The Role of the Entrepreneur in Driving Innovation in The Window Industry: from Traditional Structures to High-Tech Solutions

Serhii Kovalskyi[1]

Received: 2025-12-11
Accepted: 2026-01-14
DOI: https://doi.org/10.5281/zenodo.21226121

Abstract. The current research explores the entrepreneur as a key factor for innovation in the window industry, an industry that is undergoing a significant transformation due to smart innovations, energy efficiency requirements, and digitalization. Although the development of technologies, ranging from electrochromic glazing, thermochromic materials to smart window systems, has greatly developed the landscape of technological innovation, their uptake is uneven and especially among small and medium-sized enterprises (SMEs). From this perspective, we conclude these studies that window innovation depends not solely on technological availability but that entrepreneurial orientation, digital transformation, and organizational alignment are also essential for the innovation process to succeed in the window sector. The study builds on an empirical review of extant literature, proposing the Entrepreneurial Innovation Driver Model (EIDM) which is a framework that defines innovation as an interaction of three salient dimensions: entrepreneurial orientation, digital transformation capabilities, and technological adoption. The results suggest the role of the entrepreneur as a strategic integrator of mission-critical functions of strategic vision, operational functioning, and technological implementation. A major innovation gap identified by the study is between the potential of technologies and their actual application, which is largely the result of managerial and organizational barriers. In addition, the paper builds upon the preceding literature by providing a process-oriented framework for the exploration of innovation in the window industry while providing practical insights to SMEs who want to shift towards hi-tech, energy-efficient solutions.

Keywords: Entrepreneurial orientation, window industry, innovation, digital transformation, smart windows, SMEs, Industry 4.0, energy efficiency, technological adoption, strategic management.

[1] Faculty of Social and Humanities, Khmelnytsky Institute of Social Technologies of the Open International University of Human Development "Ukraine", Ukraine
E-mail: sergkovals@ukr.net
ORCID: https://orcid.org/0009-0005-9340-7364

1. Introduction

The window sector has been characterised by emphasis on manufacturing effectiveness, the long life and thermal insulation. But it has changed dramatically in the last decade to become a technology-led space tied to energy efficiency, sustainable lifestyles and digital connectedness. We shift from passive structural elements to active building performance system elements and light, heating, and energy control systems through the use of windows [9; 17].

Technology has led to this transformation, including smart windows with electrochromic, thermochromic and liquid crystal architectures [11; 14; 22]. Using advanced structures, energy efficiency has been optimized through the dynamic control of the environment of buildings, and a shift towards net-zero energy structures has been made [8; 15]. Meanwhile, improvements in glazing systems and façade integration have offered higher acoustic and thermal performance, also extending the functional dimensions of window solutions [2; 21].

However, the window space has seen little adoption of high-tech solutions; this in itself is also evidence of the uneven adoption of technology innovations in this space. A great number of enterprises, especially SMEs, still make use of conventional manufacturing system and have difficulty with bringing advanced innovations into the operation. This disparity suggests a fundamental problem of the technological innovation does not necessarily follow by means of its actual adoption.

Rather, innovation adoption has a far greater dependence on the managerial decision-making, organizational capabilities and strategic orientation to drive success by the different layers of organizational capacities and to the extent of innovation adoption, on its organizational capabilities and strategic direction. In this respect the entrepreneur´s role in shaping decision-making takes centre stage. Entrepreneurs are transformational, driving not only the direction but the way that innovation is being implemented, change is taken on the ground, on the ground. Evidence suggests that entrepreneurial orientation (innovative, proactive, and risky) are particularly determinant of firm performance and innovation results [1; 5].

Furthermore, digital transformation constitutes a critical infrastructure for the execution of innovation, allowing organisations to reorganize mechanisms, improve coordination, and build new business strategies [3; 19]. Yet, previous research frequently treats these three parts as distinct domains - entrepreneurship; digitalization; and technological innovation. There are also a lack of integrative theory systems which describe the interaction among them within specific industrial locations for example the window industry.

This gap impedes our ability to comprehend how innovation in reality is produced through the actual mechanisms. This paper contributes to the literature by conceptualizing the Entrepreneurial Innovation Driver Model (EIDM): a theoretical framework for explaining how an entrepreneurial orientation, digitisation and an increase in technology adoption interact as the source of innovation. The transition from traditional window systems towards modern technology solutions is a managerial one, and its impact upon technology is primarily, not exclusively, a technological and strategic one. Incorporating lessons from entrepreneurship and digital transformation in conjunction with construction innovation literature, this paper adds a more holistic understanding of innovation drives in the window industry, as well as providing some useful recommendations for firms aiming to improve competition in this technology driven context (See Figure 1).

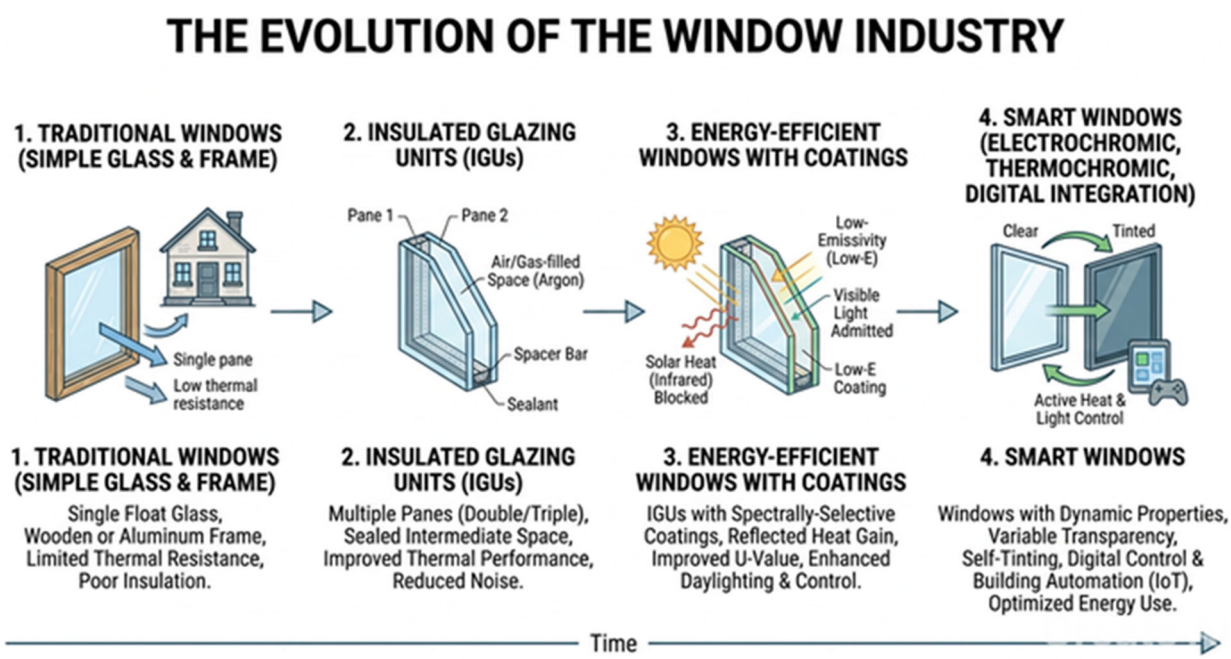

Figure 1. Industry Transformation Context.

2. Literature Review

2.1 Entrepreneurial Orientation and Innovation Performance

Entrepreneurial orientation (EO) is generally regarded as one of the main engines of innovation and success across all categories of a firm for the most part, and particularly of SMEs. EO includes critical dimensions of behavior and behaviorally constructs namely innovativeness, proactiveness, risk taking, and these dimensions together determine the ability of business owners to recognise and take advantage of novel opportunities [1].

There is empirical evidence that companies with high level of EO will have a better chance of making effective contribution to innovation and sustained competitive advantage [5]. However, EO-innovation relationship is not unique. Its external and internal relational factors have a great influence on it. Network ties also allow access to knowledge and resources thus enhancing innovation performance, like in the case of managerial relationships [12]. This is especially noticeable in the window industry where collaborating with suppliers, construction companies and technology companies to implement more flexible or sophisticated solutions is vital.

Then there's the interaction between entrepreneurial orientation, technical opportunism and organisational adaptability. By actively observing technology trends and engaging strategically with a variety of technological channels, firms can also more effectively turn opportunities into innovation solutions [12]. Meanwhile, firm qualifications and institutional positioning, as structured characteristics of different innovation resources, affect firm innovation capabilities as well in construction-related fields [16].

As a result, EO must take place not just as an internal trait, but a dynamic capability that functions in an ecosystem created by relationships, institutional constraints and technological opportunities.

2.2 Digital Transformation and SME Competitiveness

Digital transformation is becoming an important innovation accelerant in manufacturing and construction industry. It enables companies to reinvent their operational processes, strengthen decision-making capabilities, and innovate new business models [3; 19]. Cloud technology, data analytics, IoT systems and other digital innovations in SMEs support real-time coordination and efficiency of the value chain [4].

It is critically important to note that digital transformation need not just adopt technology but develop dynamic capabilities to facilitate the integration, adaptation, and reconfiguration of digital resources [7]. Digital leadership and organisational culture are pivotal in this process of innovation, for they affect which technologies are implemented and used in which manner.

The potential for innovation is expanded by digital platforms through the transformation of business models. They enable new types of value creation: customization, digital service integration, and greater customer engagement [20]. In the same line, it has been proven through empirical results that digital transformation drives businesses to innovate by shifting from product-oriented to solution-oriented offerings [10]. Furthermore, digital transformation drives competitiveness by providing operational flexibility and increased responsiveness to market shifts [4].

This is particularly important in industries which are project-based, very dynamic in nature and vary widely; such as window manufacturing industries. Overall, the literature has shown that digital transformation links entrepreneurial intention and technological implementation—which opens up the possibilities for firms to develop strategic vision into operations, and this is what makes it possible to realize those businesses (See Figure 2).

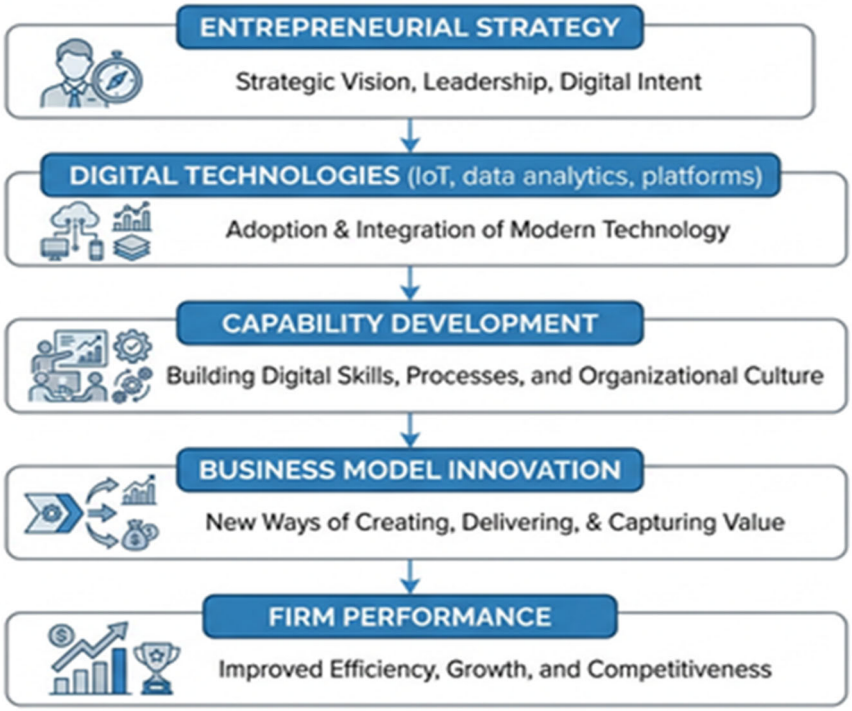

Figure 2. Digital Transformation as an Enabler

2.3 Technological Innovation in Window Systems

The window industry has undergone technological innovation at an unprecedented rate due to the demands for energy efficiency, sustainability, and increased performance. Smart window technology is one of the most game changing phenomena in this sector. These systems consist of electrochromic, thermochromic, and liquid crystal-based systems that enable dynamic control of light and heat transmission [11; 22].

Especially due to the application on solar radiation control under electrical stimulation, electrochromic windows have been particularly studied, contributing to an improvement on energy efficiency and comfort for the occupants [14]. Recent advances also utilize dual-band electrochromic systems capable of the selective modulation of visible and infrared light, and further achieving improved energy performance [15]. Self-powered smart windows, made independently, are newly developed. Such systems constitute a major advancement for net-zero energy buildings [8].

Thermochromic materials similarly provide adaptive responses in response to temperature changes leading to significant improvements in solar modulation capabilities [18]. To expand on the aforementioned technologies, electrically powered active smart windows have also been deployed, which employ electronic control systems, making them a part of glazing structures that respond in a system and control the system according to its environment [6]. Liquid crystal-based technologies offer new opportunities to dynamically control light and manage privacy simultaneously [22].

More than just smart technology, advancements in glazing systems and façade integration have also enhanced acoustic and thermal properties. Research shows that combining different analytic methods to gain optimal sound insulation for complex façades is important [2]. Similarly, hybrid glazing technologies help to improve the performance in buildings through providing more insulation and mitigating energy losses [21].

These trends indicate that window systems are no longer passive structures, but active, multifunctional elements of building envelopes, and need to be realized through a multi-sector synthesis of materials science, electronics, and engineering.

2.4 Energy Efficiency and Sustainability Imperatives

Energy efficiency is a key driver of innovation in the window industry. Windows contribute significantly to improving building energy performance by influencing heat transfer, solar gain, and ventilation dynamics [17]. Due to this, better window performance is essential for the attainment of sustainability goals and lowering energy consumption. Smart windows play a role in decarbonization strategies by alleviating the consumption of heating, cooling, and artificial lighting [9]. They are an effective means of dynamically regulating environmental conditions, fitting the needs of net-zero energy buildings [11].

Further advancements in glazing technology also have an impact on energy efficiency, with thermal insulation and solar control optimized. Research on hybrid housing systems indicates that the choice of glazing styles greatly contributes to the overall energy performance of buildings [21]. Also, more recently, smart materials technologies like electrochromic and thermochromic systems offer better control of energy flow in the building [14; 18]. In addition to energy saving, user comfort and building operation are also boosted by these technologies. Thus in the window industry sustainability concerns are not simply control but instead represent one of the key drivers for technological innovation and market differentiation.

2.5 Skills, Knowledge, and Construction 4.0 Transition

The shift towards high-tech window solutions is interrelated with the broader paradigm of Construction 4.0, which focuses on the utilization of digital technologies, automation, and data-informed processes in construction-related sectors [13]. This change will not only necessitate investment in technology but also will require radical changes in skills, knowledge, and organizational capabilities.

An important challenge found in the literature in particular, is that there are significant skills gaps. In SMEs [13], firms rarely have technical expertise (especially in advanced technologies) needed, and it restricts their success in adopting innovative solutions. These challenges are further compounded by the challenges posed by digital transformation, which mandates new approaches to data management, systems integration, and digital literacy [7].

The result is that continuous training and knowledge-building are indispensable elements of innovation strategies. Entrepreneurs, though, set the framework through which they can meet these challenges through the establishment of an environment of learning, funding for employee skills, and matching up organizations' abilities to technology. Their leadership guides businesses' successful transition from a conventional production model to integrated, technology-based systems.

2.6. Synthesis and Research Gap

The body of literature reviewed draws attention to three central dimensions of innovation in the window industry: entrepreneurial orientation, digital transformation, and technological advancement. Although there is wide research about each of these dimensions, there is a significant lack of integrative frameworks that can describe how they operate in practice (See Table 1). In particular, current studies usually study technological innovation apart from managerial decisions, as well as digital transformation, and rarely analyze specific sector use cases.

This leaves a gap in understanding how entrepreneurs make innovation operational in complex and interdisciplinary environments like the window industry. Moreover, despite the fact that the technological progress of smart windows has been well documented, their adoption remains uneven, particularly among SMEs. This implies that the obstacles for innovation are not technological but managerial and organizational.

It is essential to consider this gap, which informs the current study, which aims to jointly integrate entrepreneurial behavior, digital capabilities, and technological innovation within the conceptual framework. In doing so, it helps in a broader comprehension of innovation mechanisms in the window industry and their implementation (See Table 1).

Table 1. Literature Review Topic Synthesis

Author(s)	Research Focus	Key Contribution	Relevance to Study
Andriani et al. (2024)	Entrepreneurial orientation	EO improves innovation and performance	Defines strategic driver of innovation
Dwumah et al. (2024)	EO and SME performance	EO linked to firm success	Supports entrepreneurial role
Nugroho et al. (2024)	Networks & innovation	Network ties enhance innovation	Highlights collaboration importance
Shen et al. (2025)	Construction innovation	Organizational factors affect innovation	Links to industry structure
Cen et al. (2025)	Digital transformation	Drives corporate innovation	Enables implementation
Wang et al. (2025)	Digitalization & performance	Improves SME innovation outcomes	Supports digital layer
da Silva et al. (2025)	Digital competitiveness	Enhances efficiency	Operational relevance
Held et al. (2025)	Dynamic capabilities	Enables digital transformation	Explains adaptation
Xie et al. (2022)	Digital platforms	Drives business model innovation	Strategic transformation
Liu et al. (2024)	Business model innovation	Digital transformation shifts models	Market adaptation
Mustafa et al. (2023)	Smart windows	Key technology for energy efficiency	Technological foundation
Qin et al. (2024)	Electrochromic systems	Advanced light regulation	Innovation depth
Huang et al. (2024)	Self-powered windows	Supports net-zero buildings	Sustainability relevance

Sun et al. (2024)	Thermochromic materials	Solar modulation	Technology variation
Gadgil et al. (2024)	Active smart windows	Electrically controlled systems	Advanced integration
Zhou et al. (2025)	Liquid crystal windows	Dynamic light control	Expands tech scope
Riganti et al. (2025)	Energy-saving glazing	Improves building efficiency	Performance outcomes
Caniato et al. (2020)	Acoustic performance	Sound insulation in façades	Functional expansion
Żukowski et al. (2025)	Glazing systems	Impacts building performance	Applied context
Jørgensen et al. (2025)	Decarbonization	Energy-efficient buildings	Sustainability driver
Shrestha et al. (2025)	Window behavior	Impacts energy performance	System importance
Pittri et al. (2025)	Construction 4.0	Skills gap	Implementation barrier

3. Methodology

This research employs qualitative conceptual-analytical research design which seeks to explain how entrepreneurial action triggers innovation in the window industry. With an interdisciplinary domain entrepreneurship, digital transformation, and construction technologies, the study does not depend on primary empirical research data and instead constructs a theoretically based conceptual framework through a systematic literature synthesis.

3.1. Analytical Approach

The methodology procedure proceeds from three organized steps. First, a focused review of the peer-reviewed literature (2020–2025) was carried out in three main domains: (1) entrepreneurial orientation and SME performance, (2) digital transformation and business model innovation, and (3) technological advancements in window systems. Second, the included studies were subject to thematic analysis and coding to determine commonalities, causal effects, and structural relationships. Special emphasis was placed on the gap between technological capability and the real-world implementation of the technology. Third, the derived insights were combined into an integrated conceptual framework for cross-domain exploration of window industry-specific innovation processes.

3.2. Contribution to Scholar: Entrepreneurial Innovation Driver Model (EIDM)

The pivotal methodological contribution of this study is a formulation of the Entrepreneurial Innovation Driver Model (EIDM). This model understands innovation to be the outcome of an interplay between three interacting and dependent layers (See Figure 3):

- Entrepreneurial Orientation Layer (strategic dimension), indicating the innovativeness, the proactiveness, and risk-taking behaviour of the firm as key determinants of its innovation decisions [1; 5].
- Digital Transformation Layer (enabling dimension): encompasses the digital capabilities, platform integration, dynamic resource reconfiguration [3; 7], enabling firms to implement innovation by which innovation can be made operational.
- Technological Innovation Layer (output dimension) including the introduction of state-of-the-art window technology, such as smart glazing, electrochromic systems, and energy-efficient materials [11; 14].

The innovative aspect of the EIDM is that the entrepreneur is the fundamental integrator, who must connect strategic intentions to technological implementations through digital infrastructure. In contrast to linear innovation models, the EIDM takes a systemic view that innovation originates from coordinated operations at the various levels of an organization, technology, and the market.

3.3. Analytical Application

The EIDM is employed as an interpretative mechanism to study the shift from traditional window production to high-tech solutions. It helps the discovery of innovation bottlenecks especially for those related to managerial misalignment, limited digital capabilities, and insufficient integration of state-of-the-art technologies.

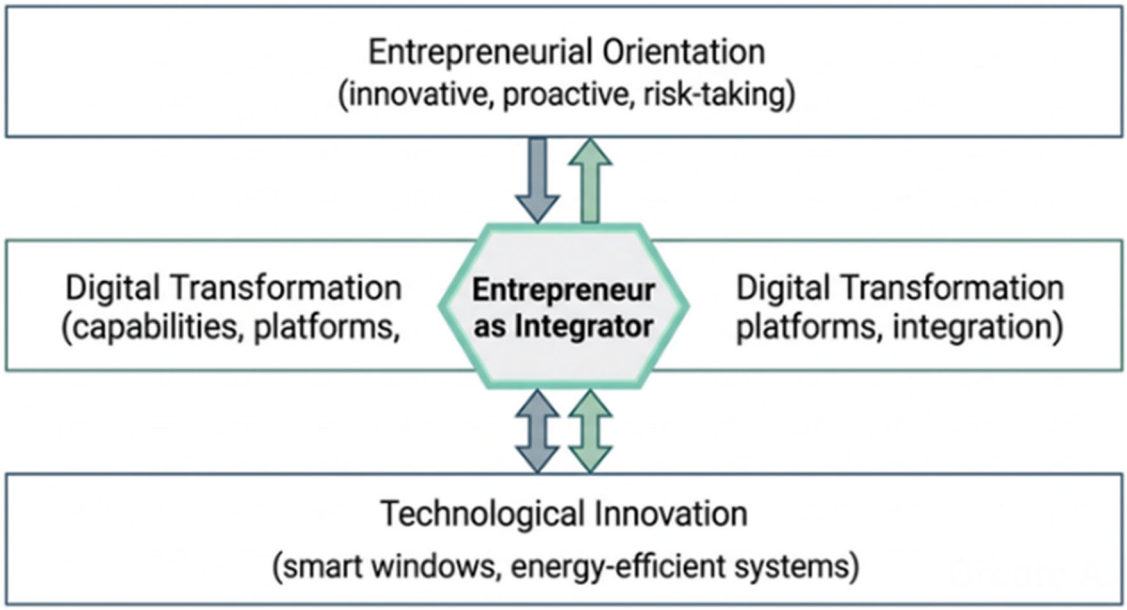

Figure 3. Entrepreneurial Innovation Driver Model (EIDM).

4. Results

The findings demonstrate that the innovation in the window industry is not purely technical but the convergence of entrepreneurial orientation, digital transformation, and technological capability via the structuration mechanisms introduced by entrepreneurial orientation that are explained within an Entrepreneurial Innovation Driver Model (EIDM). The results show that companies shifting away from traditional window production and towards high-tech technologies tend to have a steady trend of management involvement in all these dimensions.

First, entrepreneurial orientation is an active initiator of innovation. Firms with proactive leadership and a sense of calculated risk are far more prone towards exploring and implementing new window technologies. By way of example, investments in smart glazing systems, energy-efficient materials, and digitally enhanced production processes. Without that strategic intent, existing technologies can be underutilized, even with the presence of existing technology. SME contexts do not afford this resourceful mindset.

Second, digital transformation represents one of the key enablements, determining the extent to which entrepreneurial intent can be translated into operational results. Those companies with digital capabilities with process automation, data-driven decisions, and coordination via platform management better integrate complex technologies into their processes. By contrast, the lack of such capabilities leads to fragmentation between ambitions for innovation and their execution, which in turn results in less than optimal adoption of sophisticated solutions.

Third, technological innovations in the window industry are increasingly complex and interdependent in their system. Smart windows (electrochromic and thermochromic systems) need to be incorporated not only into materials but also into the building systems, control technologies, and the energy management frameworks. This complexity leads to a barrier to entry that can be resolved only through combined managerial effort and strategic alignments.

Among the prominent findings of this study is the identification of a structural innovation gap on which technological potential and operational implementation rests. This gap is more than technological though - it is organizational - as strategic intent and digital infrastructure do not align with operational capacity. According to the EIDM, successful innovation comes when these elements converge and it begins with the entrepreneur as the central coordinating agent (See Table 2).

The results overall indicate that the window industry transformation must rely on the entrepreneurial ability to leverage and align multiple dimensions of innovation as much as technological development to transform it into a high-tech, innovation-driven sector.

Table 2. EIDM Analytical Structure

EIDM Layer	Key Components	Role in Innovation	Identified Barrier	Outcome
Entrepreneurial Orientation	Innovativeness, proactiveness, risk-taking	Initiates innovation strategy	Risk aversion, limited vision	Determines innovation direction
Digital Transformation	Data systems, platforms, integration	Enables implementation	Lack of capabilities, fragmentation	Translates strategy into action
Technological Innovation	Smart windows, glazing systems, materials	Provides innovation output	High complexity, cost	Enhances product value
Integration Mechanism	Entrepreneur as integrator	Aligns all layers	Organizational misalignment	Successful innovation

The findings of this study support the key proposition that window industry innovation is not a purely technological endeavor, but a managerially managed and entrepreneurial-driven process. In the previous literature there has been a very thorough investigation of how entrepreneurial orientation, digital transformation, and smart technology could act as three different but co-existent contexts. This study adds to the literature by showing how they are not only structurally related but also how they play out through the Entrepreneurial Innovation Driver Model (EIDM).

An important implication of our findings is that entrepreneurial orientation is the primary influencer of innovation, the extent to which it facilitates is contingent on the ability of the firm to turn entrepreneurial purpose into action. This echoes prior findings that indicate positive correlation between entrepreneurial orientation and performance on innovation [1; 5], but amplifies this finding by evidencing that orientation is not enough. In the window industry where technological adoption demands a high level of cooperation and investment, entrepreneurial intention requires mechanisms that facilitate it to unfold.

Digital transformation is important here. It was shown that digital capabilities were the intermediate layer between strategy and execution, allowing firms to integrate to operationalize innovation with process integration, data-based decisions, and by real-time coordination [3; 19]. As such, digital transformation is not simply a technical overhaul but rather a structural reconfiguration of organizational processes, consistent with dynamic capabilities [7]. Businesses that do not develop these capabilities have a disparity between

innovation ambition and execution and end up adopting more fragmented or tokenized advanced technologies.

From a technological point of view, the growing complexity of window systems raises new strategic issues. Smart window technologies (exemplified by electrochromic, thermochromic and self-powered systems) represent an evolutionary jump from traditional products, demanding integration across many spheres—materials science, electronics, building systems [8; 11; 14]. These technologies have substantial advantages on energy conservation and sustainability [9; 15], but their implementation needs to be aligned with the firm's internal resources and external network role.

This results in one of the significant advancements of the study: the realization of a structural innovation disconnect. In contrast to the typical interpretations which propose that slow adoption of technology is due to cost or technological barriers, this research showed that the main constraint is organisational misalignment. But, it should be noted that firms commonly have access to cutting-edge technologies but do not have the managerial integration needed to effectively embrace them. This finding reflects broader discussions in the area of SME innovation, where limitations of resources are further compounded by gaps in capabilities [4; 13].

The EIDM seeks to provide an explanation of such a process by conceptualizing innovation as a multifaceted interaction between entrepreneurial orientation, digital transformation and technology adoption. In this model, the entrepreneur is more than decision-maker; he is also central integrator to align strategic vision with operational process and technological competence. This integrative role is particularly significant for SMEs, since their organizational structures are less formalized and their leadership influence is more direct.

An important implication is that networks and external collaboration drive them. Previous research points to the role of network ties [12] in the performance of innovation, and this study corroborates this theory. In the window industry, innovation often implies cooperation between companies. For example, suppliers of materials, vendors of technology, builders and construction providers who sell these materials need to partner with each other. In today's world, for example, entrepreneurs must take a network-oriented approach. They need to create partnerships in order to overcome internal limitations and take advantage of complementary resources.

This study thus also contributes to our understanding of industry transformation dynamics. The transition of conventional window technology towards high-fidelity solutions illustrates that trend towards high tech projects under the umbrella of Construction 4.0: Construction 4.0, with its focus on digital integration, automation, and data driven processes [13]. Through this lens, the window industry can be seen as a kind of industrial transformation within the context of which technological innovation and organizational/managerial transformation are symbiotic to technological innovation in this aspect, because the window industry is an example of a microcosm of industrial transformation of the process.

Crucially, the results also point to the role of sustainability as a contributor to, but also an inhibitor of, innovation through its own drivers and constriction. Energy efficiency-based demands and decarbonisation targets constitute strong motivation for advanced window technology application [9; 17]. But the challenge is, it is the same requirements that make innovation more complex and the industry is forced to weigh regulatory needs, technology adoption and financial sustainability. This highlights the need for strategic focus and strategic planning.

On a theoretical level, EIDM contributes to the literature by providing a process-theoretical model of the process to be adopted, which combines different domains that remain fragmented. It changes analysis of innovation factors from static to dynamic perspective –

how these factors interrelate over time. This allows for a more realistic modeling of processes of innovation from a range of complex, interdisciplinary fields.

Practically, according to the research companies that would like to innovate might set their strategic objectives on the capability improvement of their capabilities rather than on the technology acquisition. Investment in the digital infrastructure, training capacity and the organisation alignment is necessary to generate efficient innovation. It's up to entrepreneurs to also be trained in strategic vision and leadership if they want to coordinate effectively these efforts and steer through the intricacies of technological change.

And to conclude, the discussion makes it clear that when a big technological breakthrough is not the end of the line for the window industry, it is just as easy to say when the key to the success of business is to align strategy, technology, and organization into an integrated innovation path. EIDM offers a theoretical, as well as practical, framework for explaining and steering this process.

6. Conclusions

The insights from this study show that innovation in the window business is fundamentally powered by entrepreneurial initiative and not based solely on technological availability. Although developments in smart window technology and energy-efficient systems offer great opportunities, their successful uptake is conditioned on harmonizing strategic intent, digital capabilities, and operational processes of firms. The Entrepreneurial Innovation Driver Model (EIDM) proposed is a comprehensive framework that provides an understanding of this alignment by positioning the entrepreneur as the central integrator of innovation.

This research shows the key barrier to innovation cannot be technological, rather management coordination and capability development. In addition to these points, the study extends the existing literature by linking entrepreneurship, digital transformation, and technological innovation in a particular industrial environment. For practitioners, it demonstrates that innovation success should primarily rely on leadership, digital integration, and strategic alignment. Future studies should be intended to empirically validate the EIDM as well as study its applicability to different sectors of the construction and manufacturing industries.

References

1. Andriani, C., Nurhayati, M., & Ambarwati, R. (2024). Entrepreneurial orientation, business performance, and innovation in SMEs: A sustainable perspective. Cogent Business & Management, 11(1), 2302194. https://doi.org/10.1080/23311975.2024.2302194
2. Caniato, M., Bettarello, F., Marsich, L., & Fausti, P. (2020). Sound insulation of complex façades: A complete study combining different numerical approaches. Applied Acoustics, 168, 107484. https://doi.org/10.1016/j.apacoust.2020.107484
3. Cen, T., Liu, Y., & Zhang, Y. (2025). Digital transformation and corporate innovation in SMEs. Systems, 13(7), 551. https://doi.org/10.3390/systems13070551
4. Da Silva, A., Rodrigues, R., & Fernandes, C. (2025). How digital technologies enhance competitiveness in manufacturing SMEs. Operations Management Research. https://doi.org/10.1007/s12063-025-00576-8
5. Dwumah, P., Agyapong, A., & Afrifa, G. A. (2024). Association between entrepreneurial orientation and the performance of SMEs: The moderating role of network ties. Cogent Business & Management, 11(1), 2302192. https://doi.org/10.1080/23311975.2024.2302192
6. Gadgil, C., et al. (2024). Electrically powered active smart windows. Smart Materials and Devices. https://doi.org/10.1016/j.smae.2024.100004

7. Held, P., et al. (2025). Boosting SMEs' digital transformation: The role of dynamic capabilities in cultivating digital leadership and digital culture. Review of Managerial Science. https://doi.org/10.1007/s11846-025-00919-5
8. Huang, R., et al. (2024). Self-powered electrochromic smart window helps net-zero energy buildings. Nano Energy. https://doi.org/10.1016/j.nanoen.2024.109739
9. Jørgensen, B. N., et al. (2025). Energy efficiency and decarbonization strategies in buildings. Applied Sciences, 15(21), 11660. https://doi.org/10.3390/app152111660
10. Liu, K. P., et al. (2024). Digital transformation driving SME business model innovation. Journal of Small Business Management. https://doi.org/10.1080/00472778.2024.2345678
11. Mustafa, M. N., et al. (2023). Smart window technology and its potential for net-zero buildings: A review. Renewable and Sustainable Energy Reviews, 182, 113405. https://doi.org/10.1016/j.rser.2023.113405
12. Nugroho, Y., et al. (2024). Entrepreneurship orientation and management ties in the relationship between technical opportunism and innovation performance. Cogent Business & Management, 11(1), 2413393. https://doi.org/10.1080/23311975.2024.2413393
13. Pittri, H., et al. (2025). Knowledge, training, and skills gaps for emerging construction 4.0 technologies. Journal of Green Building. https://doi.org/10.1080/15578771.2025.2587943
14. Qin, L., et al. (2024). Advancements in dual-band electrochromic smart windows: Exploring single-component materials for sustainable building solutions. Solar Energy Materials and Solar Cells. https://doi.org/10.1016/j.solmat.2024.113353
15. Riganti, M., Li Castri, G., Serra, V., Manca, M., & Favoino, F. (2025). Energy saving potential of advanced dual-band electrochromic smart windows for office integration. Energy and Buildings. https://doi.org/10.1016/j.enbuild.2024.113902
16. Shen, D., et al. (2025). Qualification and construction enterprise innovation. Construction Management and Economics. https://doi.org/10.1080/01446193.2025.2486748
17. Shrestha, B., et al. (2025). A review of the importance of window behavior and its implications for building performance. Architecture, 5(4), 100. https://doi.org/10.3390/architecture5040100
18. Sun, M., et al. (2024). Energy-efficient smart window based on a thermochromic hydrogel with adjustable critical response temperature and high solar modulation ability. Polymers, 16(8), 494. https://doi.org/10.3390/polym16080494
19. Wang, S., et al. (2025). Digital transformation and innovation performance in small and medium-sized enterprises. Systems, 13(1), 43. https://doi.org/10.3390/systems13010043
20. Xie, X., et al. (2022). Digital platforms and SMEs' business model innovation: Exploring the mediating mechanisms of capability reconfiguration. Industrial Marketing Management, 103, 416–430. https://doi.org/10.1016/j.indmarman.2022.03.012
21. Żukowski, M., et al. (2025). Study of various types of glazing in a building constructed using hybrid technology with a large window area. Applied Sciences, 15(8), 4488. https://doi.org/10.3390/app15084488
22. Zhou, Y., et al. (2025). Recent progress in liquid crystal-based smart windows. Photonics, 12(8), 819. https://doi.org/10.3390/photonics12080819