrêa. 2020. "O BIM como suporte à construtibilidade e sua relação com a construção enxuta." [BIM as a tool of constructability and their relation among lean construction.] [In Portuguese] In Proc., 18th National Meeting of Construction Space. Porto Alegre, Rio Grande do Sul, Brazil: Antac.

- American Society of Civil Engineers. 1991. "Constructability and constructability programs: white paper." *J. Constr. Eng. Manage.*, 117(1), 67-89.
- Dos Reis, E. and L.L. Mauri. 2012. "O Processo Decisório Descrito pelo Indivíduo e Representado nos Sistemas de Apoio à Decisão" [The decision process from a subject and represented in a Decision Support Management.] [In Portuguese]. *Contemporary Administration Journal*, 16(3), 397-417.
- Guerriero, A., S. Kubicki, F. Berroir and C. Lemaire. 2017. "BIM-enhanced collaborative smart technologies for LEAN construction processes." In *Proc., 23rd International Conference on Engineering, Technology and Innovation (ICE/ITMC)*. Madeira Island, Portugal, USA: IEEE.
- Hijazi, W., S. Alkass and T. Zayed. 2009. "Constructability Assessment Using BIM/4D CAD Simulation Model." In *Proc., 53rd AACE International Transactions*. Seattle, Washington, USA: AACE.
- Jarkas, A.M. 2010. "Analysis and Measurement of Buildability Factors Affecting Edge Formwork Labour Productivity." *J. of Eng. Science and Technology Review*, 3(1), 142-150.
- Jiang, L. and R.M. Leicht. 2015. "Automated Rule-Based Constructability Checking: Case Study of Formwork". *Journal of Management in Engineering*. 31(1).
- Kannan, R. and H. Santhi. 2018. "Automated constructability rating framework for concrete formwork systems." *Asian Journal of Civil Engineering*, 19, 387-413.
- Kifokeris, D. and Y. Xenidis. 2017. "Constructability: Outline of Past, Present, and Future Research." *J. Constr. Eng. Manage.*, 143(8).
- Koskela, L. 1992. *Application of New Production Philosophy to Construction*. Stanford, US: Stanford University.
- Lam, P.T.I., A.P.C. Chan, F.K.W. Wong and F.W.H. Wong. 2007. "Constructability Rankings of Construction Systems Based on the Analytical Hierarchy Process". *Journal of Architectural Engineering*, 13(1), 36-43.
- Lam, P.T.I. and F.W.H. Wong. 2008. "Implementing a Buildability Assessment Model for Buildability Improvement". *Architectural Science Review*, 51(2), 173-184.
- Mao, W.E.; C. Mahame and D. Ndahirwa. 2018. "Impact of evolving construction project management techniques for proper project delivery: review on constructability review, lean construction (LC) and value engineering (VE) techniques". *International Journal of Civil Engineering, Construction and Estate Management*, 6(1), 1-16.
- Russell, J.S. and J.G. Gugel. 1993. "Comparison of Two Corporate Constructability Programs". *J. Constr. Eng. Manage.*, 119(4), 769-784.
- Van Camp, J. and J. Braet. 2016. "Taxonomizing performance measurement systems' failures". *International Journal of Productivity and Performance Management*, 65(5), 672-693.

# SERIOUS GAMES FOR LEAN MANAGEMENT – NEW TOOLS FOR LEARNING LEAN MINDSET IN ARCHITECTURE AND CONSTRUCTION

Maria Antonietta Esposito<sup>1</sup>, Caterina Ferraro<sup>2\*</sup>

## INTRODUCTION

This abstract discusses the state of the art of serious games and proposes the implementation of an innovative gaming platform currently in its initial stages of conceptualisation to enhance the use of serious games in Lean Mindset training, with a close perspective on the Architecture and Construction field. The platform is aimed at project managers and design team. It finds broader application to project organisations in general to foster the rebalancing of their People and Processes pillars.

Various games are widely used to enhance knowledge, skills, and motivation in learning users, including also Serious games (Connolly et al., 2012). New tools and methods usually require a high amount of effort in learning how to use them and research has continuously studied how to propose more and more effective didactic methods. Excessive effort requirement is time-consuming and could also reduce motivation. This is particularly important if the knowledge is necessary for the workplace environment. Lack of training of personnel could become a significant issue for project organizations firms needing their employees to be constantly aware of updated technologies, such as software and tools, like management techniques and strategies.

## LITERATURE REVIEW

The literature review on the topic, based on the most recurrent keywords (serious games, lean games, didactic simulations, and lean management) is discussed to draw useful elements for the improvement of digital serious games and their implementation in common practices for the design industry and BIM management.

Investigating the literature about Lean management and games, gamification approaches and theory become central (González and Area, 2013; Herzig, Ameling and Schill, 2015). Beyond the technical aspects, it regards the following social issue: lack of knowledge could increase the gap between already disadvantaged categories of people, who are unable to access basic sources, for distinct reasons. It is important to address the efficacy of current learning methods and implement them with sophisticated, innovative, and engaging tools (Tsalapatas, Heidmann and Jesmin, 2021) that could boost the ability of learning users to access information, use efficiently management processes, and make an impact on society by reducing wastes, which is a core point in Lean mindset (de Freitas Avelar and Marques Carvalho, 2020).

A wide variety of case studies propose insight on single-player serious games, especially for digital educational games, and in different fields of application, as health and engineering, as shown in (Mattsson, Nurminen and Reunanen, 2019) and (De Oliveira Rangel Salibi et al., 2021). Notable examples of Serious Games in the Lean mindset applied to architecture and engineering emerged as well as methods to build more effectively Lean-based simulations and games (Aqlan, 2017; Yousefi and Mirkhezri, 2020; Tagliabue et al., 2021). However, there seem to be a lack of interaction between users, even if collaboration is a core feature of a method. There is, therefore, a lack of case studies with multiplayer platform or multiplayer dynamics, even if it is stated in (Paraskeva, Mysirlaki and Papagianni, 2010) that there is room for further research in this field.

## METHOD

This abstract reports on a study of digital implementation of an existing Lean educational simulation, with other notable examples that already show evidence of Lean efficacy (Gurevich and Sacks, 2014; Ben-Alon and

---

*1 University of Florence, Italy. ORCID 0000-0002-2706-0201*

*2 University of Florence, Italy. ORCID 0000-0001-9056-3349*

*\* Corresponding author Email: caterina.ferraro@unifi.it*

Sacks, 2017). The purpose of the proposed Lean game is supporting the project organisation in finding the best combination of processes to deliver the final output in the fastest way possible, limiting errors. The Lean simulation addresses in particular the construction phase of the project, from the construction team point of view. In particular, the scope of the learning simulation is addressing the Lean strategies of “pull-system” and kaizen, trying to propose a process with less non-value adding activities than the former.

The analysed Lean simulation revolves around construction processes: participants are tasked with assembling an established number of buildings using Lego<sup>®</sup> bricks, following conventional processes and subsequently Lean processes. They are assigned to specific roles tied to rules that define and limit their agency and actions. The final objective is to build all the construction units without errors (or waste). So, the Lean simulation follows two rounds: in one traditional processes of construction are applied, in the second, Lean processes are applied. One core objective of Lean process is to reduce waste in activities, reducing non-value adding activities, thus all those activities that does not contribute to the final products in terms of quality and efficiency in delivery: this method usually also follows a waste reduction in materials, cost, effort, and time.

The Lean simulation, in its physical “in-presence” version, has been conducted recording the player actions and delivery times, writing down the results and then applying appropriate formulas for deducing the effective speed (how many units per minute were produced) and the cycle time (how long a single phase lasted, on average), comparing the traditional standard process and the Lean process. This simulation has been then adapted for being held online, using a platform for file sharing and a BIM software for modelling the units, and has shown nevertheless the efficacy of the Lean method against a conventional method. Also in this case, delivery times of the output at the end of every phase where recorded.

## PRELIMINARY FINDINGS

After conducting the experiments following the traditional process round as a control test, the preliminary results - based on parameters of time, effective speed (units/per minute) and cycle time -showed that Lean mindset has a notable advantage on conventional approach. In particular, the traditional process takes double time the Lean process to be completed: in a fixed timespan, the traditional process was never completed and lead to errors in the final output. The Lean process, instead, was completed in each timespan and with few or no errors. This confirms a common practice in the construction field that is delaying the deadline of the final delivery, to meet the requirements. In a Lean process, the deadline is a constraint that is never delayed, and the final delivery always meets the requirements. Moreover, the effective speed, therefore, the number of units produced in a minute, were greatly higher in the Lean process than in the traditional process. Following the preliminary findings, it is important to note that Lean mindset could enhance the workspace, giving a more productive method but also strategies that reduces errors and wastes, of time and effort especially. A workspace following the Lean mindset gives to people the opportunity to address problems in the production line and to resolve them, contrasting frustration and lack of motivation. Lean mindset, therefore, addresses social issues correlated to work environment, giving employees and people a better management method to do their job in a relaxed, enriched, and organized workspace.

## HIGHLIGHTS

- **Innovative learning simulation:** The contribution introduces an innovative learning simulation and its platform aimed at project organisations, project managers and design teams. The platform entails learning opportunities both related to BIM and Social Sciences, focusing on the People and Processes pillars of lean mindset.
- **Online work environment:** The proposed serious game makes use of BIM tools and processes to create a shared online work environment, supporting project organisations in dealing with communication processes and project information sharing/delivery.
- **Lean thinking approach usefulness in construction and architectural design:** construction industry does not assess non-value adding activities. Lean mindset could shift the attention from the product of architectural design to the process used to achieve the results, following a purge of non-value adding activities and, consequently, reducing waste.
- **Lean thinking helps to evaluate schedules, design, and roles distribution:** often time management is lacking a holistic view, space design is not efficient for the production that is been done and human resources are misplaced. Lean mindset allows to look to the single aspect of the production and re-integrate all the aspect in a fully functional process.

- **Lean mindset as a training by gaming result:** results shown the efficacy of Lean thinking against conventional method. Lean mindset strength relies in theory and in its application. For users is extremely important to view the results of a new method to apply it with motivation.
- **Developing or improving educational tools to teach Lean thinking:** academic and educational tools nowadays need a boost and a strong improvement through a more complete virtual environment for simulations or a firmly scheduled educational program that incorporates simulation tools in conventional teaching.
- **Online multiplayer platforms as an improved tool for education and training:** multiplayer platforms could be a good opportunity to build an environment with a full overview on all the Lean mindset aspects, adding the dynamic and social interaction between participants that is central in Lean mindset approach.

## REFERENCES

- Aqlan, F.G.W., 2017. Teaching Lean Principles through Simulation Games.
- Ben-Alon, L. and Sacks, R., 2017. Simulating the behavior of trade crews in construction using agents and building information modeling, *Automation in Construction*, 74, pp. 12–27.
- Connolly, T.M. et al., 2012. A systematic literature review of empirical evidence on computer games and serious games, *Computers and Education*, 59(2), pp. 661–686.
- de Freitas Avelar, A. and Marques Carvalho, M.T., 2020. Literature Mapping of the Use of Games for Learning Correlating with Lean: A Systematic Review, *Lecture Notes in Networks and Systems*, 122, pp. 89–101.
- González, C. and Area, M., 2013. Breaking the rules: Gamification of learning and educational materials, *Proceedings of IDEE 2013: 2nd International Workshop on Interaction Design in Educational Environments - In Conjunction with the 15th Int. Conference on Enterprise Information Systems, ICEIS 2013*, pp. 47–53.
- Gurevich, U. and Sacks, R., 2014. Examination of the effects of a KanBIM production control system on subcontractors' task selections in interior works, *Automation in Construction*, 37, pp. 81–87.
- Herzig, P., Ameling, M. and Schill, A., 2015. Workplace psychology and gamification: Theory and application, *Gamification in Education and Business*, pp. 451–471.
- Mattsson, J., Nurminen, R. and Reunanen, T., 2019. LeanGame, a digital training tool to implement lean philosophy, *Advances in Intelligent Systems and Computing*, 783, pp. 26–35.
- De Oliveira Rangel Salibi, J.G. et al., 2021. The use of games in a graduation course in an engineering faculty, *International Symposium on Project Approaches in Engineering Education*, 11(2014), pp. 283–291.
- Paraskeva, F., Mysirlaki, S. and Papagianni, A., 2010. Multiplayer online games as educational tools: Facing new challenges in learning, *Computers and Education*, 54(2), pp. 498–505.
- Tagliabue, Lavinia C et al., 2021. A Serious Game for Lean Construction Education Enabled by Internet of Things, *Smart Innovation, Systems and Technologies*, 197, pp. 225–233.
- Tsalapatas, H., Heidmann, O. and Jesmin, T., 2021. Serious Games to Support Agile and Lean Methodologies, *Lecture Notes in Educational Technology*, pp. 107–124.
- Yousefi, B.H. and Mirkhezri, H., 2020. Lean Gamification Canvas : A New Tool for Innovative Gamification Design Process, *Proceedings of the 2nd International Serious Games Symposium, ISGS 2020*, pp. 1–9.

## THE PEIRCEAN CATEGORIES MEETING DESIGN AND PRODUCTION

Lauri Koskela<sup>1</sup>, Ergo Pikas<sup>2</sup>

The American philosopher and scientist Peirce claimed that there are three ontologically distinct categories, through which the reality can be encountered: Firstness, Secondness and Thirdness. He characterizes these as follows (Peirce 1904):

*"I should define Firstness, Secondness, and Thirdness thus:*

*Firstness is the mode of being of that which is such as it is, positively and without reference to anything else.*

*Secondness is the mode of being of that which is such as it is, with respect to a second but regardless of any third.*

*Thirdness is the mode of being of that which is such as it is, in bringing a second and third into relation to each other."*

Peirce held that these categories are extremely useful, and indeed they underpin most, if not all, philosophical discussions by him. Simultaneously, he admitted that the categories are "excessively general ideas, so very uncommonly general that it is far from easy to get any but a vague apprehension of their meaning". Peirce did not succeed in convincing his contemporaries about the categories, and still today the categories are seen as an extremely difficult topic (Colapietro 2008).

Peirce presents two interesting and possibly actionable claims regarding his categories; we make reference to the first claim, while the second provides an interesting area for further research:

- All three categories are needed for understanding a phenomenon or topic.
- There are no other independent categories than these three; if needed, higher-level categories (like Fourthness) can be created by combining the three categories.

Peirce seems to have used his category theory mainly in two roles:

- Constructive role: creating taxonomies
- Explanatory/exploratory role: considering into which category a given phenomenon falls, sharpening thus understanding and definitions

This presentation aims at communicating initial outcomes of an exploration of the significance of the categories in the realm of design and production. Four insights are discussed:

- In design and production, there exist initiatives that embody the Peircean categories, without referring to them. For example, in the well-known Function-Behaviour-Structure (FBS) theory of design, as forwarded by Gero (1990), the three categories can be clearly recognized. The domain theory developed by Andreasen (Andreasen et al. 2014) is another example. Thus, the views presented in philosophy that categories provide an extremely difficult topic can be challenged: at least some concepts aligned Firstness, Secondness and Thirdness surface from the needs and context of design, and thus the categories can rather easily be illustrated. On the other hand, we claim that the Peircean categories may be used for sharpening our understanding and definitions of concepts only intuitively based on the Peircean categories.
- There are phenomena in the realm of design and production for which concepts aligned to the Peircean categories are recognized, but the idea that they form a totality (that all need to be used for understanding the phenomenon in question) is missing. The reception of the TFV theory of production by Koskela (2000) provides an example. The mainstream scholarship in operations management has

---

<sup>1</sup> The University of Huddersfield, UK. ORCID 0000-0003-4449-2281

<sup>2</sup> Tallinn University of Technology, Estonia. ORCID 0000-0001-5691-685X

\* Corresponding author Email:

not accepted this theory, arguably because it is not a unified theory of production. However, taking lead from Peirce, it is argued that the different aspects of production as reflected in the TFV theory are intrinsically separate, and cannot be unified.

- There are phenomena in the realm of design and production for which concepts aligned to the Peircean categories are recognized, but their interrelationships are not correctly (in the Peircean sense) conceived. The FBS scheme provides an example; according to it, there is no relation between the structure and the function. Based on the Peircean categories, this can be questioned.
- There are phenomena in the realm of design and production for which concepts aligned to the Peircean categories are not recognized. We argue that this hinders or prevents a systematic examination of those phenomena. An example falling into visual management, especially wayfinding, is presented. It is shown that the work by Peirce on the categories of signs can with advantage be applied to the design and improvement of typical devices of wayfinding.

The contents of this presentation represent a new trend where philosophy (of science) is argued to directly produce scientific knowledge (Pradeu et al. 2021). Although this has originally been argued for the case of natural science, it seems that the situation is comparable in production science.

At the conclusion of the presentation, the research frontier that opens is commented.

## REFERENCES

- Andreasen, M.M., Howard, T.J. and Bruun, H.P.L., 2014. Domain theory, its models and concepts. In *An anthology of theories and models of design* (pp. 173-195). Springer, London.
- Colapietro, V. 2008. Peirce's categories and sign studies. *Approaches to communication: Trends in global communication studies*, 43-58.
- Gero, J. S. 1990. Design prototypes: a knowledge representation schema for design. *AI magazine*, 11(4), 26-26.
- Koskela, L., 2000. An exploration towards a production theory and its application to construction. VTT Technical Research Centre of Finland.
- Koskela, L. & Kroll, E. 2022. The role of the Peircean categories in design theory. Presentation in the 15h International Paris Workshop of the Design Theory SIG of the Design Society 31st January and 1st February 2022.
- Peirce, C. 1904. Letters to Lady Welby. CP 8:328.
- Pradeu, T., Lemoine, M., Khelifaoui, M. and Gingras, Y., 2021. Philosophy in Science: Can philosophers of science permeate through science and produce scientific knowledge? *The British Journal for the Philosophy of Science*. In print.

## **SUSTAINABILITY**

# PHOTOVOLTAIC SYSTEMS AND BIM INTEGRATION: TRENDS AND POSSIBILITIES

Bruna Brito Liberal<sup>1\*</sup>, Thales Henrique Castro de Barros<sup>2</sup>, and Rachel Perez Palha<sup>3</sup>

## INTRODUCTION

The demand for photovoltaic (PV) systems in Brazil has increased in the last years due to factors such as the increased cost of electricity and the growth of interest in sustainable energy sources (Carstens and Cunha 2019). As a result, in the next few years, a higher presence of PV systems is expected in residences, industries, and even in larger infrastructures projects (Byrne et al. 2016; Choi and Song 2017; Ferri et al. 2022). Despite this expectation, few projects consider these technologies in design, generating extra costs in the later installation and hardly allowing a fully efficient operation of the PV (Lau et al. 2019).

In 2019, construction was responsible for 35% of the total global energy use and 38% of total global energy related CO2 emissions (Global Alliance for Buildings and Construction, 2020). Reducing building energy consumption or optimising its use on building projects by improving energy efficiency could impact on the global energy demand. An efficient method for reducing environmental problems that has gotten the attention of the sustainable development of society is the use of Building Information Modelling (BIM) to promote the integration of PV systems in the early stages of the project process. One example of this integration is a building model optimised for lower energy consumption and with power generation systems, called "zero/low energy building" (El Sayary and Omar, 2021).

This work presents a systematic review to identify techniques, methods and tools that can be used to optimise the energy generation potential, estimating the energy consumption of buildings, and reducing related costs. By highlighting works that address this integration, this systematic review also aims to assess academic development and provide an overview of the newest technologies associated with this topic. The method adopted to perform the systematic review was the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) method (Page *et al* 2021).

## METHOD

The systematic review was performed following the PRISMA guidelines. Using the Scopus database, the keywords chosen involved terms related to BIM and PV systems. The exclusion criteria were: 1) document types other than articles, reviews, or book chapters; 2) works published in a language other than English; 3) articles that were not associated with the research objective. The Boolean strings used on Scopus were: (TITLE-ABS-KEY (bim OR ("building information modeling"))) AND TITLE-ABS-KEY (bipv OR "solar energy" OR photovoltaic OR "solar cell" OR "solar panel" OR "building integrated photovoltaics") AND (LIMIT-TO (DOCTYPE,"ar") OR LIMIT-TO (DOCTYPE,"re")) AND (LIMIT-TO (LANGUAGE,"English")). By the end of the study selection, a total of 7 articles were found to be included in the review, as shown in Fig. 1.

In the identification phase, 53 registers were found and none of them were excluded before screening (i.e. none of them were duplicated). In the screening phase, 36 records were excluded by title and abstract and of the 17 records that remained, 5 were not retrieved. Finally, 12 records were assessed for eligibility and 5 were excluded for not being related to the purpose of the research, which resulted in 7 studies included in the review.

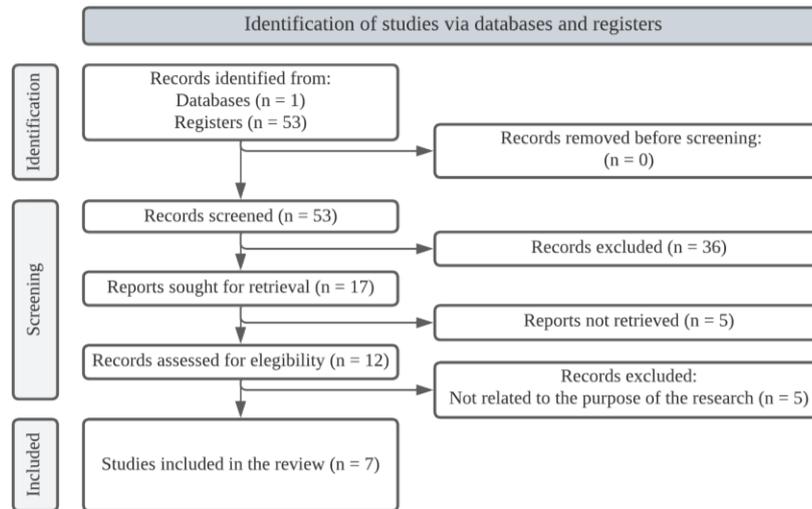
---

<sup>1</sup> Department of Civil Engineering, Federal University of Pernambuco, Brazil. ORCID 0000-0002-8424-4226

<sup>2</sup> Department of Electronics and Systems, Federal University of Pernambuco, Brazil. ORCID 0000-0002-5738-9892

<sup>3</sup> Department of Civil Engineering, Federal University of Pernambuco, Brazil. ORCID 0000-0002-4424-4184

\* Corresponding author Email: bruna.liberal@ufpe.br



**Figure 1: Study selection flow diagram.**

## RESULTS

Among the 7 eligible works at the end of the review, important contributions were identified for the inclusion of PV systems from the early stages of the project. El Sayary and Omar (2021) developed a BIM model that can be used to calculate energy consumption and provide useful information to optimise PV system designs in zero or low energy buildings. Abbasi and Noorzai, (2021) combine a multi-objective optimisation algorithm with BIM concepts and Life Cycle Assessment (LCA) to determine the trade-off between embodied and operating energy to optimize the use of renewable energy. Lin, et al. (2021) develop an automatic PV system tool fully integrated with BIM platforms to design and manage PV systems through BIM data.

Salimzadeh et al. (2020) developed a parametric modelling platform using properties of the BIM model to perform radiation simulations, optimize the characteristics of the chosen PV systems, such as size and orientation, and perform detailed cost-benefit analysis of each chosen scenario. Devetakovic et al. (2019) lists relevant geometric aspects for design PV systems and discusses the integration of these parameters in BIM environments. Ning et al. (2018) and Jakica (2018) address the concept of Building Integrated Photovoltaics (BIPV), the first proposes a uniform BIPV design platform focused on BIM and compatible with external photovoltaic models, to reduce photovoltaic system costs and energy transmission losses. The second aims to facilitate decisions in the design process of photovoltaic systems, through a review of about 200 photovoltaic system design tools, analysing, among other things, possibilities of integrating these tools with BIM software environments.

The analysis of these works made it possible to evaluate a scenario that is still incipient regarding the integration between BIM and PV technologies in the early stages of the projects. Despite the small number of works in this direction, it is expected that the current growth of research on BIM and photovoltaics will increasingly contribute to the integration of these two technologies. This review aims to popularise this integration, in view of all possible social, environmental, and economic gains that can be obtained by society.

## REFERENCES

- Abbasi, S., & Noorzai, E. (2021). The BIM-Based multi-optimization approach in order to determine the trade-off between embodied and operation energy focused on renewable energy use. *Journal of Cleaner Production*, 281, 125359.
- Byrne, J., Taminiau, J., Kim, K. N., Seo, J., and Lee, J. (2016). "A solar city strategy applied to six municipalities: integrating market, finance, and policy factors for infrastructure-scale photovoltaic development in Amsterdam, London, Munich, New York, Seoul, and Tokyo." *WIREs Energy Environment*, 5(1), 68–88.
- Carstens, D. D. S. and Cunha, S. K. (2019). "Challenges and opportunities for the growth of solar photovoltaic energy in Brazil." *Energy Policy*, 125, 396–404.
- Choi, Y. and Song, J. (2017). "Review of photovoltaic and wind power systems utilized in the mining industry." *Renewable and Sustainable Energy Reviews*, 75, 1386–1391.
- Devetaković, M. S., Đorđević, Đ., Đukanović, G., Krstić-Furundžić, A., Sudimac, B. S., & Scognamiglio, A. (2019). Design of solar systems for buildings and use of BIM tools: Overview of relevant geometric aspects. *FME Transactions*, 47(2), 387-397.

- El Sayary, S., & Omar, O. (2021). Designing a BIM energy-consumption template to calculate and achieve a net-zero-energy house. *Solar Energy*, 216, 315-320.
- Ferri, C., Ziar, H., Nguyen, T. T., Lint, H. V., Zeman, M., and Isabella, O. (2022). "Mapping the photovoltaic potential of the roads including the effect of traffic." *Renewable Energy*, 182, 427-442.
- Jakica, N. (2018). State-of-the-art review of solar design tools and methods for assessing daylighting and solar potential for building-integrated photovoltaics. *Renewable and Sustainable Energy Reviews*, 81, 1296-1328.
- Lau, S. Y., Chen, T., Zhang, J., Xue, X., Lau, S. K., and Khoo, Y. S. (2019). "A new approach for the project process: prefabricated building technology integrated with photovoltaics based on the BIM system." *IOP Conference Series: Earth and Environmental Science*, 294(1).
- Li, H., & Wang, S. (2020). Model-based multi-objective predictive scheduling and real-time optimal control of energy systems in zero/low energy buildings using a game theory approach. *Automation in Construction*, 113, 103139.
- Lin, Q., Kensek, K., Schiler, M., & Choi, J. (2021). Streamlining sustainable design in building information modeling BIM-based PV design and analysis tools. *Architectural Science Review*, 64(6), 467-477.
- Ning, G., Kan, H., Zhifeng, Q., Weihua, G., & Geert, D. (2018). e-BIM: a BIM-centric design and analysis software for Building Integrated Photovoltaics. *Automation in Construction*, 87, 127-137.
- Page, M. J., Moher, D., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., & McKenzie, J. E. (2021). "PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews." *BMJ*, 372.
- Salimzadeh, N., Vahdatikhaki, F., & Hammad, A. (2020). Parametric modeling and surface-specific sensitivity analysis of PV module layout on building skin using BIM. *Energy and Buildings*, 216, 109953.
- United Nations Environment Programme. (2020). 2020 Global Status Report for Buildings and Construction: Towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector.

# DYNAMIC IMPACTS OF POLICIES ON THE RECYCLING RATE OF CONSTRUCTION AND DEMOLITION WASTE

Mingxue Ma<sup>1</sup>, Vivian WY Tam<sup>2\*</sup>, Khoa N Le<sup>3</sup>, Robert Osei-Kyei<sup>4</sup>

## RESEARCH BACKGROUND

Construction and demolition (C&D) waste is produced during the process of construction, renovation, or demolition of structures (Mahpour, 2018), and it accounts for 30% to 40% of total solid waste (Li et al., 2020). Currently, disposing in landfills is still a common method to treat C&D waste, which inevitably occupied land resources (Li et al., 2020). In many countries and regions, illegal dumping of C&D waste has become a widespread problem, exerting negative impacts on living and natural environment (Liu, Hua & Chen, 2021). Therefore, C&D waste management has been placed as a high priority in waste management (Peng et al., 2020). In last few decades, governments in various countries adopted the concept of sustainable development and formulated policies to stimulate recycling of C&D waste (Tam, Soomro & Evangelista, 2018). Introduction of policies could result in changes in recycling rate. The effectiveness of policies has become a central concern. Therefore, studying the dynamic impacts of policies on the recycling rate could reveal effectiveness of different policies in increasing the recycling of C&D waste.

## RESEARCH PROBLEM AND AIM

The great amount of C&D waste has attracted increasing concerns from researchers. Wu et al. (2019) summarised five research focuses of previous studies associated with C&D waste management: (1) environmental perspective, (2) material perspective, (3) industrial ecology perspective, (4) management perspective and (5) buildings perspective. Recently, academic attention was paid to the use of recycled aggregate as a substitution of virgin aggregate (Bui, Satomi & Takahashi, 2018; Guo et al., 2018; Tam, Soomro & Evangelista, 2018; Wijayasundara, Mendis & Crawford, 2018). Although few studies investigated impacts of driving policies on stakeholders' behaviours in C&D waste management (Calvo, Varela-Candamio & Novo-Corti, 2014; Seror & Portnov, 2020) and assessed C&D waste management from the economic perspective (Au, Ahn & Kim, 2018; Yuan et al., 2011), studies focused on the dynamic impacts of policies on recycling rate of C&D waste were insufficient.

This study aims to develop a system dynamics model to assess dynamic impacts of policies (i.e., landfill charge, subsidies for recycling and enhanced supervision on illegal dumping) on recycling rate of C&D waste.

## RESEARCH METHOD

A system dynamic model will be developed in this study, because there is a consensus that system dynamics model particularly focuses on interactions between elements and could better examine dynamic behaviours of a system (Yuan & Wang, 2014). In addition, it could predict future tendencies, study the dynamics of a complex system and conduct overall system analysis under different scenarios (Yu et al., 2015). Numerical values related to landfill, recycling and dumping are expected to be collected from C&D waste recycling sites in China through questionnaires sent to contractors and interviewing some of the municipalities and contractors. Data related to GDP and production of C&D waste could be collected from previous literatures or municipal yearbook. Ethical approval for this project has been granted. HREC approval number is H14392.

## PRELIMINARY RESULTS

---

*1 School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0002-2215-2182*

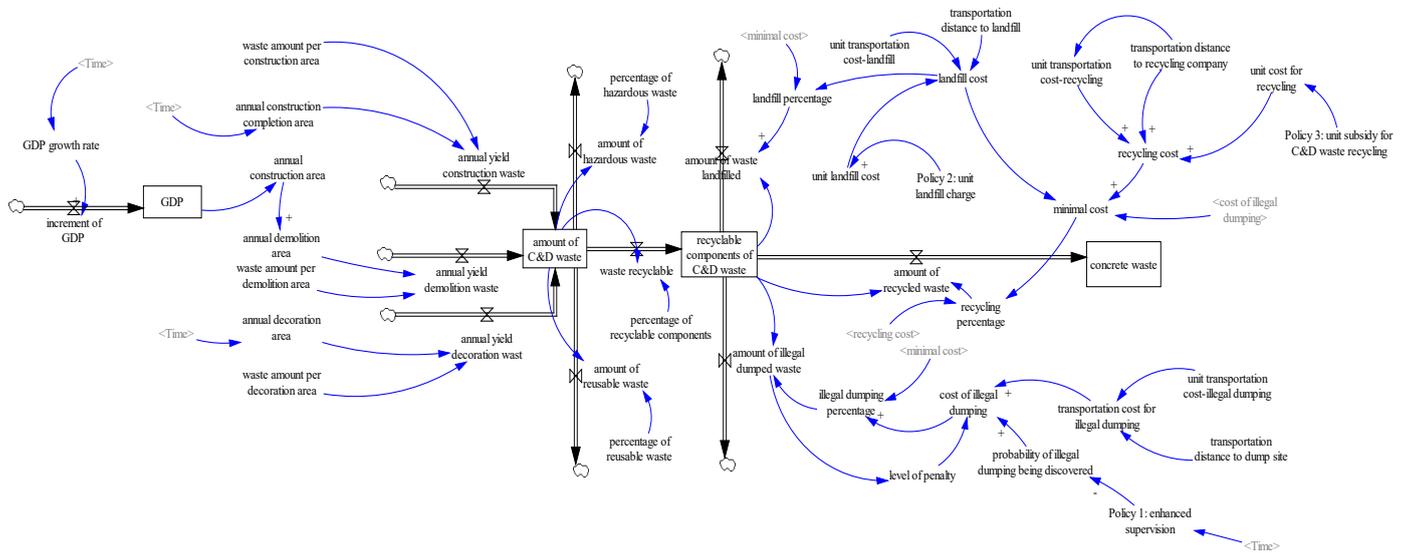
*2 School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0002-1074-8018*

*3 School of Engineering, Design and Built Environment, Western Sydney University, Australia.*

*4 School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0003-4121-1958*

*\* Corresponding author, Tel: +61 2 4736 0105; Email: vivianwytam@gmail.com*

Figure 3 presents stock-flow diagram for C&D waste management. This system could be divided into four subsystems: (1) waste generation waste, (2) waste recycling system, (3) waste landfill system, and (4) waste dumping system. All the variables and functions in the diagram will be defined in the future. In the future, a set of tests should be conducted to examine the validity of a system dynamics model before simulation and analysis: (1) boundary and structure adequacy test, (2) dimensional consistency test, (3) time step adequacy test, and (4) extreme conditions test.



**Figure 3: A stock-flow diagram for C&D waste management**

**References**

Au, L. S., Ahn, S. & Kim, T. W. 2018, 'System dynamic analysis of impacts of government charges on disposal of construction and demolition waste: a Hong Kong case study', *Sustainability*, vol. 10, no. 4, p. 1077, DOI 10.3390/su10041077.

Bui, N. K., Satomi, T. & Takahashi, H. 2018, 'Mechanical properties of concrete containing 100% treated coarse recycled concrete aggregate', *Construction & Building Materials*, vol. 163, pp. 496-507, DOI 10.1016/j.conbuildmat.2017.12.131.

Calvo, N., Varela-Candamio, L. & Novo-Corti, I. 2014, 'A dynamic model for construction and demolition (C&D) waste management in Spain: Driving policies based on economic incentives and tax penalties', *Sustainability (Basel, Switzerland)*, vol. 6, no. 1, pp. 416-35, DOI 10.3390/su6010416.

Guo, H., Shi, C., Guan, X., Zhu, J., Ding, Y., Ling, T.-C., Zhang, H. & Wang, Y. 2018, 'Durability of recycled aggregate concrete – a review', *Cement and Concrete Composites*, vol. 89, pp. 251-9, DOI 10.1016/j.cemconcomp.2018.03.008.

Li, C. Z., Zhao, Y., Xiao, B., Yu, B., Tam, V. W. Y., Chen, Z. & Ya, Y. 2020, 'Research trend of the application of information technologies in construction and demolition waste management', *Journal of Cleaner Production*, vol. 263, p. 121458, DOI 10.1016/j.jclepro.2020.121458.

Liu, C., Hua, C. & Chen, J. 2021, 'Efficient supervision strategy for illegal dumping of construction and demolition waste: A networked game theory decision-making model', *Waste Management & Research*, pp. 1-11, DOI 10.1177/0734242X211032031.

Mahpour, A. 2018, 'Prioritizing barriers to adopt circular economy in construction and demolition waste management', *Resources, Conservation and Recycling*, vol. 134, pp. 216-27, DOI 10.1016/j.resconrec.2018.01.026.

Peng, Z., Shi, C., Shi, Z., Lu, B., Wan, S., Zhang, Z., Chang, J. & Zhang, T. 2020, 'Alkali-aggregate reaction in recycled aggregate concrete', *Journal of Cleaner Production*, vol. 255, p. 120238, DOI 10.1016/j.jclepro.2020.120238.

Seror, N. & Portnov, B. A. 2020, 'Estimating the effectiveness of different environmental law enforcement policies on illegal C&D waste dumping in Israel', *Waste management (Elmsford)*, vol. 102, pp. 241-8, DOI 10.1016/j.wasman.2019.10.043.

Tam, V. W. Y., Soomro, M. & Evangelista, A. C. J. 2018, 'A review of recycled aggregate in concrete applications (2000–2017)', *Construction and Building Materials*, vol. 172, pp. 272-92, DOI

10.1016/j.conbuildmat.2018.03.240.

Wijayasundara, M., Mendis, P. & Crawford, R. H. 2018, 'Integrated assessment of the use of recycled concrete aggregate replacing natural aggregate in structural concrete', *Journal of Cleaner Production*, vol. 174, pp. 591-604, DOI 10.1016/j.jclepro.2017.10.301.

Wu, H., Zuo, J., Zillante, G., Wang, J. & Yuan, H. 2019, 'Status quo and future directions of construction and demolition waste research: A critical review', *Journal of Cleaner Production*, vol. 240, p. 118163, DOI 10.1016/j.jclepro.2019.118163.

Yu, W., Li, M., Ge, Y., Li, L., Zhang, Y., Liu, Y. & Zhang, L. 2015, 'Transformation of potential medical demand in China: A system dynamics simulation model', *Journal of Biomedical Informatics*, vol. 57, pp. 399-414, DOI 10.1016/j.jbi.2015.08.015.

Yuan, H. & Wang, J. 2014, 'A system dynamics model for determining the waste disposal charging fee in construction', *European Journal of Operational Research*, vol. 237, no. 3, pp. 988-96, DOI 10.1016/j.ejor.2014.02.034.

Yuan, H. P., Shen, L. Y., Hao, J. J. L. & Lu, W. S. 2011, 'A model for cost-benefit analysis of construction and demolition waste management throughout the waste chain', *Resources, Conservation and Recycling*, vol. 55, no. 6, pp. 604-12, DOI 10.1016/j.resconrec.2010.06.004.

## RECYCLED AGGREGATE CONCRETE: A PATHWAY TOWARDS CIRCULAR ECONOMY AND SUSTAINABILITY

WeiQi Xing<sup>1</sup>, Vivian Tam<sup>2\*</sup>, Khoa Le<sup>3</sup>, Jian Li Hao<sup>4</sup>, Jun Wang<sup>5</sup>

Circular economy has been acknowledged by many countries as a means to help mitigate the impacts on the environment and to close the loop of the product lifecycle (Prieto-Sandoval et al., 2018). In Australia, there have been policies to progressively advance the government's statement of long-term emissions reduction strategy and facilitate Australia's transition toward a net zero emissions country.

The economy of Australia is expected to have a remarkable increase in the future, driven by projected population growth and a couple of attractive infrastructure projects and development plans. On the other hand, the increasing demand for the resources and the disposal of waste is believed to have a continuous threat to the local communities, putting the ecosystem and environment at risk.

In line with circular economy strategies, Australia set a goal to improve the waste recovery rate to 80% by 2030, and significantly increase the use of recycled materials by governments and industry (Pickin et al., 2020). Under this target, the important waste stream construction and demolition waste is being more emphasised in the country, which amount has increased by 32% in the past ten years.

Regarding the construction industry, a practical and economic solution for both improving waste recovery rate and increasing recycled material utilisation is to produce recycled aggregate (Zhang et al., 2019). Concrete made with RA, known as recycled aggregate concrete (RAC), which are effective to consume the original waste material to be stored in the new concrete and reduce the landfilling, is expected to be a pathway towards circular economy and sustainability (Xing et al., 2022).

Life cycle assessment (LCA) is to evaluate the impacts and loadings of a product or service by quantifying material and energy uses and waste released to the environment throughout its lifespan. It is an ideal tool to support a circular economy from the environmental perspective because LCA is able to quantify the burden shifting to address the benefits of closing-loop of the product required by circular economy. To provide an insight into the environmental performance among concretes, a comparative LCA study of concrete with virgin and recycled aggregates is carried out, especially focusing on carbon emissions and energy consumption. LCA model is built based on statistical data published in Australia including the national life cycle inventory database, together with data from Australian-context literature and professional LCA software. Functional unit defined is a cubic meter of ready-for-use concrete considering its 28 days compressive strength, and the corresponding system boundary of the model is from cradle to gate, where the construction, use and maintenance, and demolition phases are excluded. A total of 381 mix designs regarding virgin aggregate concretes (VAC) and RAC from 33 studies are collected, which global warming potential and fossil fuel consumption are analysed by adopting LCA methodology.

According to Figure 4, it can be seen that the global warming potential of concretes concentrates on 300 to 500 kg CO<sub>2</sub> eq., and fossil fuel energy consumption of the majority of concrete mixes is from 1000 to 1700 MJ. Both indicators generally increase with the development of concrete strength. In addition, with the same mix design, substituting the virgin aggregate with the recycled one leads to a minor reduction in carbon emission but a more obvious saving in energy consumption. When supplementary cementitious materials are incorporated, the environmental benefits of RAC compared to VAC are more pronounced. From all mix designs and the corresponding LCA results, RAC is evident to have the lower carbon emission and fossil fuel consumption than those of VAC under the same compressive strength.

---

<sup>1</sup> School of Engineering, Design and Built Environment, Western Sydney University, Australia, ORCID 0000-0002-8193-2672

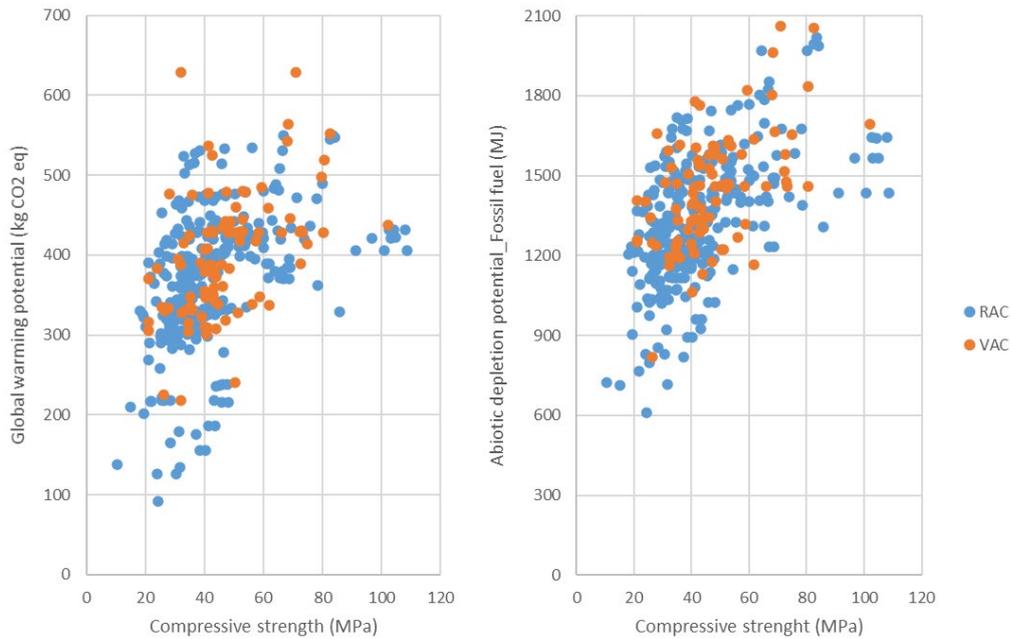
<sup>2</sup> School of Engineering, Design and Built Environment, Western Sydney University, Australia, ORCID 0000-0002-1074-8018

<sup>3</sup> School of Engineering, Design and Built Environment, Western Sydney University, Australia

<sup>4</sup> School of Engineering, Design and Built Environment, Western Sydney University, Australia

<sup>5</sup> School of Engineering, Design and Built Environment, Western Sydney University, Australia, ORCID 0000-0003-3384-4050

\* Corresponding author, Tel: +61 2 4736 0105; Email: vivianwytam@gmail.com



**Figure 4. Global warming potential and abiotic depletion potential of concrete mixes**

A LCA enables to investigate the environmental impacts of different concretes and optimise the products concerning mechanical, economic and environmental behaviours. Since there is a relationship between the mechanical and environmental performance of concrete indicated in Figure 4, it is possible to estimate the carbon emission and energy consumption based on the characteristic of aggregate and its compressive strength. Ultimately, concrete products in a higher compressive strength but lower environmental impacts is more favoured and would promote the sustainability in the industry.

## REFERENCES

- Pickin, J., Wardle, C., O'Farrell, K., Nyunt, P., Donovan, S. 2020. National waste report 2020. *Department of Agriculture, Water and the Environment*. Blue Environment.
- Prieto-Sandoval, V., Jaca, C., Ormazabal, M., 2018. Towards a consensus on the circular economy. *Journal of Cleaner Production*, 179, 605-615. <https://doi.org/10.1016/j.jclepro.2017.12.224>.
- Xing, W., Tam, V. W. Y., Le, K. N., Hao, J. L., Wang, J., 2022. Life cycle assessment of recycled aggregate concrete on its environmental impacts: A critical review. *Construction and Building Materials*, 317, 125950. <https://doi.org/10.1016/j.conbuildmat.2021.125950>.
- Zhang, Y., Luo, W., Wang, J., Wang, Y., Xu, Y., Xiao, J., 2019. A review of life cycle assessment of recycled aggregate concrete. *Construction and Building Materials*, 209, 115-125. <https://doi.org/10.1016/j.conbuildmat.2019.03.078>.

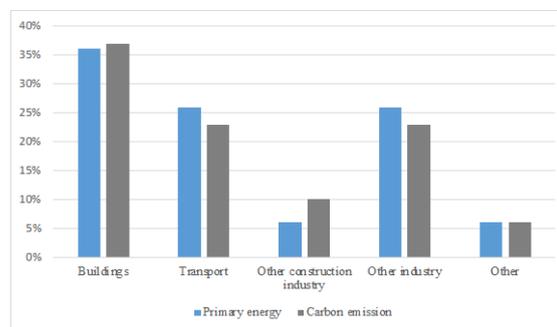
# MORE ACCURATELY PREDICTING THE LIFE CYCLE ENERGY CONSUMPTION OF RESIDENTIAL BUILDINGS IN CHINA BASED ON THE EA-LSTM MODEL

Lei Liu<sup>1</sup>, Vivian W.Y. Tam<sup>2\*</sup>, Khoa N. Le<sup>3</sup>

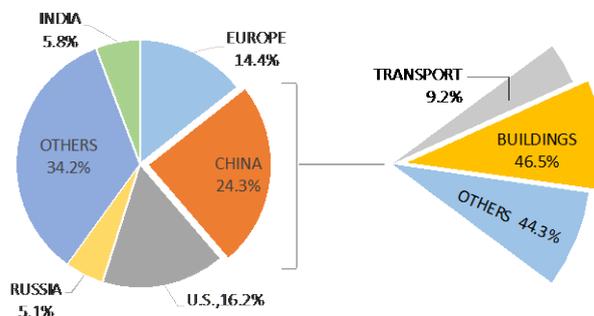
## RESEARCH BACKGROUND

With the global economy rapidly developing in the past decades, primary energy, as one of the important drivers, has been consumed and wasted at an alarming rate. According to the energy report published by the BP Statistical Review of World Energy, the average annual increase rate of primary energy consumption reached nearly 2%, and the total energy consumption has even reached 173,340 terawatt-hours in 2019 (Ritchie & Roser 2020). Inevitably, it has become the arch-criminal of air pollution. The amount of carbon dioxide emission produced by primary energy reached the historically highest level of 33.1 Gt CO<sub>2</sub> in 2018 (IEA, 2019). Among these, the construction industry contributes 36% of global energy use and 37% of carbon emission, making it one of the largest emission sectors worldwide (Global Alliance for Buildings and Construction, 2021), as shown under Figure. 1.

Thus, driven by the global goal of “carbon peak” and “carbon neutrality”, building energy conservation has become one of the most urgent issues to be solved. Since energy structures and demands will be changed significantly in the next few decades, energy consumption prediction needs to be paid more attention to in academia and practice. Significantly, it plays an important role in energy policies adjustment and environment assessments (Lu *et al*, 2022).



**Fig. 1 The energy consumption proportion of industries**



<sup>1</sup> School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0001-8556-6297

<sup>2</sup> School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0002-1074-8018

<sup>3</sup> School of Engineering, Design and Built Environment, Western Sydney University, Australia

\* Corresponding author Email: V.Tam@westernsydney.edu.au

**Fig. 2 The energy share in China (Petroleum, 2020)**

## RESEARCH PROBLEM

China, as one of the fastest and growing developing countries, has become the biggest energy consumer (24.3%), and its buildings' energy use has accounted for nearly half of its total energy consumption (Fig. 2). However, although advanced technologies and various methods were applied, there is still a significant difference between actual and expected energy consumption (Du et al., 2021). After the literature review, it was found that most studies ignored the importance of mobile energy relating to the building environment in the life cycle energy system (Pérez-Neira *et al.*, 2020). Besides, current prediction methods exist with different degrees of limitation. For example, some didn't collect detailed physical data, and others can't figure out potential relationships between parameters, thereby causing calculation overlap (Dixit, 2017). Thus, this study is to explore how to reduce China's energy consumption prediction errors based on the two influencing factors: the life cycle energy boundary of buildings, and the prediction method selection.

## AIM

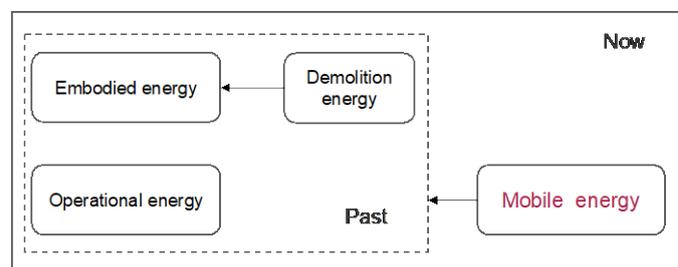
Develop a static model to predict the short-term (by 2030) and long-term (by 2050) building energy consumption of China based on an intact life cycle energy boundary.

## OBJECTIVES

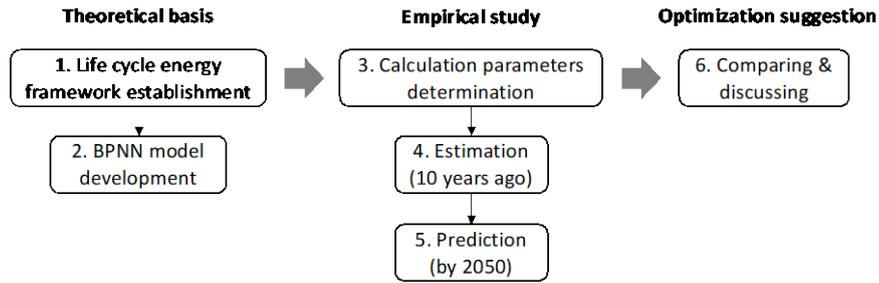
1) Proposing an intact life cycle energy of building framework; 2) Creating a Back Propagation Neural Network (BPNN) prediction model; 3) Estimating China's building energy consumption during the period from 2012 to 2021; 3) Predicting the energy consumption and energy structure change by 2050.

## METHODOLOGY

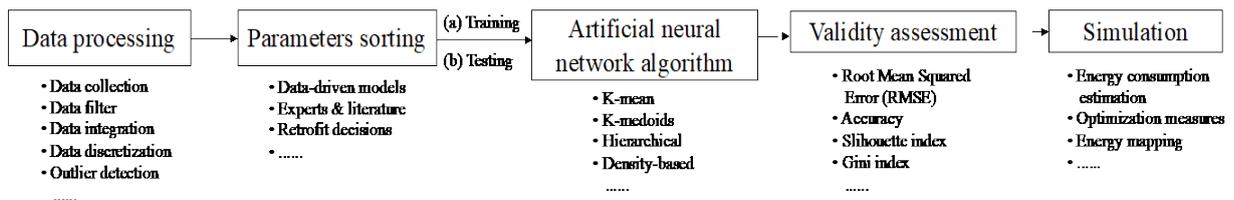
The analysis steps of this research are shown in Fig. 4. To be specific, 1) Based on the background analysis and the attributional life cycle assessment (ALCA), an intact life cycle energy framework will be established, which includes embodied, operational, and mobile energies, as shown in Figure. 3; 2) According to the Back Propagation Neural Network (BPNN) method, the calculation parameters of life cycle energy will be explored and determined, thereby establishing the prediction model. 3) In line with the model requirement and historical data from the China Statistical Yearbooks, the building energy consumption in the past ten years will be estimated carefully; 4) Based on the Back Propagation Neural Network (BPNN) prediction procedures, the amount of energy consumption and energy structure change by 2050 are calculated out. The detailed calculation procedure is shown in Figure 5; 5) Comparing with others' prediction results, this study will further qualitatively discuss current energy policies and services adjustment.



**Figure 3. The life cycle energy of buildings framework**



**Fig 4. The analysis steps of methodology**



**Fig 5. The detailed calculation procedures of BPNN model**

## WORK PROGRESS

To date, the life cycle energy boundary establishment and explanation was developed. However, there is a need to further develop the BPNN model and set their calculation parameters to estimate the total energy consumption in the past ten years, as well as the prediction for the next 30 years.

## PRELIMINARY RESULTS

1) The mobile energy relating to the building environment is a major energy consumption source, the same as embodied and operational energies. 2) The amount of life cycle energy consumption of buildings by 2050, including embodied, operational, mobile, and total energies; 3) The development model of the construction industry of China by 2050; 4) The short-term and long-term change in China's building energy structure.

## CONTRIBUTIONS TO KNOWLEDGE

1) it proposes a new and intact theoretical framework of LCE-B to extend researchers' conception; 2) it can help policymakers review and update energy-saving policy plans to 2050, and help stakeholders adjust current energy services, according to the comparison between prediction results and energy-saving goal.

## REFERENCES

- Dixit, M.K., Embodied energy analysis of building materials: An improved IO-based hybrid method using sectoral disaggregation. *Energy*, 2017. 124: p. 46-58.
- Du, Q., et al., The energy rebound effect of residential buildings: Evidence from urban and rural areas in China. *Energy Policy*, 2021. 153: p. 112235.
- Ritchie, H & Roser, M (2020) - "Energy". Published online at OurWorldInData.org. <https://ourworldindata.org/energy>.
- IEA (2019), Global Energy & CO2 Status Report 2019, IEA, Paris <https://www.iea.org/reports/global-energy-co2-status-report-2019>.
- Global Alliance for Buildings and Construction (2021), 2021 Global Status Report for Buildings and Construction.
- Lu, C., S. Li, and Z. Lu, Building energy prediction using artificial neural networks: A literature survey. *Energy and Buildings*, 2022. 262: p. 111718.
- Pérez-Neira, D., M.P. Rodríguez-Fernández, and C. Hidalgo-González, The greenhouse gas mitigation potential of university commuting: A case study of the University of León (Spain). *Journal of Transport Geography*, 2020. 82: p. 102550.
- Petroleum, B., Statistical Review of World Energy 2020. 2020

# SENSITIVITY ANALYSIS ON BUILDING DESIGN VARIABLES FROM LIFE CYCLE ASSESSMENT PERSPECTIVE

Yijun Zhou<sup>1</sup>, Vivian WY Tam<sup>2\*</sup>, Khoa N Le<sup>3</sup>

## RESEARCH BACKGROUND

Buildings consume energy and produce environmental pollutions (IEA, 2021). A significant proportion (nearly 70%) of the environmental impacts of buildings are determined by the decisions made in design (Liu et al., 2015; R. Wang et al., 2020; W. Wang et al., 2005). Therefore, selecting environmentally preferred building designs has great potential to reduce the environmental impacts of buildings.

A building design involves many variables, such as the window-to-wall ratios, the building orientation, between others. There are thousands of feasible design alternatives by varying these variables. However, the choice of specific values for variables in design practice heavily depends on designers' previous experience (Wang et al., 2005; Silva & Ghisi, 2020). As a results, carbon-intensive design decisions may be made as personal experience cannot precisely foresee the energy demands and environmental impacts of each alternative design. For creating environmentally preferred building designs, it is therefore considered important to choose appropriate values for design variables. Designers must be enabled to understand how the environmental performance of buildings depend on the design variables.

Having examined previous related literature (Flager et al., 2012; Liu et al., 2015; Rahmani Asl et al., 2015; Lobaccaro et al., 2018; Hasik et al., 2019; Hong et al., 2019; Wang et al., 2020), three limitations in addressing this issue are identified: 1) unclear design variables related to environmental performance of building, 2) incomplete environmental performance criterion, and 3) less effective traditional one-at-a-time approaches for assessing the environmental impacts of buildings.

To address above issues, a critical problem in this study is to understand how environmental performance of buildings depends on the design variables. Thus, the aim of this study is to estimate the influence of design variables on the life-cycle environmental impacts of buildings.

## METHODS

To achieve the research aim, a framework is developed in this study. The framework consists of five steps, as shown in Figure 1. First, design variables affecting life-cycle environmental performance of buildings were identified from previous literature. Then, the constraints of design variables were determined in line with building codes, regulations, and technical standards, thereby producing potential design alternatives. Afterwards, life cycle assessment and energy simulation tools were adopted to computationally iterates through all potential design alternatives for corresponding environmental impact results. Fourth, variance-based sensitivity analysis was conducted using Morris method to obtain the sensitivity indices showing the relationship between environmental performance characteristics and design variables. Last, a residential building located in Chongqing, China was used as a case study for implementing the proposed framework. Two building performance criteria namely, global warming potential and primary energy consumption were considered. The simulation experiment considered 5 design variables, namely the window-to-wall ratio, building orientation, building shape, floor area, and number of floors.

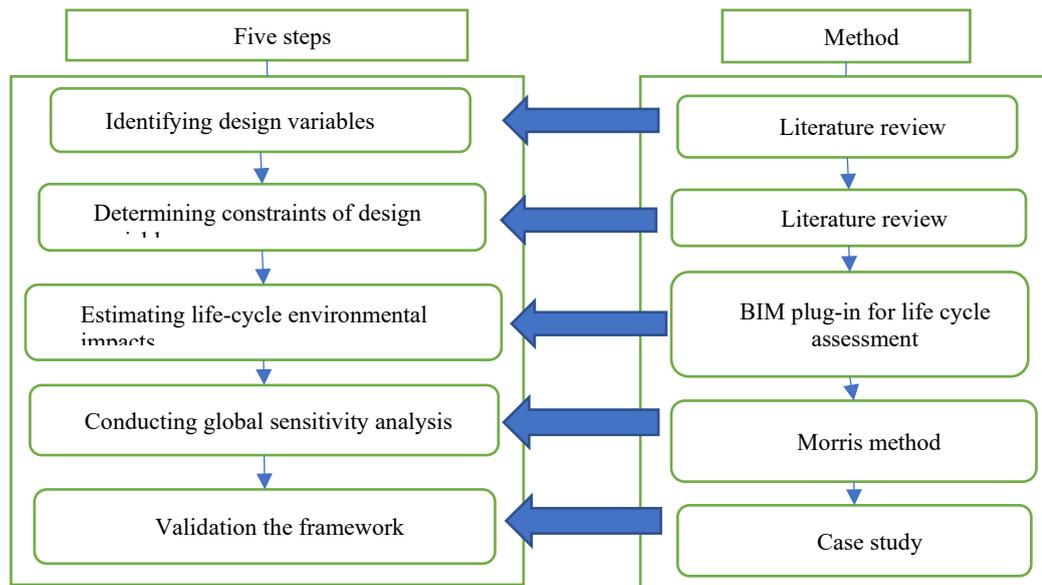
---

<sup>1</sup> School of Engineering, Design and Built Environment, Western Sydney University, Australia

<sup>2</sup> School of Engineering, Design and Built Environment, Western Sydney University, Australia. ORCID 0000-0002-1074-8018

<sup>3</sup> School of Engineering, Design and Built Environment, Western Sydney University, Australia

\* Corresponding author V.Tam@westernsydney.edu.au



**Figure 1 framework of the processes for clarifying the influence of design variables on building environmental impacts**

## PRELIMINARY RESULTS

The case validated the feasibility of the framework. A total of 1362 design alternatives were performed to explain the variation of environmental impacts for building design variables. The sensitivity indices show building orientation (indices=0.35) and window-to-wall ratios (indices=0.22) are the most influential variables. A maximum reduction of 62% of primary energy demands can be achieved for north direction and a reduction of 35% of greenhouse gas emissions can be achieved by optimising the window-to-wall ratios and building orientations.

The results of the case demonstrated the validity of the developed framework. The application of this framework can be generalised to other building cases. However, a limitation in this study is that the environmental impacts results of some building components are retrieved from the databases of other countries due to the absence of life cycle inventory data in local places. More research efforts should be put on how to improve the accuracy of the life cycle inventory data for building components. Despite this, the results in this study can lead to a better understanding of the design variables most significantly determining a building's environmental performance.

## REFERENCES

- Flager, F., Basbagill, J., Lepech, M., & Fischer, M. (2012). Multi-objective building envelope optimization for life-cycle cost and global warming potential. *EWork and EBusiness in Architecture, Engineering and Construction - Proceedings of the European Conference on Product and Process Modelling 2012, ECPPM 2012*, April 2017, 193–200. <https://doi.org/10.1201/b12516-32>
- Hasik, V., Ororbia, M., Warn, G. P., & Bilec, M. M. (2019). Whole building life cycle environmental impacts and costs: A sensitivity study of design and service decisions. *Building and Environment*, 163(August), 106316. <https://doi.org/10.1016/j.buildenv.2019.106316>
- Hong, T., Kim, J., & Lee, M. (2019). A multi-objective optimization model for determining the building design and occupant behaviors based on energy, economic, and environmental performance. *Energy*, 174, 823–834. <https://doi.org/10.1016/j.energy.2019.02.035>
- IEA. (2021). 2021 Global status report for buildings and construction. [https://globalabc.org/sites/default/files/2021-10/GABC\\_Buildings-GSR-2021\\_BOOK.pdf](https://globalabc.org/sites/default/files/2021-10/GABC_Buildings-GSR-2021_BOOK.pdf)
- Liu, S., Meng, X., & Tam, C. (2015). Building information modeling based building design optimization for sustainability. *Energy and Buildings*, 105, 139–153. <https://doi.org/10.1016/j.enbuild.2015.06.037>
- Lobaccaro, G., Wiberg, A. H., Ceci, G., Manni, M., Lolli, N., & Berardi, U. (2018). Parametric design to

minimize the embodied GHG emissions in a ZEB. *Energy and Buildings*, 167, 106–123.  
<https://doi.org/10.1016/j.enbuild.2018.02.025>

Rahmani Asl, M., Zarrinmehr, S., Bergin, M., & Yan, W. (2015). BPOpt: A framework for BIM-based performance optimization. *Energy and Buildings*, 108, 401–412. <https://doi.org/10.1016/j.enbuild.2015.09.011>

Silva, A. S., & Ghisi, E. (2020). Estimating the sensitivity of design variables in the thermal and energy performance of buildings through a systematic procedure. *Journal of Cleaner Production*, 244, 118753. <https://doi.org/10.1016/j.jclepro.2019.118753>

Wang, R., Lu, S., Feng, W., Zhai, X., & Li, X. (2020). Sustainable framework for buildings in cold regions of China considering life cycle cost and environmental impact as well as thermal comfort. *Energy Reports*, 6, 3036–3050. <https://doi.org/10.1016/j.egyr.2020.10.023>

Wang, W., Zmeureanu, R., & Rivard, H. (2005). Applying multi-objective genetic algorithms in green building design optimization. *Building and Environment*, 40(11), 1512–1525. <https://doi.org/10.1016/j.buildenv.2004.11.017>

