Integrating Digital Tools in One-Stop-Shop Business Models for Climate-Smart Single Family Home Renovation in the European Union

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Abstract

The ageing building stock in the European Union (EU) is not adequately equipped to deal with the changing climate, posing a significant challenge for climate change mitigation and adaptation. This has driven governmental institutions and private firms to expediate their renovation efforts; integration of one-stop-shop (OSS) regimes for encouraging higher rates of renovation could stimulate the rate of renovation by up to 6% annually, the aimed rate for the 2030 Renovation Wave by the European Commission. While OSS solutions present a great opportunity for addressing the challenges posed by climate change by allowing older homes to become better prepared through climate-smart retrofitting, these solutions have had mixed results in the past. Given the urgency of the situation as predicted in various scenarios by the IPCC, it is imperative to assess the effectiveness of OSS solutions in accelerating the rate of renovation. This research aims to investigate how digitalisation of aspects of the customer journey of an end user participating in an OSS home renovation platform can lead to overcoming challenges faced by previously implemented instances of it.

To answer this question, first a systematic literature review of previous OSS schemes implemented in Europe, digital tools commonly applied for renovation, and state-of-the-art strategies and models for the purpose of facilitating customer journeys were studied. Through a characterisation of these mechanisms, opportunities for integration of digital tools were identified and suggested for each stage of the customer journey. It was found that through utilisation of technologies such as application programming interfaces (API), for increased access and real-time updating; blockchain infrastructure for information transparency and symmetry, and urban building energy modelling for predictive assessment, some important pitfalls of OSS implementation can be addressed. This study is expected to contribute to the renovation sector, ultimately leading to improving buildings' adaptive capacity, which is critical for the EU's sustainable development objectives going forward.

Key words: climate adaptation, retrofit, one-stop shop, blockchain, urban building energy modelling.

1 Introduction

Despite substantial global efforts to mitigate CO2 emissions, relatively less attention has been given to adapting to climate change impacts (Juhola et al., 2014). However, the urgency of prioritizing climate adaptation is evident as inevitable 1.5˚C global warming approaches (Juhola et al., 2012). While the building sector's emission reduction potential is acknowledged (Hunkin & Krell, 2019), deep renovation rates in the EU remain stagnant (0.5% to 2.5% annually) (Sibileau, 2021), underscoring the significance of climate-smart retrofitting. This involves upgrading structures to

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enhance resilience and sustainability amid climate change, accounting for factors like higher temperatures and extreme weather (European Commission, 2013).

The sluggish renovation pace results from factors like fragmented markets in certain EU nations, where limited industry services prevail (Mlecnik, Straub, & Hauvik, 2019). One-stop-shop (OSS) models have effectively boosted renovation rates in EU member states (Bertoldi et al., 2021), particularly in Germany and the Netherlands, integrating adaptation and mitigation actions for climate-resilient spaces. Essential factors include government backing, stakeholder collaboration, and clear regulations. Wider OSS adoption could potentially raise renovation rates up to 6% by the 2030 renovation wave (European Commission, 2020). Given the current state of the home renovation market, there is a clear need for an overhaul in the system to encourage greater preparation for the consequences of climate change (European Commission, 2020).

The need for a comprehensive information hub spanning various aspects of home renovation was recognized back in 2008, as evidenced by the UK government's creation of an early-stage OSS resource for sharing data on potential climate disasters, consultations with renovation providers, and homeowner-relevant information (Building.co.uk). Similar initiatives with varying scopes emerged in the Netherlands, Iceland, and other European countries (Bertoldi et al., 2021). Building on this, Sequeira and Gouveia developed a multifaceted digital OSS platform (2022), but they found that managing the intricate network of interactions among stakeholders, their distinct offerings, expertise, and business models required more than a simple digital platform.

To address these complexities, the integration of blockchain technology and urban building energy modelling (UBEM) integrating blockchain technology holds promise. Blockchain's decentralized and immutable ledger system offers a secure and transparent platform for stakeholders in the home renovation ecosystem. It streamlines data sharing and transactions between renovation providers, homeowners, and government agencies, reducing administrative burdens and dispute risks. Smart contracts automate agreements, payments, and compliance checks, further enhancing efficiency. Moreover, blockchain's data security features ensure data integrity and confidentiality, fostering trust among all parties. Urban building energy modelling engines are utilized for analysing urban energy-related scenarios at a district or a city level. Building data availability as inputs of UBEMs is one of these tools using challenges. Providing BIM models of the city’s buildings could help UBEM stakeholders to have more accurate outputs. Because of BIM multidisciplinary workflow, to facilitate BIM communication some researchers are trying to define a new workflow between BIM role players. Having BIM models of buildings by using UBEM leads to accurate simulation results.

A comprehensive evaluation of prior strategies is vital to grasp the current potential of one-stop-shop business models in the market. Given the evolving nature of this model, assessing past strategies becomes crucial to identify success factors and hindrances within its adoption across EU nations (Sosna, Rodríguez, & Velamuri, 2010). This study aims to pinpoint opportunities along the customer journey for home renovation and, guided by the triple helix theory of innovation, analyse how adopting such business practices can be optimized. The proposed approach involves utilizing digital tools to address challenges encountered throughout the customer journey during home renovation. The research question in focus here is “**How can the integration of digital tools in the homeowner customer journey for a one-stop-shop business model for renovation promulgate climate-smart home renovation in the EU?**” To answer this question, this paper first employs a literature review to investigate the current landscape of the home renovation market. By identifying common characteristics contributing to OSS regime effectiveness and common weaknesses, the study aims to enhance administrative efficiency and user experiences. Based on past lessons, suggestions within the customer journey model suggested by Mainali et al. (2018) and

TurnKeyRetrofit (2019) are provided. Additionally, insights from innovation theory are used to assess the growth potential of these industries. It is also found that there is significant room of the development of a digital ecosystem, that requires participation of certain different stakeholders for its development. Based on the identified areas of improvement, a triple helix model for innovation is proposed for further development within the digital platform sector for furthering OSS implementation in Europe.

2 Structure of the literature review

Clarivate Web of Science (WoS) and SCOPUS were used to collect journal and conference articles. The search was limited to English language journal and conference papers. The papers were then ranked by the number of citations and the top 10% were isolated. Papers without strong relevance to the topic at hand were then removed, along with duplicate results present in both search engines, and the remaining papers were analysed. The search terms used with these search engines are presented in Appendix 1.

2.1 Findings from the literature review

The creation of a digital platform is not a wholly novel solution as there have been numerous instances where such solutions have been implemented already (Sequeira & Gouveia, 2022). For increasing participation, creating a digital ecosystem can be useful. Valdez-de-Leon (2019) posits that the creation of a successful digital ecosystem must possess the following elements:

- **The platform** needs to be openly accessible; modular and compatible with multiple different axillary components; and reliable and secure to ensure trust from different types of users.
- **The network effects**, the ecosystem needs to perpetuate itself and attract more end-users and more participants. To do this, it is necessary to create right financial incentives for each of the stakeholders involved and how participation within this ecosystem is more beneficial than not participating in it or participating in a competing ecosystem. In this case, this would mean presenting a business model that has an in-built financial incentive for SMEs participating within the scheme and for financial institutions like banks and other loan providers as well as general consumers.
- **Market expectation** Participation in an ecosystem relies heavily on the number of people that the user expects will participate in rather than its current state (Eisenmann et.al. 2007 cited in Valdez-de-Leon 2019).

2.2 Integration of auxiliary tools

Digitalisation of the ecosystem can have numerous implications beyond increasing ease of access for general consumers. There are numerous technical factors that can be integrated to improve upon the digital platform to augment the abilities of the platform. The inclusion or usage of these tools impacts directly the barriers discussed in Table 3. Beyond the need for increasing accessibility for general consumers to the platform, which may be achieved through a solution as simple as implementing application programming interfaces (APIs) (Valdez-de-Leon 2019), the platform needs to sustain a strong supply chain network, requiring a well-integrated database allowing stakeholders to make relevant business decisions in a timely manner (Nouwailati & Al-Habibi, 2022); this can be supplemented/reinforced through addition of blockchain technology (BT) for greater transparency between different stakeholders (Qian & Papadonikolaki, 2020). The blockchain can be used for tracking (instantaneous information sharing and presenting history experience), contracting (minimising pre-project efforts), transferring (ensuring timely, accurate payments) (Wong et al., 2008 cited in Qian & Papadonikolaki, 2020). Integration of BT can

improve interaction between actors leading to improved contractual agreements and better information sharing, reducing interaction costs, and improving process efficiency (Paunov, 2012).

The platform needs to facilitate absorptive capacity of firms to improve their ability to adapt to new information, assimilate, and apply it for commercial purposes (Cohen & Levinthal, 1990, cited in Abourokbah, Mashat, & Salam, 2023). Increased absorptive capacity has positive impacts on digital capabilities (Vigren, Kadefors, & Eriksson, 2022) and supply chain agility and supply chain resiliency (Martinez-Sanchez & Lahoz-Leo, 2018). A supply chain can achieve better supply chain resiliency by fostering strong relationships with key suppliers and customers, running a well-integrated business process, enhancing employees' skills for improved performance (Abourokbah, Mashat, & Salam, 2023). Continuous technological upgrades and increased integration can enable swift and agile responses to the demands of the consumer (Shamout, 2020; Sigian, Tarigan, & Jie, 2021).

2.3 Characterisation of OSS regimes

Since 2007, 63 one-stop shop home renovation projects have been commissioned across the EU, 56 of which are currently active (European Commission, 2021). Directive 2018/844/EU provided an amendment advocating for the implementation of further OSS solutions for improved building performance and energy efficiency, with an amendment in 2020 further advocating for greater initiatives regarding adaptation to disasters caused by climate change (European Commission, 2018). More than 2/3rds of EU nations currently have some OSS project initiative in the renovation sector in place, but there is great variation in the level of coverage provided by each scheme (Bertoldi et al., 2021). Table 1 represents the main distinctions between different types of OSS projects.

Table 1 Distinctions between types of OSS regimes and opportunities for digitalisation

Attribute	Distinctions	**Possible digitalisation process**
OSS operating model (Bertoldi et al., 2021; European Commission, 2021)	**Facilitator model:** The OSS platform is used to create a space where the homeowner can be connected to a variety of different services; the government facilitates interaction between the different stakeholders.	Due to the limited functionality the OSS platform has under this model, inclusion of a simple website with database includes all necessary functionality and information required.
	Coordinator model: The OSS platform has an active role in overseeing different phases of the renovation process in addition to facilitating inter-party communication. The platform may be maintained either by a governmental organisation or a private firm.	Inclusion of simple database APIs in combination with a website would allow renovation and financial service providers to have access to a customer base of interested clients. Integrated UBEM-based APIs allow consumers to calculate savings (Hong et al., 2016), potential costs before consultation: time-saving opportunity for renovation service providers (Pardalis et al., 2022).
	Development model: The OSS platform is a complete ecosystem of	In addition to previous tools, implementation of a blockchain system allows for easier information sharing between renovation service provider (Vigren, Kadefors, & Eriksson, 2022), homeowner, and oversight agencies involved with follow-up (Paunov, 2012). This also improves trust between all actors due to much greater level of transparency

		with data as all stakeholders can obtain access (Abourokbah, Mashat, & Salam, 2023). Utilizing UBEM tool allows stakeholders to have synergy with each other actions (Buckley et al, 2021)
Operation mechanism (Bertoldi et al., 2021)	Operating through a local office with energy experts that collect data	
	Operated through an online tool for self-assessment	Improves access for younger homeowners and people living in suburban/outer areas (Bertoldi et al., 2021).

Some key issues were identified as the main barriers to the implementation of these OSS mechanisms for home renovation, presented in Table 2.

Table 2 Identified barriers to OSS and how digitalisation can be used to overcome them

Type of barrier	**Description**	**Aspects of digitalisation that can be used to overcome**
Economic	High initial investment costs (Schleich et al., 2021) with delayed benefits for the consumer (Schleich et al., 2016)	Energy savings and potential damage reductions can be calculated through UBEM-integrated tools (Hong et al., 2016), for calculation of returns and payback period, which can be used as an incentive for performing the renovation despite investment cost.
	Lack of ownership in case of renters, presenting low incentive for investment (Melvin, 2018)	-
	Lack of financial stability of the homeowner leading to loan denial (Schleich et al., 2021)	-
	Lack of relevant financial incentives provided for homeowner from the insurance provider (Bird and Hernández, 2012)	Integration of BT allows real-time updating of the home's financial status, possibility to instantaneously provide updates (Nouwailati & Al-Habibi, 2022). With the usage of UBEM tools, energy calculations can be made more accurately (Oraiopoulos, 2022)
Informational	Informational asymmetry between the homeowner, contractor, and governing body leading to lack of trust (De Wild, 2019; Wilson et al., 2015)	With constant update of information to web portal through API access and through access to blockchain (Valdez-de-Leon, 2019)
	Lack of relevant guidelines provided by municipal bodies regarding necessary renovations and pricing mechanisms (Juhola et al., 2014)	-
	Lack of cohesive platform for finding accurate information regarding home renovations (Pardalis et al., 2022)	With the creation of a web database, all information can be shared and recorded, and easily accessed through the API (Valdez-de-Leon, 2019) or for faster access through
	Lack of business model synergy between different firms (Bashir & Farooq, 2019)	Instantaneous updates from other firms operating within the same sphere allows greater absorptive capacity, so new opportunities to collaborate are created (Shamout, 2020)

In addition to this, Appendix 2 contains a list and description of numerous current BIM and UBEM tools that can be integrated into the customer journey for building renovation. While BIM models

contain more information regarding the functional characteristics of buildings, UBEM models provide information about energy consumption and thermal comfort (Armijo et al., 2022). The use of digital tools for renovation of buildings can be divided into two groups based on their complexity: the first group is used for primarily one-dimensional calculations and validation of previous calculations, while the second group can be used for more comprehensive and complex calculations. This information is presented in Appendix 2.

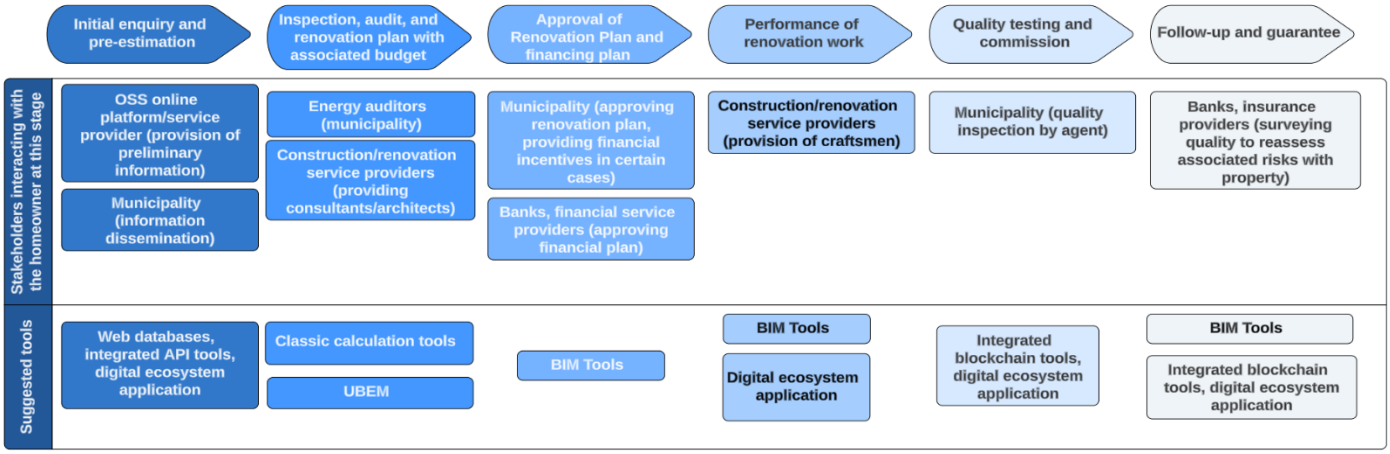

Figure 1 Adapted customer journey model (TurnkeyRetrofit, 2019; Mainali et al., 2018)

3 Implications for relevant stakeholders

The early stage of development for the OSS business models within the climate-smart renovation sector, coupled with the numerous stakeholders involved allows for the usage of analysis of the situation using the triple helix model of innovation when looking at potential integration for digital tools. Secondly, based on this it is also possible to identify where, based on the consumer journey of the end-user undertaking the home renovation process it is possible to integrate these new digital tools. The customer journey is a modified version created based upon the journey proposed by the Buildings Performance Institute of Europe (BPIE) as part of the TurnKeyRetrofit project (2019).

3.1 Contributions to the consumer value chain

Figure 1 addresses some modifications of the traditional home renovation customer value chain that was obtained from a project conducted at TurnKey Retrofit (2019). It integrates some of the tools discussed in the process as an attempt to optimise the process and increase participation from the main stakeholders that are involved in this interaction, namely municipal and governmental authorities, homeowners, and SME renovation service providers.

3.2 Triple helix model of innovation for a digital platform

With the need for innovation in digitalisation of the home renovation supply chain, it is important to acknowledge the necessity for contribution of certain stakeholders into the development of this digitalisation process (Etkowitz, 2022). The triple helix model of innovation presents the appropriate method of analysing the potential contributions of this platform as a platform with the proposed attributes does not exist yet in any form. With the ecosystem proposed, there is a great need for development of different aspects and fostering of the necessary relations between certain institutions.

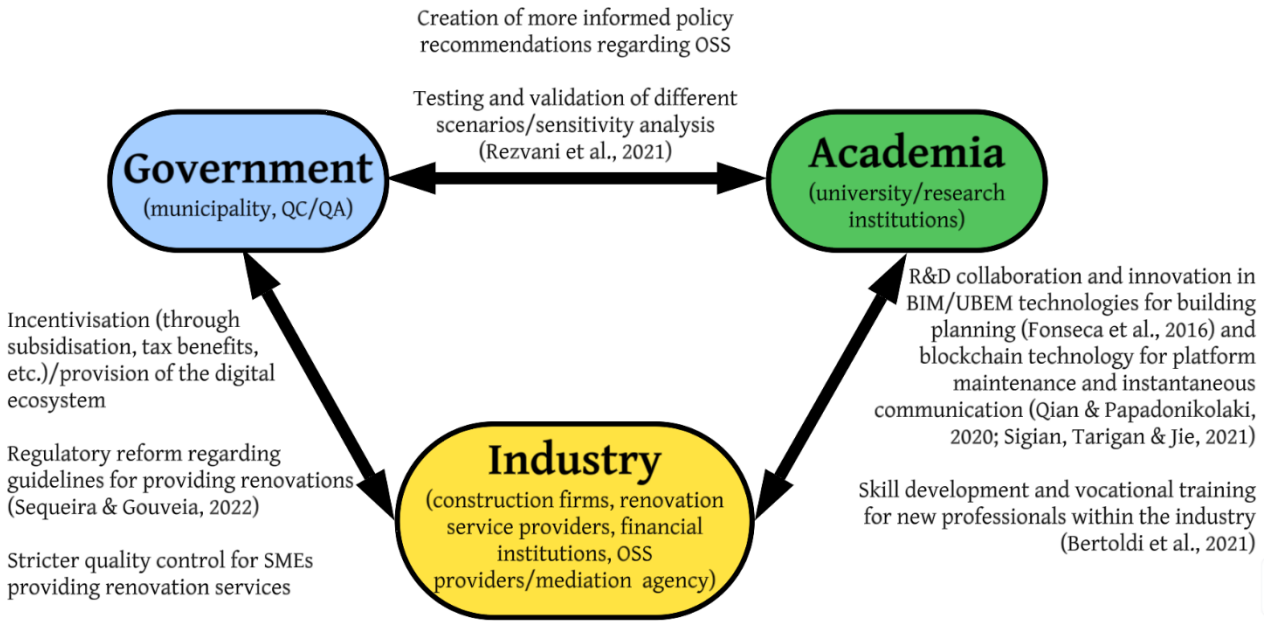

Figure 2 Triple helix model for the industry-academia-government (Etkowitz, 2003) nexus for digital ecosystem innovation

4 Conclusion and further remarks

This paper explores how digital tools can enhance the customer journey in a one-stop-shop home renovation process. Integrating a cutting-edge digital platform with emerging technologies fosters engagement among diverse stakeholders in the climate-responsive home renovation market. By leveraging APIs and blockchain, this integrated ecosystem overcomes barriers to widespread home renovation adoption. This approach enhances accessibility for consumers, aids decision-making through real-time data, and optimizes resource allocation via UBEM and BIM tools. Through the inclusion of APIs for data collection and blockchain technology for information storage, sharing, and security, the system allows for the centralized collection of extensive data. This data serves the dual purpose of continuous self-improvement of the system and ensuring accountabilities for all participants, thereby reducing uncertainty among stakeholders.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

Shashwat S. wrote the first draft and was involved with the literature review. Ahmad contributed to the collection of information on UBEM tools, some of the references, and with refinements in the second draft. Brijesh M and Krushna M provided guidance and input throughout the process. All authors discussed and reviewed the content of the manuscript.

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5 References

Abourokbah, S.H., Mashat, R.M. and Salam, M.A. (2023) 'Role of Absorptive Capacity, Digital Capability, Agility, and Resilience in Supply Chain Innovation Performance', *Sustainability*, 15(4), NA, available: https://link.gale.com/apps/doc/A743494220/AONE?u=anon~a8c72fa5&sid=googleScholar&xid=8a2aad05 [accessed 05 Aug 2023].

Armijo, A., Elguezabal, P., Lasarte, N., & Weise, M. (2021). A methodology for the digitalization of the residential building renovation process through open bim-based workflows. Applied Sciences, 11(21), 10429.

Bashir, M., & Farooq, R. (2019). The synergetic effect of Knowledge Management and business model innovation on firm competence. *International Journal of Innovation Science*, *11*(3), 362–387. https://doi.org/10.1108/ijis-10-2018-0103

Bertoldi, P., Boza-Kiss, B., Della Valle, N., & Economidou, M. (2021). The role of one-stop shops in energy renovation - a comparative analysis of OSSs cases in Europe. Energy and Buildings, 250, 111273. ISSN 0378-7788. JRC124675.

Bird, S., & Hernández, D. (2012). Policy options for the split incentive: Increasing energy efficiency for low-income renters. Energy Policy, 48, 506–514. https://doi.org/10.1016/j.enpol.2005.01.010

Buildings Performance Institute of Europe. (2019). Turnkey Renovation: Definition and Rating Scheme for High-Efficiency Energy Retrofitting Concepts for Residential Buildings (Report No. TR_D1.1_BPIE_30_08_2019_FV). Retrieved from https://www.turnkey-retrofit.eu/wp-content/uploads/TR_D1.1_BPIE_30_08_2019_FV.pdf

Buckley, N., Mills, G., Reinhart, C., & Berzolla, Z. M. (2021). Using urban building energy modelling (UBEM) to support the new European Union's Green deal: Case study of dublin Ireland. *Energy and Buildings*, *247*, 111115. https://doi.org/10.1016/j.enbuild.2021.111115

Building.co.uk. (2008). Government launches a one-stop shop for adapting to climate change. Retrieved from https://www.building.co.uk/news/government-launches-one-stop-shop-for-adapting-to-climate-change/3119252.article

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. Administrative Science Quarterly, 35, 128-152.

Daniotti, B., Masera, G., Bolognesi, C. M., Lupica Spagnolo, S., Pavan, A., Iannaccone, G., ... & Cucuzza, M. (2022). The development of a BIM-based interoperable toolkit for efficient renovation in buildings: From BIM to digital twin. Buildings, 12(2), 231.

De Wilde, Mandy. "The sustainable housing question: On the role of interpersonal, impersonal and professional trust in low-carbon retrofit decisions by homeowners." Energy Research & Social Science 51 (2019): 138-147. https://doi.org/10.1016/j.erss.2019.01.004

ETH, C. I. (2021). ENergy aware BIM Cloud Platform in a Cost-effective Building REnovation Context.

Etzkowitz, H. (2003). Innovation in innovation: The triple helix of university-industry-government relations. *Social Science Information*, *42*(3), 293–337. https://doi.org/10.1177/05390184030423002

European Commission. (2020). A Renovation Wave for Europe – Greening our Buildings, Creating Jobs, Improving Lives: European Commission Communication. Brussels: European Commission.

European Commission, Joint Research Centre, Boza-Kiss, B., Bertoldi, P., Della Valle, N., et al. (2021) *One-stop shops for residential building energy renovation in the EU : analysis & policy recommendations*. Publications Office. https://data.europa.eu/doi/10.2760/245015

Fonseca, J. A., Nguyen, T. A., Schlueter, A., & Marechal, F. (2016). City Energy Analyst (CEA): Integrated framework for analysis and optimization of building energy systems in neighborhoods and city districts. Energy and Buildings, 113, 202-226.

Hong, T., Chen, Y., Lee, S. H., & Piette, M. A. (2016). CityBES: A web-based platform to support city-scale building energy efficiency. Urban Computing, 14, 2016.

Juhola, S., Goodsite, M.E., Davis, M. *et al.* Adaptation decision-making in the Nordic countries: assessing the potential for joint action. *Environ Syst Decis* **34**, 600–611 (2014). https://doi.org/10.1007/s10669-014-9524-3

Langlais R (2009) Adaptigation. J Nordregio 4:2

Martinez-Sanchez, A., & Lahoz-Leo, F. (2018). Supply chain agility: a mediator for absorptive capacity. Baltic Journal of Management, 13(2), 264-278.

Melvin, Jesse. "The split incentives energy efficiency problem: Evidence of underinvestment by landlords." Energy Policy 115 (2018): 342-352. https://doi.org/10.1016/j.enpol.2017.11.069

Nouvel, R., Brassel, K. H., Bruse, M., Duminil, E., Coors, V., Eicker, U., & Robinson, D. (2015). SimStadt, a new workflow-driven urban energy simulation platform for CityGML city models. In Proceedings of International Conference CISBAT 2015 Future Buildings and Districts Sustainability from Nano to Urban Scale (No. CONF, pp. 889-894). LESO-PB, EPFL.

Nouwailati, K., & Al-Halabi, O. (2022). Leveraging Data to Establish Local Supply Chains: Rethinking Value Creation to Support Local Content in Saudi Arabia. KPMG. Available online: https://home.kpmg/sa/en/home/insights/2022/06/leveraging-data-to-establish-local-supply-chains.html

Oliveira, L., Fleury, A., & Fleury, M. T. (2021). Digital power: Value chain upgrading in an age of digitization. International Business Review, 30(6), 101850. https://doi.org/10.1016/j.ibusrev.2021.101850

Oraiopoulos, A., & Howard, B. (2022). On the accuracy of urban building energy modelling. Renewable and Sustainable Energy Reviews, 158, 111976.

Qian, X. (Alice), & Papadonikolaki, E. (2021). Shifting trust in construction supply chains through blockchain technology. Engineering, Construction and Architectural Management, 28(2), 584-602.

Rezvani, S., Neumann, M., Noordzij, J., Sušnik, M., Elagiry, M., & Pridmore, J. (2021). BIM-SPEED Inhabitant's App: A BIM-Based Application for Crowdsourcing of Inhabitants' Input in Renovation Projects. Environmental Sciences Proceedings, 11(1), 28.

Schleich, Joachim, et al. "Making the implicit explicit: A look inside the implicit discount rate." Energy Policy 97 (2016): 321-331. https://doi.org/10.1016/j.enpol.2016.07.044

Schleich, Joachim, Corinne Faure, and Thomas Meissner. "Adoption of retrofit measures among homeowners in EU countries: The effects of access to capital and debt aversion." Energy Policy 149 (2021): 112025. https://doi.org/10.1016/j.enpol.2020.112025

Sequeira, M. M., & Gouveia, J. P. (2022). A sequential multi-staged approach for developing digital one-stop shops to support energy renovations of residential buildings. *Energies*, *15*(15), 5389. https://doi.org/10.3390/en15155389

Shamout, M. D. (2020). The nexus between supply chain analytic, innovation and robustness capability: Does firm age matter? VINE Journal of Information and Knowledge Management Systems, 51, 163-176.

Siagian, H., Tarigan, Z. J. H., & Jie, F. (2021). Supply chain integration enables resilience, flexibility, and innovation to improve business performance in COVID-19 era. Sustainability, 13, 4669.

Sibileau, H. (2021) *DEEP RENOVATION: SHIFTING FROM EXCEPTION TO STANDARD PRACTICE IN EU POLICY*. rep. Brussels: Buildings Performance Institute Europe. Available at: https://www.bpie.eu/wp-content/uploads/2021/11/BPIE_Deep-Renovation-Briefing_Final.pdf (Accessed: 08 July 2023).

Sosna, M., Trevinyo-Rodríguez, R. N., Velamuri, S. R. Business Model Innovation through Trial-and-Error Learning: The Naturhouse Case. *Long Range Planning* **43**, 383-407 (2010). https://doi.org/10.1016/j.lrp.2010.02.003

Valdez-De-Leon, O. (2019). How to Develop a Digital Ecosystem: A Practical Framework. Technology Innovation Management Review, 9(8).

Vigren, O., Kadefors, A., & Eriksson, K. (2022). Digitalization, innovation capabilities and absorptive capacity in the Swedish real estate ecosystem. Facilities, 40(15/16), 89-106

Wilson, C., Crane, L., & Chryssochoidis, G. (2015). Why do homeowners renovate energy efficiently? Contrasting perspectives and implications for policy. Energy Research & Social Science, 7, 12–22. https://doi.org/10.1016/j.erss.2015.03.002

Wong, W.K., Cheung, S.O., Yiu, T.W. and Pang, H.Y. (2008), "A framework for trust in construction contracting",International Journal of Project Management, Vol. 26, pp. 821-829

Appendix 1

Search terms used for finding relevant literature

Topic	Web Of Science	Scopus
Previous OSS models and supply chain	one-stop shop renovation (Topic) and 2019 or 2020 or 2021 or 2022 (Publication Years)	TITLE-ABS-KEY (supply AND chain AND digitalisation) AND (LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018)) AND (LIMIT-TO (LANGUAGE , "English"))
New relevant digital tools	renovation digitalisation (All Fields) and 2023 or 2022 or 2021 or 2020 or 2019 (Publication Years) value chain digitalisation (All Fields) and 2023 or 2022 or 2021 or 2020 or 2019 TS=(digital platform AND one-stop shop AND deep renovation)	TITLE-ABS-KEY (value AND chain AND digitalisation) AND (LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018)) AND (LIMIT-TO (LANGUAGE , "English")) TITLE-ABS-KEY (renovation AND digitalisation) AND (LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR , 2018)) AND (LIMIT-TO (LANGUAGE , "English"))
Business model innovation, innovation theory, supply chain innovation	home renovation supply chain	TITLE-ABS-KEY (home AND renovation AND supply AND chain) AND (LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018)) AND (LIMIT-TO (LANGUAGE, "English"))
Home renovation digital tools	TS = ((building OR house OR home OR construction) and renovation and digital tool)	

Appendix 2

Projects	Tools	Description
BIM4Ren	BIM	Being developed as part of a joint European research effort with 23 partners from around Europe. The active participation of end users is critical in this project since it ensures that innovations are centred on user demands and actual requirements. The fundamental goal of the BIM4Ren project is to develop a set of digital tools that have been rigorously designed and tweaked to meet the unique needs of each user's typology. By doing so, the initiative hopes to provide a user-centred approach in which end users' viewpoints and feedback are central to the development process (Armijo et al., 2021)
BIMSPEED	BIM	Harmonised Building Information Speedway for Energy-Efficient Renovation has a clear and ambitious objective: to facilitate the adoption of BIM across all stakeholders. Its main aim is to significantly reduce the duration of deep renovation projects by a minimum of 30% (Rezvani et al., 2021)
ENCORE	BIM	(ENergy aware BIM Cloud Platform in a COst-effective Building Renovation Context) intends to expand refurbished stock in Europe and around the world by providing low-cost BIM technologies that cover the whole renovation life cycle. It incorporates all stakeholders, makes information transmission easier, and combines modern data collecting services like as LiDAR and UAVs (ETH, 2021)
BIM4EEB	BIM	(BIM-based Fast Toolkit for Efficient rEnovation in Buildings) aims to transform the renovation sector by developing an appealing and powerful BIM-based toolbox. This toolkit will provide comprehensive support to designers during the design and planning phases, enabling construction companies to execute their tasks efficiently and allowing service organisations to provide appealing building retrofitting solutions. Furthermore, BIM4EEB seeks to help both public and private owners by providing an easy-to-use tool that streamlines decision-making and asset management. This will be accomplished through the use of augmented reality and updated digital logbooks, which will improve the overall refurbishment process and its outcomes (Daniotti et al., 2022)
CityBES	UBEM	A district or city-scale efficiency initiative that focuses on energy modelling and analysis of a city's building stock. EnergyPlus is used by CityBES to simulate building energy use and savings from energy efficient retrofits. CityBES offers a variety of features for city planners, energy managers, building owners, utilities, energy consultants, and researchers (Hong et al., 2016)
CEA	UBEM	City Energy Analyst is a computer framework for analysing and optimising energy systems in neighbourhoods and municipal districts. This adaptable platform allows for the evaluation of energy, carbon, and financial benefits across numerous urban design scenarios, as well as the optimal implementation of distributed generating schemes (Fonseca et al., 2016).
SimStadt	UBEM	Provides procedures for analysing solar and PV potential, calculating energy demand and CO2 emissions, and creating and simulating refurbishment scenarios. These characteristics allow for complete and analytical assessments to aid in urban planning and decision-making processes (Nouvel et al., 2015).