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Barriers to the digitalisation and innovation of Australian Smart Real Estate: A managerial perspective on the technology non-adoption

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ABSTRACT

The real estate sector brings a fortune to the global economy. But, presently, this sector is regressive and uses traditional methods and approaches. Therefore, it needs a technological transformation and innovation in line with the Industry 4.0 requirements to transform into smart real estate. However, it faces the barriers of disruptive digital technology (DDT) adoption and innovation that need effective management to enable such transformation. These barriers present managerial challenges that affect DDT adoption and innovation in smart real estate. The current study assesses these DDTs adoption and innovation barriers facing the Australian real estate sector from a managerial perspective. Based on a comprehensive review of 72 systematically retrieved and shortlisted articles, we identify 21 key barriers to digitalisation and innovation. The barriers are grouped into the technology-organisation-external environment (TOE) categories using a Fault tree. Data is collected from 102 real estate and property managers to rate and rank the identified barriers. The results show that most of the respondents are aware of the DDTs and reported AI (22.5% of respondents), big data (12.75%) and VR (12.75%) as the most critical technologies not adopted so far due to costs, organisation policies, awareness, reluctance, user demand, tech integration, government support and funding. Overall, the highest barrier (risk) scores are observed for *high costs of software and hardware* (T1), *high complexity of the selected technology dissemination system* (T2) and *lack of government incentives, R&D support, policies, regulations and standards* (E1). Among the TOE categories, as evident from the fault tree analysis, the highest percentage of failure to adopt the DDT is attributed to E1 in the environmental group. For the technological group, the highest failure reason is attributed to T2. And for the organisational group, the barrier with the highest failure chances for DDT adoption is the *lack of organisational willingness to invest in digital marketing* (O4). These barriers must be addressed to pave the way for DDT adoption and innovation in the Australian real estate sector and move towards smart real estate.

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1. Introduction and background

The real estate sector is a key contributor to global economies. According to PWC (2018), global real estate transactions reached $873 billion for commercial properties in 2017. In 2019, commercial real estate was valued at about $30 trillion and residential property at $160 trillion (ecyY, 2019; Ullah and Sepasgozar, 2020). It accounts for 75% of the total value of the global property. This shows huge investment potential and attraction for global real estate investors (Kumar et al., 2019). As per the Direct (2020) report, between February 2019 to February 2020, the house price index in Australia rose by 6.1%, with a monthly rise of 1.1%. Further, in terms of the median house prices of the major Australian cities, Sydney has seen the highest increase of 10.9%, followed by Melbourne (10.7%), Canberra (5.0%), Darwin (4.1%), Brisbane (1.9%) and Perth (0.4%), making the national major property price rise of 7.3%. Other major cities, such as Adelaide and Hobart, saw a decrease of 4.0% and 7.8% in property prices (ABS, 2020). According to realestate.com.au, based on the data reported between May 2019 to May 2020, the Australian property and real estate sector has been doing well with a national increase of 4.81%in the property prices. State-wise, New South Wales (NSW) saw an average increase of 9.17% in the property prices, Victoria (VIC) with 5.68% increase, Queensland (QLD) with 3.99%, Western Australia (WA) with 0.7% and Tasmania (TAS) with 12.1% increase. The only state to notice a decline is that of the Northern Territory (NT) that saw a decline of 0.85%. However, this decline may be due to the state's lack of data points as data is available for only two regions in this state. According to CBRE (2020), Sydney's forecasted GDP shows a 2.3% increase for real estate and 2% for the overall NSW economy. The changes will be driven by the residential markets and high levels of government infrastructure development spending. The spendings are forecasted to be dominated by disruptive digital technologies and innovation-oriented entrepreneurial ventures (Fields and Rogers, 2019).

Digital technologies are at the forefront of global innovation and disruption in multiple sectors. From specialised fields such as nanotech, quantum biology and nutrigenomics to simple day-to-day activities and recreations such as cell phones and smart gadgets, disruptive digital technologies (DDTs) are pervasive (Iivari et al., 2020; Low et al., 2020). While the world faces the impacts of digital disruptions, fields like real estate lag the technology curve by over five years (Ullah et al., 2018) and the adoption of digital technologies is not up to the mark, particularly in the Australian real estate sector (Shaw, 2018). Though there is potential for disruption in real estate (Ullah and Sepasgozar, 2020; Ullah et al., 2018), the state of practice is marred with challenges mainly due to the traditional mindsets of the real estate managers (Saull et al., 2020). However, it must change if this sector aims to transform into a smart sector in line with industry 4.0. (Ullah et al., 2018). Hence, there is a strong need to study and explore the potential of various technologies in the real estate sector (Low et al., 2020; Sepasgozar et al., 2019; Ullah et al., 2019). Further, the barriers to their adoption should be investigated and a mitigation framework proposed to tackle this serious yet ignored issue. This will bring higher productivity and improved quality of service for all the stakeholders.

The literature on barriers to DDT adoption and innovation is scarce. Despite the fact that these technologies have been explored by various studies in real estate and smart cities (Kim et al., 2018; Munawar et al., 2020; Sinaeepourfard et al., 2018; Stone et al., 2018; Ullah et al., 2018; Yang et al., 2019). The key focus of these relevant studies is user perspective and reasons for their adoption. But the managerial perspective is almost unexplored. It must be explored to unearth the pertinent reasons behind the non-adoption of DDTs in real estate. As the people in the business, managers are directly affected by the lack of utilisation of real estate services by the users. Thus, it is expected that the managers must be inclined to adopt these technologies as the users prefer them (Ullah et al., 2019, 2018). This makes it even more important to know the point of view of managers and the reasons behind their reluctance to adopt digital technologies in the face of obvious advantages. The lack of literature on this important aspect of DDT adoption and innovation provides a serious research gap. So, the current study targets this gap and explores the non-adoption of disruptive digital technologies from a managerial perspective in the Australian real estate sector. The top technologies available and their awareness levels have also been captured and the impediments to their adoption highlighted. Further, using a fault tree that considers DDT non-adoption as a fault, the key barriers have been quantified to show the individual contribution to the non-adoption of digital technologies.

Additionally, risk matrices are used to quantify different risks and barriers in managerial and behavioural studies (Knutson and Huettel, 2015; Ni et al., 2010). These matrices have been used to quantify and place the barriers in different matrix zones in various studies. These studies include evaluation of safety barriers performance (Hefaidh et al., 2019), analysis of factors affecting the success of oil and gas construction projects (Kassem et al., 2019), risk assessment module for a metropolitan construction project (Samantra et al., 2017) and assessment of natural gas spherical tank (Luo et al., 2018). The barriers are organised in three zones in the matrix as per their criticality: the green zone containing barriers with lower scores or criticality, the yellow zone containing barriers with medium scores or criticality and the red zone containing very critical barriers. Placing the risks or barriers in pertinent zones helps the management team to develop appropriate responses. For barriers in the green zone, no extensive efforts are required and these should be monitored to note any abrupt changes that may require senior management involvement. For barriers in the yellow zone, regular monitoring and some follow up are required as these barriers can convert into critical barriers if not managed. The barriers in the red zone are the most critical ones and must be proactively managed and responded to (Kassem et al., 2019; Knutson and Huettel, 2015; Ni et al., 2010). Without a proper response plan and active implementation, these barriers can have devastating effects on the projects. Thus the resources can be assigned to the barriers based on their order of critically: Red > Yellow > Green (Ullah et al., 2016). Such classification can help the management allocate resources to key barriers and develop proactive plans for high-priority barriers. In real estate studies, risk matrices have been used for real estate logistics (Wang, 2021), commercial real estate development (Thilini and Wickramaarachchi, 2019), risk allocation in public–private partnerships in real estate and others. But not in the adoption of DDTs in real estate, providing a research gap.

Risk matrices are aided through fault tree analysis (FTA), which is a renowned technique for risk management. FTA is a well-developed method for understanding how a system can fail (Hsu et al., 2020). It helps study root-cause problems in a system and is a widely used modelling method for risk analysis. It can show the cause and effect relationships among the tree structure events due to its logical, structured diagram. It begins with a "top event" that is to be analysed and is generally displayed as a rectangle. The related events based on logical relations are drawn below, which branch downward in the shape of a tree to their root causes until all possible basic events are reached (Hinrichs and Buth, 2019). Once the top event is identified, the next step is to identify intermediate events. This can be any event except the top event that could be broken into events causing it. This process continues until all root causes are identified. These are named "basic events" and "gate events" and show the lowest level in a fault tree structure. The relationships between all events starting from the top to the basic events are described through logical gates such as AND, OR, or other gates (Shoar and Banaitis, 2019). The failure probability analysis is a dictating factor in most human decisions regarding decision analysis. Such assessments can be done through the FTA. It can also be used to connect any unexpected event to individuals or other higher-level events in the tree. Thus, the probability of occurrence of a specific failure or hazard can be assessed. It provides a qualitative model for a good understanding of the causes of unwanted events. It can be quantified to obtain additional information about the probability of occurrence of any event from top to bottom. Such risk assessments and prioritisation can help develop preventive plans for non-adoption or proactive plans for adoption of various DDTs in real estate.

FTA has been used in various domains of science, such as risk assessment of chemical storage tanks (Yazdi et al., 2017), self-healing in distributed automation systems (Dai et al., 2018), risk assessment of river basins (Gachlou et al., 2019), waste management (Makajic-Nikolic et al., 2016), reliability study of the motor system in electric vans (Shu et al., 2019) and others. It has been used in the construction domain to identify and prioritise the most influencing factors on labour productivity in a construction project (Shoar and Banaitis, 2019) and understand and visualise schedule deviations in construction projects (Hsu et al., 2020). Similarly, it has been extensively used in smart cities context such as assessing collapsed energy systems (Kishita et al., 2017), city administration issues and missing observations (Sasu et al., 2016), cyber risk mitigation of the industrial IoT (Falco et al., 2018), evaluation of distributed stream processing frameworks (Nasiri et al., 2019), reliability analysis of hybrid renewable energy system (Khare et al., 2019), risk assessments in smart city sensor network applications (Hinrichs and Buth, 2019) and others (Lytras et al., 2021). However, the barriers to the non-adoption of DDTs in smart real estate are not explored through FTA. This gap is targeted in the current study. The closest attempt to assess the non-adoption of technologies is provided in Wolverton and Cenfetelli (2020). However, they focused on user behaviour of generic non-adoption and did not utilise FTA for smart real estate DDT adoption.

Overall, this study has the following objectives:

1. To highlight the key barriers in DDT adoption and innovation in the Australian real estate sector.
2. To develop a conceptual fault tree and link the barriers to the tree for a holistic assessment of the reasons for the non-adoption of DDTs.
3. To investigate the awareness levels of the Australian real estate managers regarding DDTs and their innovation.
4. To develop a risk matrix and allocate the barriers to pertinent quadrants based on risk scores.

This study is a novel approach to capture and assess the barriers to the digitalisation and innovation of the Australian smart real estate sector from a managerial perspective. Previous studies have not captured this at global or local levels, making this the first of its kind study to target this novel area. Further, the risk matrix, the associated FTA and classification of barriers in the TOE categories have not been reported for the Australian real estate context. It is targeted in the current study, making it a novel and innovative approach to capturing managerial perceptions of DDT adoption barriers. This study has perks for both real estate users and managers where the DDTs can satisfy the users and increase the business for managers when adopted. Accordingly, it is expected that the study will attract a wider audience ranging from real estate users, agents, managers, property developers and managers, strata and facility managers, smart city developers, technology enthusiasts, urban planners and wider interdisciplinary researchers from the academic community.

1.1. Digital disruptive technologies and their applications in smart real estate

Plenty of digital technologies are introduced in the global real estate sector. From the disruptive big9 to sector-specific domains such as digital twins and BIM, DDTs have been explored by different studies (Saull et al., 2020; Shirowzhan et al., 2020). These DDTs aim to transform traditional real estate into smart real estate.

As defined by Ullah et al. (2018), smart real estate is "a property or land that uses various electronic sensors for collecting and supplying data to its service users, agents and real estate managers to manage assets and resources efficiently". It is user-centric, sustainable and leverages DDTs. These features are integrated to attain holistic benefits. Smart real estate is a technology-dependent domain, just like its doppelganger smart cities (Ullah and Sepasgozar, 2020). Accordingly, various technologies have been introduced and studied in relevant contexts to help real estate users make better, informed and regret-free decisions (Low et al., 2020; Ullah et al., 2016, 2019, 2018).

Big9 technologies have been introduced and their applications are discussed in the real estate sector (Ullah et al., 2018). These include drones and Unmanned Aerial Vehicles (UAVs), the internet of things (IoT), clouds, software as a service (SaaS), big data, 3D scanning, wearable technologies, virtual and augmented realities (VR and AR), and artificial intelligence (AI) and robotics. These technologies are at the centre of smart real estate endeavours and can enable real estate users or service consumers in decision-making (Tupikovskaja-Omovie and Tyler, 2020). They can also help address the needs of four key stakeholders: consumers, agents and associations, government and regulatory authorities and complementary industries. For example, the needs of a government, such as economic growth, ethical checks, standards, policy implementation and privacy and information protection, can be managed through IoT, big data and clouds to shape positive user perceptions that will enhance their trust in technologies (Ghouri and Mani, 2019).

Similarly, VR and AR, SaaS, 3D scanning, drones, AI and robotics and wearable techs can aid the needs of referrals, networking and reputational enhancements for agents, managers and complementary industries (Ullah et al. 2019). Further, these big9 technologies can be used for addressing all the basic needs of smart real estate stakeholders, such as buy/sell or rent, regulations and protection and business profits. Also, these can provide immersive experiences such as neighbourhood insights, price and costs reduction, mortgage management, market insights and awareness, proximity to amenities calculations, house layout and design visualisation, managing taxes and returns and others (Ullah et al., 2018).

Smart digital marketing technologies have been used for sustainable property development to enable companies to obtain real-time customer insights and create and communicate value for customers more effectively (Low et al., 2020; Sun et al., 2020). This is achieved through technological models such as the marketing technology acceptance model (MTAM) for digital marketing strategy and organisational capability development. Using these technologies, strategies like creating real-time interactions, creating key performance indicators to measure digital marketing and personalising and encouraging innovation in digital marketing are facilitated to adopt digital technologies. Munawar et al. (2020) proposed a framework for implementing big data in smart real estate and smart city disaster management. They argue that big data can address customer grievances related to the poor quality of real estate information that will increase customer satisfaction. Further, data from social media, drones, multimedia and search engines can be used to tackle natural disasters such as floods, bushfires and earthquakes and plan emergency responses in the smart cities.

Other technologies used as enablers for smart real estate include digital twin and CyberGIS (Shirowzhan et al., 2020). These can be used for improving connectivity and measuring the impact of constructing infrastructure in smart cities. These DDTs enable digital transformation and technology adoption by smart citizens when coupled with advanced tools such as mobile scanners, geospatial AI, UAVs, geospatial AR apps and light detection in smart cities. Similarly, blockchain is another important DDT being investigated and applied to the smart real estate sector (Ullah and Al-Turjman, 2021). It has been used for relational value calculation, land registration, enhancing trust in real estate, digital rebuilding and smart contracts in real estate (Karamitsos et al., 2018; Linoy et al., 2020). Other technologies include network and datacentre automation, photonic quantum computing, platform economics, renewables including hydrogen for mobility and storage, mixed reality, click funnels and others (Mora et al., 2018).

1.2. Barriers to adoption of DDTs in real estate

While the benefits of technological innovations and DDT adoption are evident, there are many barriers to adopting these technologies. These barriers range from technological aspects and capabilities to human resources and organisational or environmental constraints, as listed in Appendix A. The three main categories of barriers, identified by Molinillo and Japutra (2017), Kim et al. (2018) and Liang and Qi (2017), are technological (T), organisational (O) and environmental (E).

This categorisation forms basis for the development of TOE frameworks which help assign roles and responsibilities to the pertinent teams and departments to efficiently manage the barriers (Tran et al., 2014; Zhu et al., 2004). For example, the technological barriers can be best managed by the technical team, the organisational by the organisational management team and the external barriers can either be outsourced or managed through collaborations with other organisations and external teams. These TOE frameworks have been used in multiple studies such as assessment of smart city readiness for technology adoption and its risk management (Dewi et al., 2018), smart city governance (Ullah and Al-Turjman, 2021; Ullah et al., 2021), smart city implementation (Anindra et al., 2018), data-driven innovative smart cities (Bibri and Krogstie, 2020), developing sustainable and innovative digital nations (Kar et al., 2019), leveraging value from technology opportunities (Bremser et al., 2019a,b) and others. In the case of real estate studies, TOE frameworks have not been used for assessing barriers to the adoption of DDTs in Australian real estate. The closest reported studies are by Umam et al. (2020), who used TOE for smart district services; Zhu et al. (2004), who used it for e-business value creation in the financial real estate industry; and Neupane et al. (2019), who used it to develop a conceptual framework to enhance the trust of stakeholders in smart city initiatives for Australian regional cities. Similarly, for technology adoption, Senyo et al. (2016) used TOE for cloud computing adoption in Ghana and Tran et al. (2014) used it for e-procurement adoption in Vietnam.

The technological barriers in real estate include the cost of the software and hardware (Etim et al., 2016). Technology innovations such as collaborative and social media enable the project teams to effectively communicate, support their development initiatives and information sharing and reduce project communications costs (Ghouri and Mani, 2019). This reduces the DDT adoption and innovation costs and increases the quality of communication for improved productivity. For pertinent adoption, stronger approaches to technology awareness, education and leadership are advised to offer services accessible to all citizens (Nam and Pardo, 2011). This can help eliminate barriers related to language, culture, education, skills development and disabilities and develop and maintain smarter, sustainable and all-inclusive real estate and city organisations. The inabilities of organisations to handle big data associated with DDT adoption and innovation, the information complexity, top management support and the technological competence of organisations to handle data are also some DDT adoption and innovation barriers (Haneem et al., 2019; Kim et al., 2018). Other technological barriers include lack of access to market data required for integrating the DDT with existing infrastructure, lack of legal frameworks supporting the adoption, lack of understanding of smart contracts, inability to create and manage independent online portals and low accuracy of property valuation as listed in Appendix A (Chen et al., 2017; Kim et al., 2018; Lafuente and Berbegal-Mirabent, 2019; Mohanty et al., 2016; Sepasgozar et al., 2019; Sinaeepourfard et al., 2018).

Organisational barriers include a lack of management and lenders' trust in innovation and new DDT adoption. According to Ho et al. (2017), trust and openness to innovation and DDT adoption by users, managers and key stakeholders are essential. Thus managers, users and all stakeholders must be open to experimentation and willing to change their behaviours to enable DDT adoption and innovation. This is achieved through trust-building activities such as open communication and honest data sharing (Asadi et al., 2019). Another key organisational barrier is rigidity (Liang and Qi, 2017). Traditional and unflexible organisations may go obsolete in the competitive era where companies with advanced technologies are wiping their competitors. The real estate organisation's routine rigidity and lack of digital communication skills among agents are also the key barriers in their DDT adoption and innovation (Dooley, 2017). The role of agents is significant in real estate technological development and their reluctance to adopt DDTs and tech-averse nature hinder technological innovation and advancement (Ullah and Sepasgozar, 2020). This highlights the need for a behavioural change on behalf of the agents and real estate managers. Other organisational barriers include lack of willingness to invest in digital technologies, unawareness of improved productivity, stakeholder coordination and cooperation and willingness to shift to ICT-based intermediaries as listed in Appendix A (Asadi et al., 2019; Dooley, 2017; Ho et al., 2017; Liang and Qi, 2017; Low et al., 2020; Stone et al., 2018; Thakor and Merton, 2018).

The environmental barriers are external to the organisation and beyond their control. Lack of government incentives, R&D support, policies, regulations and standards are key barriers to adopting DDTs in real estate (Anthony et al., 2019). The same has been stressed by Dwivedi et al. (2017) and Aina (2017), who outlined government support and policies and well-defined industry standards to pave the way for advanced DDT adoption and innovation. Another key barrier is high safety and privacy concerns by users. User acceptance of DDTs is highly dependent on their safety and privacy concerns which must be addressed for DDT adoption and innovation (Khatoun and Zeadally, 2017; Mora et al., 2018). If not addressed, users will be reluctant to adopt the DDT or use the associated service. Another key barrier discussed by Sanford and Oh (2010) is public demand for the technology. Resistance to technology adoption and lack of demand discourage small businesses from adopting them. However, it is dependent on and addressable by responding to user concerns and spreading awareness about potential benefits. Other critical environmental barriers include trust in outsourcing the data, cognitive dissonance of users and rigid market attributes of the real estate sector (Aina, 2017; Alwahdani, 2019; Anthony et al., 2019; Babin et al., 2017; Dwivedi et al., 2017; Khatoun and Zeadally, 2017; Mora et al., 2018; Yang et al., 2019).

1.3. Theoretical perspectives of the current study

In terms of the theoretical contributions and underlying theories, this study contributes to the theories of Diffusion of Innovation (DOI), Hedonic Demand (HDT), Technology Acceptance Model (TAM), Contingency (CT), Expected Utility (EU) and Real Options (ROT).

DOI explains how, why and at what rate new ideas and technologies spread. Prof. Everett Rogers proposed this theory in 1962 (Rogers, 2010). There are five established adopter categories: Innovators, Early Adopters, Early Majority, Late Majority, Laggards. Innovators want to be the first to try the latest technologies. They are characterised by their venturesome behaviour, higher risk appetite and effortlessness in adopting DDTs. Early Adopters are opinion leaders who enjoy leadership roles and embrace change opportunities. They are usually aware of the latest technologies, user manuals and information sheets to adopt DDTs. The early majority are rarely leaders but are quick adopters. However, they need evidence that the innovation works before they can adopt it. The late majority are sceptical of change and will not adopt any DDT that the majority has not adopted. Laggards are bound by tradition and very conservative in their approach. They are the hardest to convince and may need strategies such as statistics, fear appeals and pressure from people in the other groups to persuade them to adopt DDTs. The current study explores the DOI in the Australian real estate sector through its holistic approach towards DDT adoption, awareness and barriers to DDT adoption and innovation in Australian real estate. Accordingly, perceptions of managers are investigated to categorise them into one of the five DOI categories. Further, different strategies and suggestions are provided for managing different categories of managers. For example, in the case of laggards, policy-level changes and regulatory regimes might be required. On the other hand, for innovators and early adopters, insights into the potential benefits of the technologies will help adoption.

According to HDT, users are willing to pay for technology or service equivalent to its offered value (Bartik, 1987). Thus, the price an individual is happy to pay for a technology reflects their perceived value or usefulness. Thus, the demand for value is not the object that dictates the adoption of a technology or service; it is the value that dictates adoption. However, the valuation of technology and its characteristics is easier said than done and is usually challenging to explain. In real estate, HDT is used to adjust for the problems associated with researching a good that is as heterogeneous as technologies. These technologies are characteristically different and cannot be generalised. Therefore, features such as speed, implementation costs, infrastructure and other valuations are used to justify the adoption and other parameters (Gokmenoglu and Hesami, 2019). The current study contributes to this theory by investigating the key characteristics of the technologies related to the hedonic parameters such as virtual tours, UAVs assisted sales and other playful technologies in line with Felli et al. (2018).

TAM, an extension of the theory of reasoned action, was introduced by Davis in 1985 (Davis, 1985). It models how users come to accept or adopt any technology. Its key constructs are perceived usefulness, ease of use, user satisfaction and behavioural intention to use the technology. Perceived usefulness corresponds to the degree to which technology can increase the user's job performance. Perceived ease of use refers to the technology being effortless to use. These two constructs appeal to users as they can effectively achieve their targets through technology. As a result, they are inclined to change their behaviour towards adopting technology (Ullah et al., 2018). TAM has been extended as TAM 2 and TAM 3 through additional constructs such as subjective norm, voluntariness, image, job relevance, output quality and result demonstrability (Venkatesh and Bala, 2008; Venkatesh and Davis, 2000). The current study highlights the usefulness of technologies through the management perspective that can inform the users and incline them to use and adopt DDTs. Further, user-related factors are taken into consideration that, when addressed, will enhance user satisfaction.

The current study uses CT, EU and ROT concepts and develops a risk matrix applicable to smart real estate using FTA. CT claims that there is no best way to organise a corporation, lead a company or make decisions. Instead, the optimal course of action is contingent upon the internal and external situation (Donaldson, 2001). Accordingly, the current study does not generalise the DDT adoption and innovation rather explores context-specific Australian real estate sector and the pertinent organisations. The study further proposes contextual recommendations for adopting technologies in different real estate organisations following the CT. EU relates to the outcomes of actions and provides an insight into how to choose rationally when you are not sure which outcome will result from your actions (Bernardo, 1979). Accordingly, the product or technology with the highest utility or value is selected to be rational. It is closely aligned with HDT in the context of prioritising and pursuing the value of DDTs. The current study follows a similar approach as the EU for DDT adoption and innovation through a detailed investigation of DDTs, highlighting the potential advantages and removing the barriers to their implementation.

Similarly, another theory utilised in the current study is that of ROT. ROT was coined by Myers (1977) and is based on the theory of financial options to the realm of strategic decision making. These real options are "opportunities to purchase real assets on possibly favourable terms" related to the costs, market power and other factors. Accordingly, the managers have a right to make or else abandon some available choices related to business projects or investment opportunities. It usually involves tangible or real assets. The current study through the adoption of disruptive digital technologies using UAVs, VR gadgets, wearable devices and other high-tech gadgets adds to the list of options of the managers for paving the path for DDT adoption and innovation, utilising the concepts of ROT.

The rest of the paper is organised as follows. Section 2 presents the three-staged study method where the key stages of literature retrieval, fault tree development and questionnaire development and deployment are discussed. Section 3 presents the results and pertinent discussions where the literature synthesis and data collection results are presented and discussed. These include the respondents' details, experience and locations, DDT awareness, most important digital technologies and reasons for their non-adoption. Further, the risk scores assigned by the respondents to the barriers are used to develop a risk matrix and assign values to the fault tree analysis that are also discussed in this section. Finally, Section 4 concludes the research and presents the key takeaways and future research directions.

2. Research method

This study is conducted in three stages, as shown in Fig. 1. In stage 1, the relevant literature was retrieved using Web of Science (WoS) and Scopus search engines and synthesised to identify key barriers to adopting DDTs. The barriers were subsequently scored and analysed to highlight the critical barriers in stage 2. A fault tree was proposed based on the identified barriers and all assumptions and formulae were listed for subsequent analyses. In stage 3, a questionnaire was developed through which real estate managers were surveyed to provide risk scores to the fault tree nodes. Finally, all the results were listed and discussed. Further, conclusions and recommendations are presented based on the results and future directions for enhancing the study are proposed.

2.1. Stage 1: Literature retrieval and synthesis

Following the established academic research guidelines and PRISMA principles, the current study shortlists key barriers or risks to real estate DDT adoption using a comprehensive and systemic literature review. The same has been used in recent relevant studies in real estate and its technology management (Munawar et al., 2020; Ullah and Sepasgozar, 2020; Ullah et al., 2018). The research repositories of Scopus and WoS are used to shortlist relevant documents. The keywords and strings used for searching on both platforms consist of "real estate", "technology adoption", "risks" and "barriers". The timeframe is limited to the last decade (2010–20) to keep a recent focus on the risks and barriers to DDT adoption and innovation. Document types were restricted to research articles, conference papers and books or book chapters only. This is in line with Akram et al. (2019) who highlight the superior quality of knowledge in these document types compared

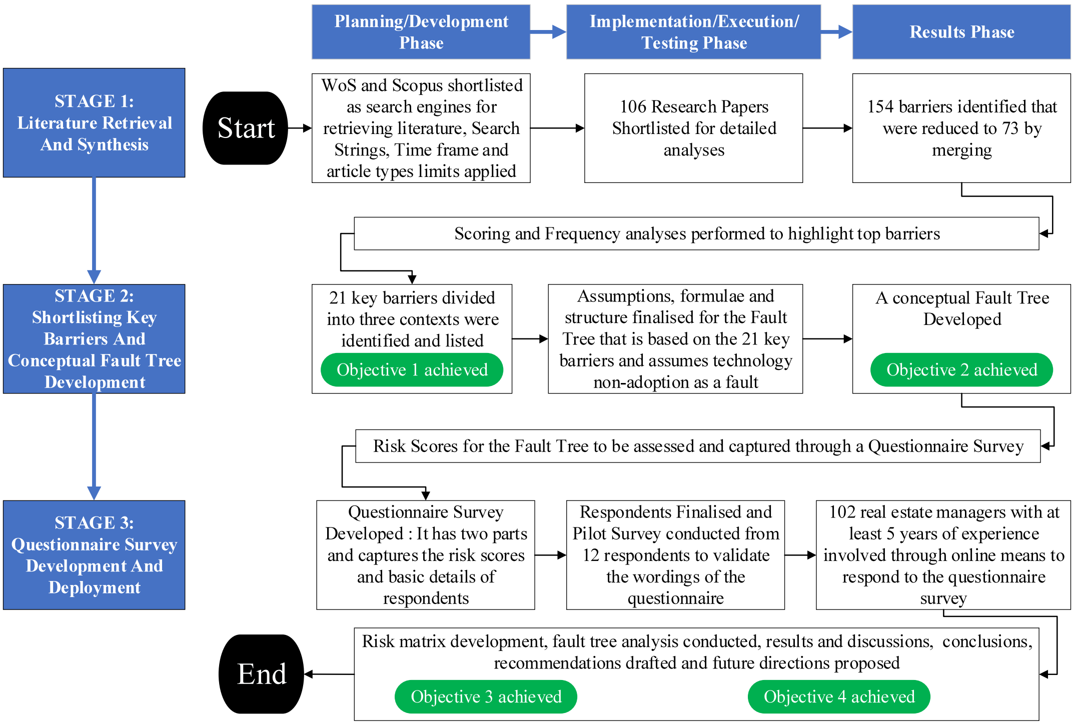

Fig. 1. Research methodology.

Table 1
Scopus and Web of Science search strings and results.

Search Engine	Search Strings	Results
Scopus	(TITLE-ABS-KEY (real AND estate) AND TITLE-ABS-KEY (technology AND adoption) AND TITLE-ABS-KEY (risk) OR TITLE-ABS-KEY (barrier))	84
	AND PUBYEAR > 2009	65
Web of Science	TOPIC: (real estate) AND TOPIC: (technology adoption) AND TOPIC: (risk) OR TOPIC: (barrier)	45
	Timespan: 2010–2020. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.	36
Duplicates		24
Irrelevant article types (Editorial or erratum or letter or note or comment)		4
Total Shortlisted		72

to others. Table 1 lists the search strings and results for each type of search engine. A total of 72 retrieved documents were reviewed in the current study to highlight the pertinent risks and barriers to adopting new disruptive technologies in real estate from a managerial perspective, as provided in Appendix B.

A total of 154 barriers or risks were identified from the 72 shortlisted and reviewed articles. Barriers are treated as risks as they pose a negative outcome in the form of non-adoption of a DDT. Thus, these are the downside or threat form of a risk to the prospect of DDT adoption and innovation. Further, the positive side or opportunities are not considered related to risks. Risks or barriers such as privacy concerns, traceability of data to users and public safety have been merged under a single category of "user and public safety and privacy concerns". Similarly, stakeholder collaboration, stakeholder cooperation and stakeholder willingness to participate have been merged into "stakeholder coordination and cooperation". Following similar lines, a total of 81 barriers have been merged. Thus, the identified barriers were narrowed to 72, as listed in Appendix A.

2.2. Stage 2: Shortlisting the key barriers and conceptual fault tree development

The 72 shortlisted barriers are divided into three categories based on the relevant literature (Molinillo and Japutra, 2017). These include the TOE categories. Table 2 shows the top shortlisted barriers among each category. The shortlisting

Table 2
Critical barriers to DDT adoption.

Category	Barriers	Code	f	Weight			TW	S	RS	CS
				N_h	N_m	N_l				
	High costs of software and hardware	T1	10	7	2	1	42	52	0.10	0.10
	High complexity of the selected technology dissemination system	T2	7	6	1		33	40	0.07	0.17
	Lack of information acquisition, integration, maintenance and data management capabilities	T3	7	6	1		33	40	0.07	0.24
Technological	Lack of access to market data to integrate the selected technology with existing infrastructure	T4	8	4	3	1	30	38	0.07	0.31
	Lack of legal frameworks supporting the adoption of the selected technology	T5	6	4	2		26	32	0.06	0.37
	Lack of understanding of smart/electronic contracts to use the selected technology	T6	6	3	1	2	20	26	0.05	0.42
	Lack of ability to create and manage independent online portals supporting the selected technology	T7	6	3	1	2	20	26	0.05	0.47
	Low accuracy of the estimated property value of the technology	T8	4	3	1		18	22	0.04	0.51
	Lack of management and lenders trust in innovation and new technology adoption	O1	15	11	4		67	82	0.17	0.17
	Highly rigid firm-specific strategies and institutional constraints	O2	7	4	2	1	27	34	0.07	0.24
Organisational	Lack of digital communication skills among agents	O3	7	3	3	1	25	32	0.07	0.31
	Lack of organisational willingness to invest in digital marketing	O4	6	3	2	1	22	28	0.06	0.37
	Lack of awareness of improved productivity due to the technology	O5	6	3	2	1	22	28	0.06	0.43
	Lack of stakeholder coordination and cooperation	O6	6	3	1	2	20	26	0.05	0.54
	Lack of organisational willingness to shift from human intermediaries to ICT-based intermediaries	O7	6	3	1	2	20	26	0.05	0.59
	Lack of government incentives, R&D support, policies, regulations and standards	E1	10	8	2		46	56	0.15	0.15
	High safety and privacy concerns by users	E2	9	5	3	1	35	44	0.12	0.27
Environmental	Lack of public demand for the selected technology	E3	6	3	2	1	22	28	0.08	0.34
	Lack of trust in outsourcing the organisational data	E4	6	3	2	1	22	28	0.08	0.42
	High resistance to the selected technology acceptance by the users (cognitive dissonance)	E5	6	3	2	1	22	28	0.08	0.49
	Highly rigid market attributes of the real estate sector	E6	5	3	2		21	26	0.07	0.63

Note: f is the frequency. N_h the number of papers with high weight, N_m the number of papers with medium weight (3), N_l the number of with low weight (1) to the barrier, TW the total weight, S the score, RS the relative score and CS is the cumulative score.

is done based on Eqs. (1) to (3).

$$Total\ Weight\ (T.W) = (N_h * 5) + (N_m * 3) + (N_l * 1) \tag{1}$$

$$Score\ (S) = f + T.W \tag{2}$$

$$Relative\ Score\ (R.S) = \frac{Score}{Category\ Score} \tag{3}$$

where f refers to the frequency of barriers. N_h is the number of papers assigning high weight (5) to a barrier, N_m the number of papers giving medium weight (3) and N_l the number of papers assigning low weight (1) to a barrier. Using these values, total weights were calculated to be added with the frequencies of these barriers to get the scores for shortlisting the most important barriers from the literature. Relative scores (RS) were calculated by dividing these scores by the sum of scores for each category (category score). The cumulative scores (CS) were calculated and barriers were shortlisted till the cumulative scores crossed 50. Thus, the barriers contributing to more than half of the category score were treated as critical. Based on the shortlisting mechanism, 21 critical barriers were identified that were ranked and divided into the three TOE categories, as shown in Table 2.

FTA is conducted for the 21 key barriers. The current study uses FTA to assess the managerial perspective for non-adoption of DDTs in the smart real estate sector. FTA is a suitable candidate for this study because it can help detect and

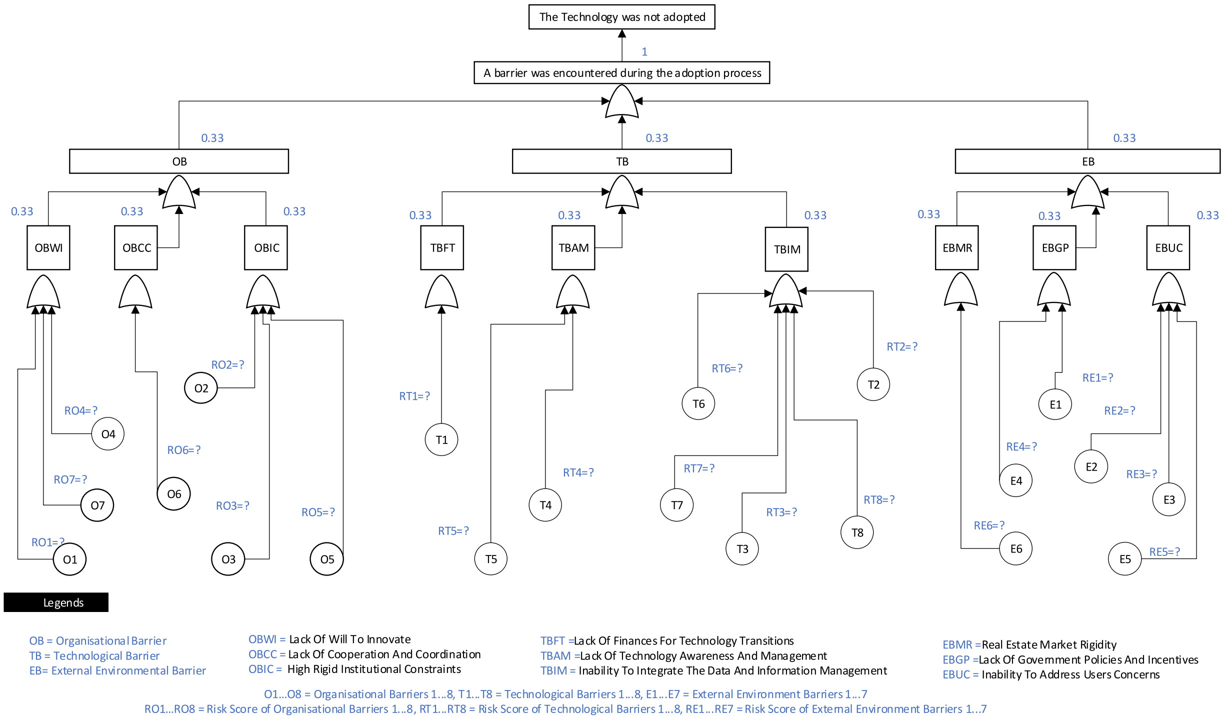

Fig. 2. Scored fault tree diagram with assumed and missing risk scores.

analyse the underlying faults or barriers related to non-adoption directly or failure of the adoption system that contributes to non-adoption of various technologies, thus helping the management make necessary decisions or amendments to the existing systems for a holistic adoption of technologies. FTA is a key method for risk management and risk modelling to assess and model the pertinent risks in any technology-oriented project (Bannerman, 2015). Accordingly, it is suited for the current study as it aims to assess the barriers related to DDT non-adoption in real estate in the form of the risk matrix. Further, FTA can help the management find the minimal cut set, which refers to a combination of minimum basic events, the occurrence of which will cause the top event (in this case, the non-adoption) of DDT. The value of FTA lies in its ability to identify not only low-probability and high-consequence events but also high-consequence events that can result from the combination of events regardless of probability or severity (Sherwin et al., 2020). In this case, it can help the real estate managers find and focus on the high-consequence barriers for DDT non-adoption.

Accordingly, Fig. 2 shows the conceptual fault tree for the non-adoption of DDTs due to the identified barriers. It must be mentioned that the fault tree only considers the downside of risk. Thus, opportunities are not listed or discussed. The tree shows the identified barriers in a conceptual arrangement where the main event of the DDT non-adoption is linked to the causing and initiating events of technological, organisational, or external barriers at level 2. Accordingly, each event node is subdivided into sub-events based on the logical grouping of barriers at level 3 and at the final level (level 4), the 21 key barriers are presented. In the fault tree shown in Fig. 2, the main event is the non-adoption of a DDT which is caused by a barrier encountered during the adoption process, as evident from the top two boxes in the fault tree.

At the next level, the TOE branches are presented. These TOE categories are further branched into their constituent barriers. The organisational barriers consist of *lack of will to innovate* (OBWI), *lack of cooperation and coordination* (OBCC) and *high rigid institutional constraints* (OBIC). The technological barriers are divided into *lack of finances for technology transitions* (TBFT), *lack of technology awareness and management* (TBAM) and the *inability to integrate the data and information management* (TBIM). Similarly, the external environmental barriers are divided into *real estate market rigidity* (EBMR), *lack of government policies and incentives* (EBGP) and the *inability to address users' concerns* (EBUC). All these branches contain the 21 key barriers as listed in Table 2. Overall, the fault tree moves from the main event: the non-adoption of DDTs through its TOE branches into sub-branches and finally into the barrier responsible for the non-adoption.

In FTA, basic events are investigated through a comprehensive questionnaire survey where the experts are asked to assign risk scores to each barrier. Accordingly, in line with risk scoring, both probabilities and impacts are enquired from the experts. Eq. (4) lists the basic calculation formula for the risk score, where P means the probability of occurrence and I the impact of the barrier. All the missing risk scores in Fig. 2 are denoted by R, followed by the initial of the TOE category. For example, the risk score of barrier T1 is denoted by RT1 and so on.

$$Risk\ Score\ \ (RS) = P \times I \tag{4}$$

Probability					
Very High 0.9	0.045	0.090	0.180	0.360	0.720
High 0.7	0.035	0.070	0.140	0.280	0.560
Moderate 0.5	0.025	0.050	0.100	0.200	0.400
Low 0.3	0.015	0.030	0.060	0.120	0.240
Very Low 0.1	0.005	0.010	0.020	0.040	0.080
Impact	Very Low 0.05	Low 0.1	Moderate 0.20	High 0.4	Very High 0.8

Fig. 3. Probability and Impact matrix as adopted from PMBOK 5th edition (PMI, 2013).

Fig. 2 shows the scored fault tree for the current study with all assumptions. At each level of analysis, the sum of scores is equal to 1. The values of risk scores for the last nodes (level 4) are to be calculated using a comprehensive questionnaire survey. The product of risk scores, its connecting nodes from level 1 to 3, gives the probability of the DDT not being adopted due to that particular barrier. Eq. (5) is used to calculate the probability of failure due to a particular node.

$$F_n = RS_n \times V3_n \times V2_n \times V1_n \tag{5}$$

$V3_n$, $V2_n$, and $V1_n$, as shown in the diagram, are assumed as 0.33, 0.33 and 1, respectively. This is based on the assumption that at each level, the sum of values is equal to 1. Thus $V3_n$ and $V2_n$ at lower levels have a value of 0.33 as there are three constituent components, whereas $V1_n$ is a single node, thus getting the entire value of 1. Thus Eq. (5) becomes:

$$F_n = RS_n \times .33 \times .33 \times 1 \tag{6}$$

Accordingly, all the values for RS_n are calculated through the questionnaire survey and substituted in Eq. (6) to calculate the probability of failure (P_f) due to individual barriers. For example, consider the barrier of *lack of user trust in the system* (RE_3). If we assume its probability of occurrence as 60% and its impact on adoption as 70%, then the normalised values will be 0.6 and 0.7. Using Eq. (4), the Risk Score will be:

$$Risk\ Score\ \ (RS) = P \times I = .6 \times .7 = .42$$

If this value is substituted in Eq. (6), we get:

$$P_f = RS_n \times .33 \times .33 \times 1 = .42 \times .33 \times .33 \times 1 = .0457$$

Thus, the probability of failure due to this barrier is 4.57%. This concept is used to calculate individual P_f.

2.3. Stage 3: Questionnaire development, validation and deployment

A comprehensive questionnaire in the English language was developed using the University of New South Wales Qualtrics platform to capture the opinion of real estate managers regarding the non-adoption of disruptive technologies in Australia. The questionnaire was designed to take 10–15 min to complete and consisted of two parts. Part 1 enquired about the basic details from respondents such as their gender, job title, total experience, organisation names, location (state), technologies they are aware of and the reasons for not using them. They were further asked to select the most important DDT for their organisation that has not been adopted so far. This was referred to as the "selected technology" and the questions in part 2 referred to it.

Part 2 enquired about the risk scores in terms of probabilities and impacts of the identified barriers. The respondents were requested to assign values to probabilities and impacts in terms of the selected technology. A five-point nonlinear scale, ranging from very low to very high, was used to measure probability and impact (PMI, 2013). For probability, very low = 0.05, low = 0.1, moderate = 0.2, high = 0.4 and very high = 0.8. For impact, very low = 0.1, low = 0.3, moderate = 0.5, high = 0.7 and very high = 0.9. The matrix is adopted from PMI (2013) PMBOK 5th edition, as shown in Fig. 3. The responses are recorded and discussed accordingly in subsequent sections.

The questionnaire was validated through a pilot survey of 25 respondents working in the domains of real estate, smart cities and construction. These respondents comprised 17 academic researchers, including Ph.D. students and lecturers in construction management and property sectors, four real estate website users, two real estate agents and one real estate manager and web designer based in Australia. The average experience of researching or using real estate technologies was between 5–10 years (eleven less than five years, thirteen 5–10 years and one 10–20 years). They validated the survey questions and proposed changes in case of ambiguities—this ensured clarity of communication and logic. Accordingly, the content validity and the construct validity for the survey questions were ensured. For checking the reliability of the questionnaire, the internal consistency of the data was assessed using the Cronbach alpha test, where the value of alpha greater than 0.7 is acceptable for such studies (Heale and Twycross, 2015).

Table 3
Details of channels used to contact respondents.

Source	Male	Female
LinkedIn	719	150
Emails	493	345
Facebook	27	15
Phone Calls	24	08
Other Social Media	08	03
Total	1271	521
Requested Total	**1792**	
Received	121	28
Received Total	**149**	
Valid	83	19
Valid Total	**102**	

Table 4
Authors analysis of retrieved documents.

Author	Scopus Citations	Web of Science Citations	Total Docs
Shih, Y.-y	46	36	2
Chan, A.P.C		21	2
Darko, A.		21	2
Gou, Z.		21	2
Lee, T.K.	12	11	2
Tan, A.C.	12	11	2
Wong, C.C.	12	11	2
Zhang, S.	12	11	2
Sepasgozar, S.M.E.	4		2
Ullah, F.	4		2

The questionnaire was distributed among 1792 Australian real estate managers, developers, agents and high-level executives. Non-probability sampling approach was adopted in the current study for targeting the respondents. Mixed approaches of selective sampling and judgemental sampling were used in the current study. In the case of selective sampling, the key attributes to recruit the participants were usage and awareness of the digital technologies for at least two years and the respondents identifying themselves working in a managerial position in respective real estate or property management organisation in Australia. For the judgemental sampling, only managerial personnel in the Australian real estate and property sectors were recruited for this study, whereas others were restricted from participating in the survey. The respondents were contacted through LinkedIn, official email addresses, Facebook, phone calls and other social media and a survey link was shared with them. Two weeks after the initial contact, they were followed up. As a result, 149 responses were received, giving a response rate of approximately 8%. Among them, 102 were complete and used for further analysis, whereas the remaining 47 were rejected due to incompleteness. Thus, the correct response rate was around 6%. As the total number of real estate managers identified by the Real Estate Institute of Australia is 117,880, as per Needham et al. (2008) and Grembowski (2015), the sample size should be at least 96 using a 50/50 split and 10% sampling error. Similarly, Sandelowski (1995) suggested that the sample be between 100 to 200 respondents to conduct mixed quantitative studies effectively. Thus, the sample of 102 satisfies the limits mentioned in these studies. The respondent details and channel of contact, along with the gender of the respondents, are provided in Table 3.

3. Results and discussions

3.1. Literature synthesis

As described in the method section, stage 1 of the study presents the results and pertinent discussion of literature synthesis. Fig. 4 shows the breakdown of the shortlisted articles in both Scopus and WoS. The research articles were in the highest number (52 Scopus, 26 WoS) followed by conference papers and book chapters. As discussed by Akram et al. (2019), many journal articles in the review signify superior data quality. The journal articles provide more accurate and appraised information due to their rigorous review process. Thus, a larger presence of journal articles in the data set highlights the data's quality for subsequent analysis.

An author-based analysis was done to identify the authors contributing the most to barriers in smart real estate DDT adoption and innovation. The inclusion criterion was a minimum appearance in two research articles. Table 4 shows that none of the authors has contributed to more than two research articles in this area, which points to the novelty and under-exploration of this area. Table 4 further highlights the citations to the reviewed documents using Scopus and WoS search engines.

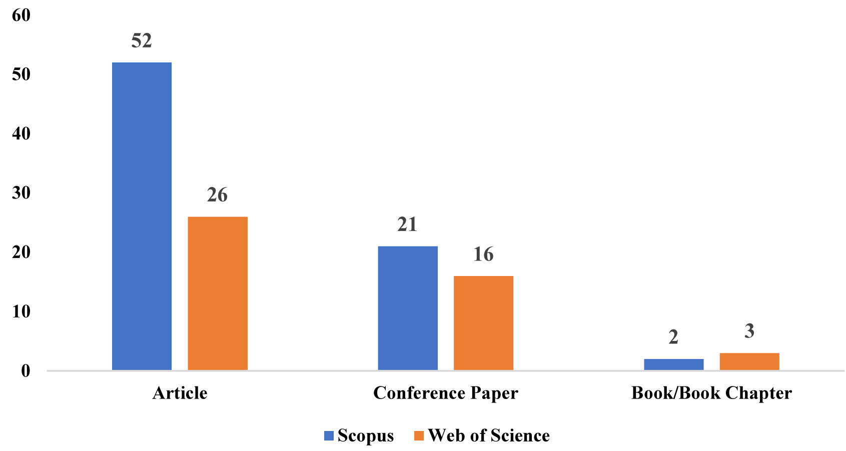

Fig. 4. Types of retrieved documents.

Afterwards, keyword analysis was conducted for the shortlisted articles. Fig. 5, generated through VOSviewer, provides an overview of keywords and their linkages in both search streams. The analysis uses both author provided and stock keywords. Accordingly, the top keywords reported in WoS are "technology adoption" reported in six articles, "information technology" in five and "technology acceptance", "construction management", and "model" in four articles each. Similarly, in the Scopus shortlisted articles, the keywords "real estate" and "technology adoption" are reported in 15 articles followed by "construction industry", "innovation" and "sustainability" in five and "economics", "energy conservation", "information technology", "internet", "investment" and "real estate development" in four articles each. A minimum of three appearances for keywords is used to generate Fig. 5. As evident, most of the reported keywords revolve around "technology". This highlights the relevance of the retrieved articles to the topic of the study. Simultaneously, the focus on DDT is positive for the transformation and digitalisation of the real estate sector into smart real estate. Such a focus is needed to persist and studies focused on DDT adoption in real estate are needed to assess the impediments to their adoption and paving the path for their utilisation. Another highly relevant aspect is that of innovation, as reported by both Scopus and WoS retrieved articles. Technologies and innovation go hand and hand and present a positive focus for digital transformation and innovation in real estate in line with the aims of the current study.

3.2. Survey results and discussion

3.2.1. Respondent demographics

In terms of the profession, more than half (55%) of the respondents are classified as real estate agents (22), followed by real estate/property web or IT managers (21) and real estate/property manager/consultants (13). Other respondents include academic researchers/lecturers in real estate and property (07), strata/asset/facilities managers (06), real estate or property developers (04), CEO or founder of real estate agencies (04), real estate or property customer relation managers (03), Property technology (Proptech) managers (03) and others (19) as shown in Fig. 6. The presence of high-level personnel and people working in managerial positions is positive for the current study, aiming to capture their perspectives. Further, these are the people with decision-making authority who can bring the change or pave the way for technological transformation. Thus, the involvement of these managerial position holders and agents in the data collection is valuable for inferring meaningful and implementable results.

In terms of experience, around 54% of the respondents (55) had more than ten years of experience in the real estate and property management fields, as shown in Table 5. Highly experienced respondents provide useful insights into the industry situation. However, experienced respondents may not be tech-pros; therefore, young and more tech-savvy respondents are also needed for a holistic assessment of the industry. Low et al. (2020) state that the younger workforce is digitally savvy and usually accepts DDTs faster than other age groups. Accordingly, the current study has more than 25% of the respondents as fresh or new entrants to the real estate industry, as evident from less than five years of experience.

The map in Fig. 7 shows the state-wise distribution of respondents in Australia. Interestingly, over 90% of the respondents belong to Australia's north-eastern regions. These include New South Wales (64 respondents), Victoria (14), Queensland (11) and Australian Capital Territory (03). Other states include Western Australia (05), South Australia (02), Tasmania (02) and the Northern Territory (01). Thus, all the Australian states are covered in the study despite lower responses from some states.

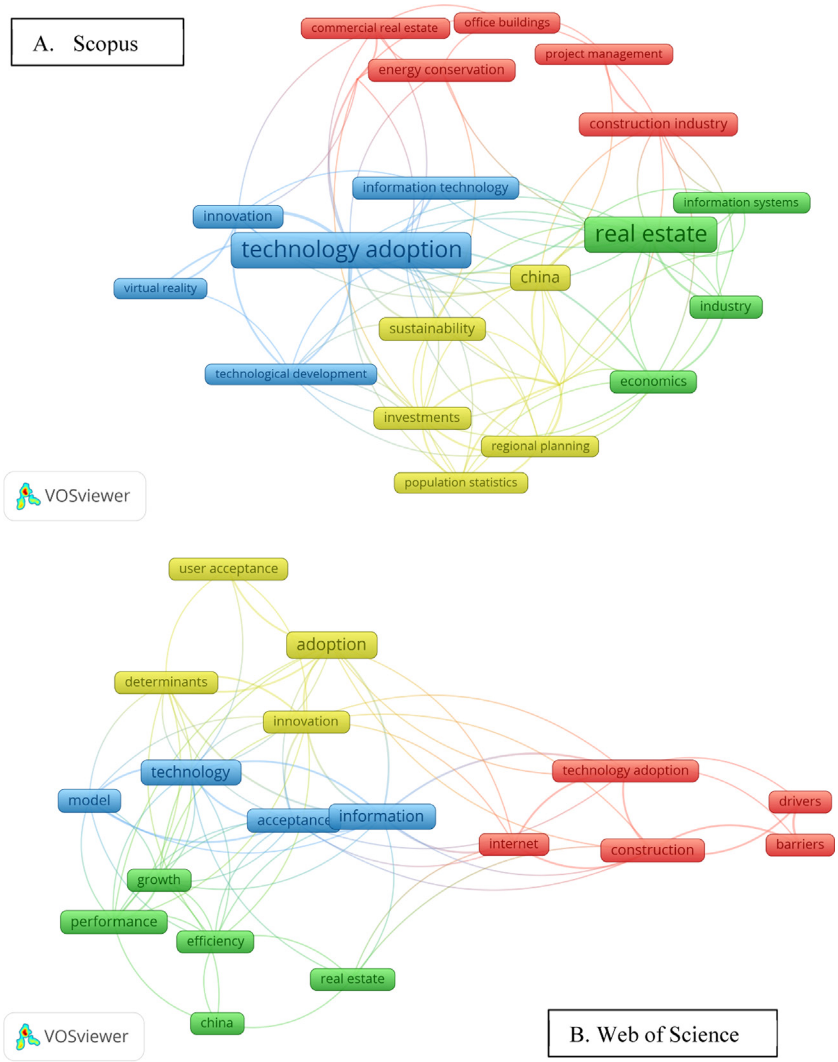

Fig. 5. Keyword analysis of retrieved documents.

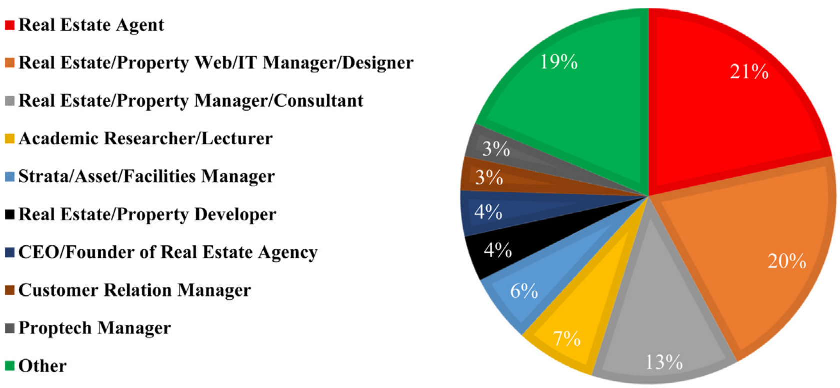

Fig. 6. Respondents jobs/roles.

Table 5
Respondent experience.

#	Experience	%	Count
1	Less than 5 years	25.49%	26
2	5–10 years	20.59%	21
3	10–20 years	25.49%	26
4	More than 20 years	28.43%	29
	Total	**100%**	**102**

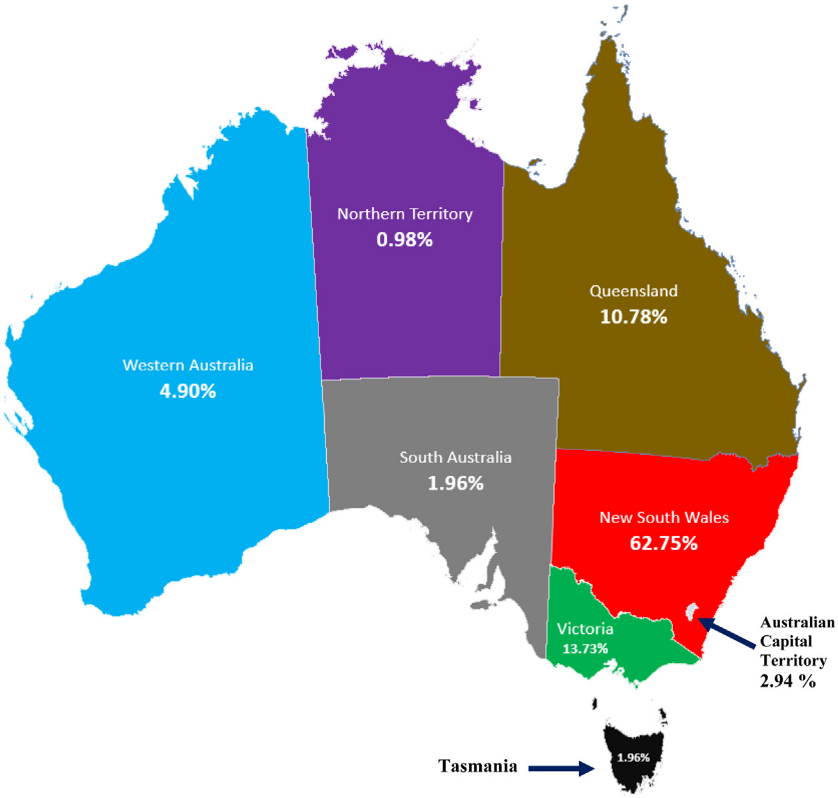

Fig. 7. Respondent location.

3.2.2. DDT awareness

It is encouraging to see that most of the respondents were aware of the disruptive digital technologies, as evident from Fig. 8. As much as 77.5% of respondents (79) are aware of AI, closely followed by VR (75.5%), drones (72.5%) and others. The key point to note is that even for very specialised technologies such as 3D scanning and LIDAR, the awareness is more than 50%, which is a positive sign as the first step to adoption and acceptance is awareness. This means that given positive incentives and support by the government authorities, the goal of disrupting the real estate industry is achievable. Accordingly, incentives must be provided to address DDT non-adoption and pave the path towards a smart real estate and property industry.

Not only is there a positive attitude and awareness of the mentioned disruptive technologies, but some respondents have also started developing and using Proptechs such as TractionNext. It is an automation tool that provides a more relevant and engaging brand experience to customers. It provides real-time insights and reporting across multiple digital channels in one place so the customers can easily leverage data intelligence to drive performance. Similarly, other technologies reported by the respondents include computer networking, cybersecurity, software-defined networking in a wide area network (SDWAN), network automation, datacentre automation, software automation, photonic quantum computing, platform economics and network effects, which are largely enabled through technology-driven business models, renewables including hydrogen for mobility and storage, mixed reality, digital twins, click funnels and HoloLens 2. Thus, there is critical awareness that can be leveraged through incentives to adopt disruptive technologies in Australian real estate.

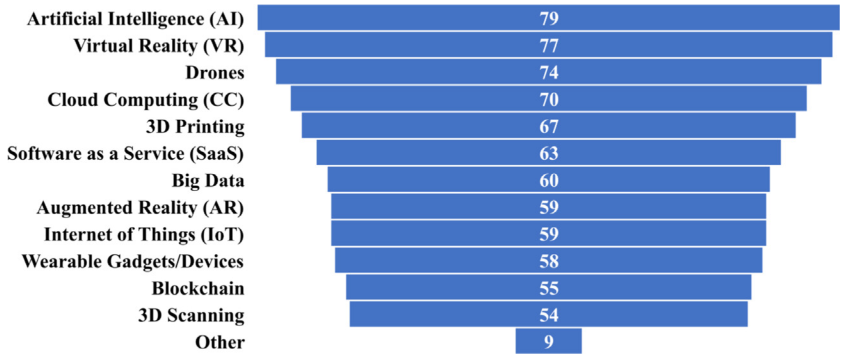

Fig. 8. DDT awareness.

Table 6
Most important disruptive technologies not adopted.

#	DDT	Importance	Count
1	Artificial Intelligence (AI)	22.55%	23
2	Big data	12.75%	13
3	Virtual Reality (VR)	12.75%	13
4	Cloud Computing	8.82%	9
5	Software as a Service (SaaS)	6.86%	7
6	Augmented Reality (AR)	5.88%	6
7	Blockchain	5.88%	6
8	Wearable Gadgets/Devices	5.88%	6
9	Drones	3.92%	4
10	Internet of Things (IoT)	3.92%	4
11	3D Printing	2.94%	3
12	3D Scanning	1.96%	2
13	Other	5.88%	6
Total		**100%**	**102**

3.2.3. Most important DDTs and reasons for non-adoption

When asked to select the most important DDT that their organisations have not adopted, 22.5% of the respondents selected AI, followed by big data and VR (12.75%). 3D scanning has been declared the least important DDT by the respondents, which reinforces the fact that lack of awareness may deprive the managers of understanding the importance of DDT. The importance of all the technologies is listed in Table 6.

When asked about the reasons for non-adoption of the selected technologies, more than half of the respondents (58) stated costs or expenses associated with the selected technologies. The word cloud shown in Fig. 9 is generated based on the response to an open-ended question that enquired about the reasons for non-adoption of the selected technologies. The question stated, "Please give concise reasons for non-adoption of the selected technology by your organisation". Accordingly, the reasons for non-adoption stated by more than ten respondents include funding (41 respondents), company/organisation policies/practices (32), lack of awareness (31), DDT adoption reluctance (29), lack of understanding of technologies (26), reluctance to explore new technologies (17), lack of people/user demand (17), barriers/issues/problems/risks in the integration of technologies (16), limited data management capabilities (16), lack of govt support (16), proper use/leveraging abilities (16), valuation complexities (14), rigid business policies (13), need for the DDT (12) and time required to adopt and understand the DDT (12). The higher mention of funding and organisational practices highlights the need for government and regulatory organisations to incentivise relevant organisations using carrots and sticks. For carrots, the incentives such as funding support, tax rebates and recognition in the form of awards can be provided. Similarly, for the sticks, in case of non-compliance, fines and penalties may be imposed. These will motivate the organisations to change their traditional mindset and be more flexible in their digitalisation and innovation approach. This will pave the way for transforming real estate into a smart and innovative real estate sector.

3.3. Risk scores, matrix development and the fault tree analysis results and discussion

In part 2 of the questionnaire, the respondents were provided with a list of barriers, as shown in Table 2. They were asked to rate the probabilities and impacts of the barriers to adoption in their organisations based on the selected technology. Table 7 provides the ranking of barriers and their counts and percentages of probabilities. The top "very highly" ranked barriers include *high costs of software and hardware* (T1) with a count of 23, followed by *lack of information acquisition, integration, maintenance and data management capabilities* (T3) and *lack of government incentives, R&D support,*

Fig. 9. Word Map of non-adoption reasons.

policies, regulations and standards (E1) with a count of 17 each and *lack of trust in outsourcing the organisational data* (E4) with a count of 14.

In terms of the low or very low scores, *lack of organisational willingness to invest in digital marketing* (O4) has the lowest rank, with over 52% of respondents ranking it as low to very low or not applicable. This is followed by the *lack of stakeholder coordination and cooperation* (O6) with a 49% score and *low accuracy of the estimated property value of the technology* (T8) with a 74% score. This is also in line with the respondents' detailed discussion where the will was highlighted to be there and stakeholder coordination or technology accuracy points were not mentioned to be problematic. The mean probability values assigned by the respondents, the standard deviations and variances are also provided in Table 7, showing the data to be more closely aligned with the mean and within 1–2 standard deviations. All the mean values are normalised for subsequent analyses and the development of the risk matrix. The highest mean probability score is observed for T1, followed by T2, T3 and E4.

Following the same procedure, all scores for impacts of the barriers are listed in Table 8. The barrier with the highest scores for impact is the *lack of information acquisition, integration, maintenance and data management capabilities* (T3), with 43% of respondents declaring its impact as high to very high on DDT non-adoption. This is followed by *high safety and privacy concerns by users* (E2) and *lack of trust in outsourcing the organisational data* (E4), with more than 40% responding, assigning it high to very high scores. The barriers with the lowest assigned scores are *lack of organisational willingness to invest in digital marketing* (O4), with a 48% score assigned to it as low to not applicable.

This is followed by *low accuracy of the estimated property value of the technology* (T8) and *lack of stakeholder coordination and cooperation* (O6), getting more than 45% lower impact scores. These are in line with the probabilities scores. Thus, in the respondents' opinion, probabilities and impacts are closely related. The mean values of the respondent's values, the standard deviations and variances are provided in Table 8 that shows the data to be more closely aligned with the mean and within 1–2 standard deviations.

On average, the mean scores for impacts are lower than the probabilities, as shown in Table 8. Overall, the highest normalised mean score is observed for O4 with a score of 0.6, followed by T2, E1, O3, O2, T5 and T7 with scores of 0.56 and above. The lowest values are observed for E3, which is the only barrier to have an impact of less than 0.5.

After calculating the probabilities and impacts of barriers, their risk scores are calculated by multiplying the probabilities and impacts and the normalised risk scores are calculated that will be subsequently used to assign the values in the fault tree, as shown in Table 9. For calculating the normalised risk scores (NRS), Eq. (7) is used.

$$NRS = \frac{B_i}{\sum_i^n CB_i} \tag{7}$$

where B_i refers to the barrier for which score is calculated and CB_i represents the barriers in the specific category. Thus, a barrier risk score divided by the sum of the risk scores of all barriers gives its normalised risk score. The highest risk scores are observed for T2 (0.38) followed by T1 (0.37) and E1 (0.34) whereas the lowest scores are reported for E3 (0.22), T8 (0.26) and O5 (0.27).

After calculating the risk scores and normalised values, the matrix given in Fig. 3 is used to code the barriers as per their significance. As shown in Fig. 10, all the barriers end up in the high-risk zone of the matrix. This was expected

Table 7
Probabilities scores, mean, standard deviations and variances.

Barrier	Not applicable		Very low		Low		Moderate		High		Very high		Total	Mean	StdDeviation	Variance	NSMean
	%	Count	%	Count	%	Count	%	Count	%	Count	%	Count					
T1	1.96%	2	4.90%	5	8.82%	9	28.43%	29	33.33%	34	22.55%	23	102	3.54	1.19	1.41	0.71
T2	1.96%	2	3.92%	4	15.69%	16	35.29%	36	35.29%	36	7.84%	8	102	3.22	1.05	1.11	0.64
T3	2.94%	3	11.76%	12	17.65%	18	24.51%	25	26.47%	27	16.67%	17	102	3.1	1.35	1.83	0.62
T4	1.96%	2	13.73%	14	22.55%	23	24.51%	25	25.49%	26	11.76%	12	102	2.93	1.29	1.67	0.59
T5	6.86%	7	14.71%	15	21.57%	22	26.47%	27	21.57%	22	8.82%	9	102	2.68	1.37	1.89	0.54
T6	4.90%	5	19.61%	20	13.73%	14	36.27%	37	14.71%	15	10.78%	11	102	2.69	1.36	1.84	0.54
T7	4.90%	5	13.73%	14	22.55%	23	26.47%	27	24.51%	25	7.84%	8	102	2.75	1.31	1.71	0.55
T8	11.76%	12	11.76%	12	23.53%	24	30.39%	31	16.67%	17	5.88%	6	102	2.46	1.37	1.88	0.49
O1	4.90%	5	16.67%	17	17.65%	18	24.51%	25	24.51%	25	11.76%	12	102	2.82	1.4	1.97	0.56
O2	4.90%	5	17.65%	18	19.61%	20	25.49%	26	22.55%	23	9.80%	10	102	2.73	1.37	1.89	0.55
O3	5.88%	6	18.63%	19	18.63%	19	29.41%	30	15.69%	16	11.76%	12	102	2.66	1.4	1.97	0.53
O4	4.90%	5	23.53%	24	24.51%	25	18.63%	19	14.71%	15	13.73%	14	102	2.75	1.4	1.95	0.55
O4	5.88%	6	16.67%	17	16.67%	17	28.43%	29	21.57%	22	10.78%	11	102	2.56	1.46	2.13	0.51
O5	1.96%	2	13.73%	14	24.51%	25	29.41%	30	19.61%	20	10.78%	11	102	2.83	1.25	1.57	0.57
O6	7.84%	8	14.71%	15	26.47%	27	23.53%	24	16.67%	17	10.78%	11	102	2.59	1.41	1.99	0.52
E1	9.80%	10	8.82%	9	17.65%	18	28.43%	29	18.63%	19	16.67%	17	102	2.87	1.5	2.25	0.57
E2	4.90%	5	14.71%	15	16.67%	17	25.49%	26	23.53%	24	14.71%	15	102	2.92	1.42	2.01	0.58
E3	5.88%	6	25.49%	26	13.73%	14	31.37%	32	12.75%	13	10.78%	11	102	2.52	1.42	2.01	0.50
E4	4.90%	5	9.80%	10	18.63%	19	26.47%	27	23.53%	24	16.67%	17	102	3.04	1.39	1.92	0.61
E5	6.86%	7	13.73%	14	18.63%	19	31.37%	32	19.61%	20	9.80%	10	102	2.73	1.37	1.87	0.55
E6	10.78%	11	14.71%	15	19.61%	20	28.43%	29	18.63%	19	7.84%	8	102	2.53	1.43	2.03	0.51

Table 8
Impact scores, mean, standard deviations and variances.

Barrier	Not applicable		Very low		Low		Moderate		High		Very High		Total	Mean	Std Deviation	Variance	NS Mean
	%	Count	%	Count	%	Count	%	Count	%	Count	%	Count					
T1	1.96%	2	5.88%	6	17.65%	18	36.27%	37	24.51%	25	13.73%	14	102	2.6	1.44	2.06	0.52
T2	1.96%	2	4.90%	5	27.45%	28	33.33%	34	27.45%	28	4.90%	5	102	2.93	1.42	2.02	0.59
T3	2.94%	3	10.78%	11	18.63%	19	24.51%	25	36.27%	37	6.86%	7	102	2.67	1.44	2.08	0.53
T4	2.94%	3	11.76%	12	25.49%	26	21.57%	22	31.37%	32	6.86%	7	102	2.58	1.39	1.93	0.52
T5	4.90%	5	14.71%	15	22.55%	23	20.59%	21	29.41%	30	7.84%	8	102	2.79	1.37	1.89	0.56
T6	5.88%	6	15.69%	16	18.63%	19	32.35%	33	19.61%	20	7.84%	8	102	2.77	1.27	1.61	0.55
T7	6.86%	7	13.73%	14	21.57%	22	30.39%	31	17.65%	18	9.80%	10	102	2.78	1.35	1.82	0.56
T8	11.76%	12	8.82%	9	26.47%	27	21.57%	22	23.53%	24	7.84%	8	102	2.68	1.32	1.75	0.54
O1	7.84%	8	13.73%	14	21.57%	22	18.63%	19	26.47%	27	11.76%	12	102	2.76	1.47	2.16	0.55
O2	3.92%	4	20.59%	21	15.69%	16	30.39%	31	20.59%	21	8.82%	9	102	2.87	1.25	1.56	0.57
O3	4.90%	5	14.71%	15	20.59%	21	28.43%	29	18.63%	19	12.75%	13	102	2.91	1.42	2.02	0.58
O4	7.84%	8	20.59%	21	19.61%	20	16.67%	17	21.57%	22	13.73%	14	102	3.01	1.23	1.52	0.60
O4	5.88%	6	15.69%	16	20.59%	21	23.53%	24	23.53%	24	10.78%	11	102	2.68	1.36	1.85	0.54
O5	3.92%	4	14.71%	15	20.59%	21	27.45%	28	27.45%	28	5.88%	6	102	2.53	1.52	2.31	0.51
O6	9.80%	10	10.78%	11	24.51%	25	23.53%	24	20.59%	21	10.78%	11	102	2.7	1.34	1.8	0.54
E1	9.80%	10	10.78%	11	17.65%	18	30.39%	31	17.65%	18	13.73%	14	102	2.94	1.06	1.11	0.59
E2	6.86%	7	10.78%	11	19.61%	20	22.55%	23	27.45%	28	12.75%	13	102	2.65	1.54	2.37	0.53
E3	8.82%	9	15.69%	16	17.65%	18	33.33%	34	15.69%	16	8.82%	9	102	2.17	1.16	1.35	0.43
E4	5.88%	6	12.75%	13	17.65%	18	23.53%	24	26.47%	27	13.73%	14	102	2.75	1.4	1.97	0.55
E5	7.84%	8	11.76%	12	15.69%	16	34.31%	35	20.59%	21	9.80%	10	102	2.77	1.47	2.16	0.55
E6	14.71%	15	14.71%	15	10.78%	11	29.41%	30	23.53%	24	6.86%	7	102	2.77	1.37	1.88	0.55

Table 9
Risk scores.

Barrier	Probability	Impact	Risk Score	NRS
T1	0.71	0.52	0.37	0.145
T2	0.64	0.59	0.38	0.148
T3	0.62	0.53	0.33	0.130
T4	0.59	0.52	0.30	0.119
T5	0.54	0.56	0.30	0.117
T6	0.54	0.55	0.30	0.117
T7	0.55	0.56	0.31	0.120
T8	0.49	0.54	0.26	0.104
O1	0.56	0.55	0.31	0.148
O2	0.55	0.57	0.31	0.149
O3	0.53	0.58	0.31	0.147
O4	0.55	0.60	0.33	0.157
O5	0.51	0.54	0.27	0.130
O6	0.57	0.51	0.29	0.136
O7	0.52	0.54	0.28	0.133
E1	0.57	0.59	0.34	0.189
E2	0.58	0.53	0.31	0.174
E3	0.50	0.43	0.22	0.123
E4	0.61	0.55	0.33	0.188
E5	0.55	0.55	0.30	0.170
E6	0.51	0.55	0.28	0.157

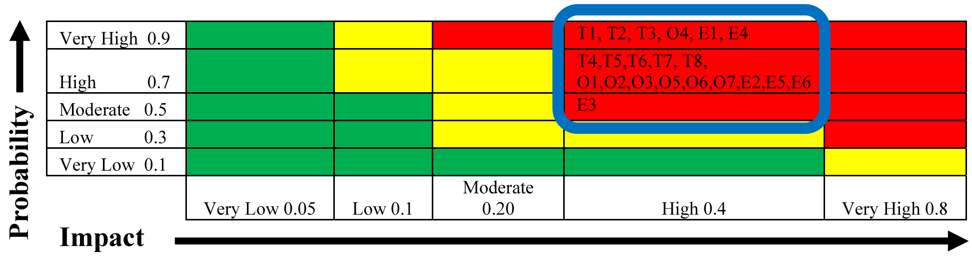

Fig. 10. The risk matrix for the current study.

to be identified from an extensive literature review and duly vetted by the pilot study respondents. The results of the main survey responses verify these barriers to be of high risk for non-adoption of technologies in the Australian real estate sector. The top-ranked barriers are T1, T2, T3, O4, E1 and E4. The relatively lower ranked barrier is that of E3. Thus, careful attention should be paid to these barriers if the Australian real estate sector wants to fulfil the dream of transformation into a smart real estate sector.

3.4. Fault tree analysis results and discussion

The normalised risk scores are substituted in the fault tree presented in Fig. 11. Eq. (8) is used to calculate the failure values of each branch of the fault tree.

$$FV_i = \frac{RS_i}{\sum_i^n CRS_i} \times 0.33 \times 0.33 \times 100 \tag{8}$$

where FV_i is the failure value of the ith barrier, RS_i the risk score of the ith barrier and CRS_i is the scores of all the barriers in the category. The branched value of a barrier is calculated by multiplying the value with 0.33 (33%) and 0.33 (33%) for the branches above it. All the values sum up to be 0.33 or 33%, which is the assumption for all branches, as stated in the method section. Further, to calculate the possible failure value of the individual barriers, Eq. (9) is used.

$$F_i(\%) = \frac{FV_i}{\sum FV_i} \times 100 \tag{9}$$

For calculating the possible failure (F) value in the system due to a specific barrier, the individual values of the FV_i are divided by the sum of all FV_i. Further, to convert this value into a percentage, it is multiplied by 100. Thus, in this step, the sum of all values is 1 or 100% showing the contributions of individual barriers to the adoption system's failure. These are shown in red in the FTA diagram given in Fig. 11.

The value at each level of the fault tree sums up to 1 and 0.33 or 33% at each sub-level. Overall, the highest percentage of failure (6.3%) to adopt DDTs is attributed to *lack of government incentives, R&D support, policies, regulations and standards*

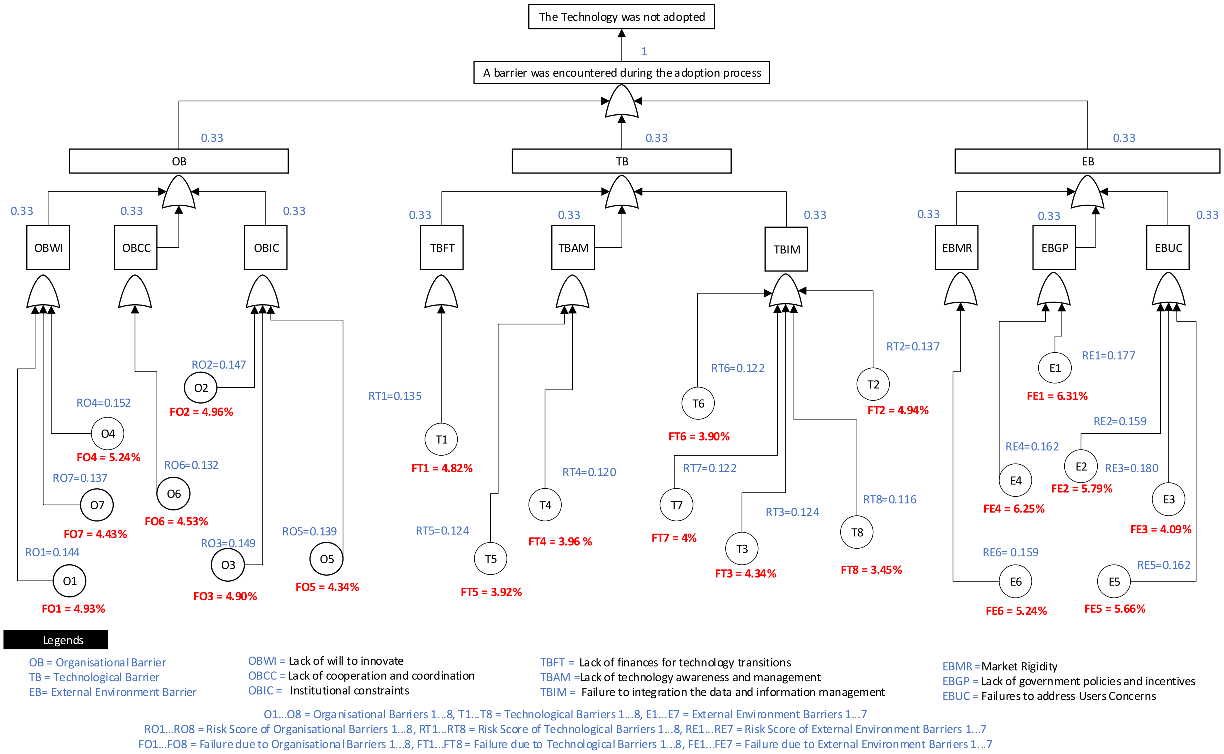

Fig. 11. Fault tree with individual failures values.

(E1), which is also the highest cause of failure in the environmental group. This is in line with Anthony et al. (2019), who stressed the need for policy framework and associated propositions by the government institutions to achieve sustainability and adopt green information technologies. Dwivedi et al. (2017) also stressed the need for government policies to adopt new technologies and highlighted that government context is usually not captured in such studies. It must be captured to develop holistic adoption frameworks. The pertinent reasons for the lack of regulations by the government may be interesting to know in this context.

Similarly, Aina (2017) also stressed the need for smart policies, government support, well-defined standards and smart planning for achieving the goals of smart cities through advanced DDT adoption and innovation. This is in line with the views of most of the respondents where the government support, financial incentives and lack of policies and industry-wide standards are listed as barriers to adopting digital technologies. Accordingly, more incentives, fundings, recognition, awards and support in the form of high-quality standards and policies must be provided to aid the digital transformation and DDT adoption and innovation in the Australian real estate sector.

The second highest barrier responsible for DDT non-adoption (also the second-highest in the environmental group) is the *lack of trust in outsourcing the organisational data* (E4). This is in line with Alwahdani (2019), who highlighted trust as the key enabler for data outsourcing and the exchange of the associated technological and technical knowledge. Trust can be enhanced through a well-designed contract, client capability and vendor capability, operational readiness, transparency, client-vendor relationship and open communication. Four elements were found to significantly impact trust-building between the client and the vendor: a well-designed contract, vendor capability, transparency and communication. Furthermore, external consultant support and top management support are instrumental in enhancing trust. According to Babin et al. (2017), 40% of outsourcing arrangements have failed in the last two decades due to lack of trust that resulted in not achieving the objectives, or original contracts were suspended, renegotiated, or re-tendered, costing over US$440b in business losses. Thus, trust is a critical element for outsourcing success and buyers and providers should invest in it when outsourcing their data. These can be done through confidence-building measures, open and honest communication and listening to suggestions of vendors, suppliers and other businesses. Accordingly, awareness seminars, skill development training and highlighting and marketing of the benefits of digital technologies by vendors and government can aid the adoption process. Such awareness will increase the organisational willingness to invest in digital marketing and digital technologies, increased willingness to shift from human intermediaries to ICT-based intermediaries and more trust in outsourcing the organisational data to aid holistic industry-wide DDT adoption and innovation.

The third leading cause of failure (third in the environmental domain as well) is *high safety and privacy concerns by users* (E2). Since users are at the forefront of technological advancement and adoption and their acceptance of DDT is absolutely essential in an organisation's decision to adopt the DDT, their concerns must be taken with utmost seriousness and satisfactorily addressed. Mora et al. (2018) discussed that digital technologies in smart cities are exposed to cybersecurity threats that hinder their acceptance by users. They suggested leveraging blockchains to balance security and privacy issues and tackle them in smart city users. Accordingly, Yang et al. (2019) proposed a blockchain and AI-based decentralised framework to provide a secure and privacy-preserving infrastructure in smart cities that integrate technologies to provide mutual trust between individuals, businesses and governments, leading to greater transparency of activity and less operational overhead.

Similarly, Khatoun and Zeadally (2017) stressed that making digital technologies in smart cities beneficial and trustworthy for public adoption is imperative to ensure cybersecurity and control crimes. This will require ongoing efforts and support from all stakeholders, including politicians, governments, legal institutions, energy providers, network operators, vehicle manufacturers, cloud providers, research laboratories and industry. Trust is a key factor that can be developed through more user feedback, inviting them to head offices to have an immersive and visualised experience of the technologies and regular surveys and awareness programs coupled with digital marketing investments. For this to materialise, management and lenders' trust in DDT adoption and innovation must be enhanced, the digital communication skills among agents improved and organisational willingness to invest in digital marketing increased through stakeholder coordination and cooperation. This will tackle the cognitive dissonance and address their safety and privacy concerns, increasing the demand for technologies.

In terms of the technological barriers, the top barrier is the *high complexity of the technology dissemination system (T2),* with a value of 4.92%. This is in line with Lafuente and Berbegal-Mirabent (2019) who highlighted that the productivity of technology transfer and dissemination is affected by changes in the configuration of the organisation outcome portfolio. This results from benchmarking own and market peer performance levels. Though benchmarking own performance facilitates internal resources exploitation and yields superior productivity results, changes in the organisational portfolio based on comparisons with market peers might generate greater operational costs that negatively impact productivity. The complexities are directly proportional to the complexities of the systems used to transfer the technologies. Chen et al. (2017) argued that the uniqueness of data could quickly expand the information dissemination and accurately grasp the degree of control for information resources.

Further, strong relationships between stakeholders, including users, can reduce the cost of information dissemination and improve the degree of information adoption that can reduce complex systems development and usage challenges. This can effectively improve the speed and quality of information, dissemination networks and systems and better serve DDT adoption. For this to materialise, it is imperative to develop trust between the users and managers. Further, the complexities of the dissemination systems can be handled through training and skill development seminars that can be incentivised at both organisational and government levels. In this context, a recognition and award system can help motivate the agents, managers and other stakeholders to uplift their digital skills and enhance their abilities to understand and effectively advocate the adoption of digital technologies.

The second highest barrier in the technological domain is the *high costs of software and hardware* (T1), with a value of 4.82%. Mohanty et al. (2016) argued that the number of smart components or digital technologies depends on the cost and available technology infrastructure in the form of software and hardware that can be used to disseminate it. Similarly, Mohamed et al. (2020) stressed using cost-effective technological solutions for smart cities such as UAVs. According to Sepasgozar et al. (2019), the theory of transaction cost analysis needs to be integrated within the set of theories that emphasise socio-economic dimensions and explain the acceptance of the DDT.

Further, any DDT that is likely to reduce the organisation's cost is more likely to be adopted. Thus, technology suppliers must explain and focus on cost savings due to digital technologies. Accordingly, the users will also adopt the DDT if it helps them save money. Therefore, the cost reduction of digital technologies positively affects user intention to adopt them. So, the cost of the DDT and the infrastructure requirement coupled with user costs dictates its adoption. Similarly, as discussed by most of the respondents, funding from the government and establishing more venture capitals can help overcome the cost of adoption and digital transformation of the real estate industry. Further, the increased benefits and enhanced productivity of the technologies must be properly highlighted to motivate the investors and clients to invest in these technologies.

The third highest barrier in the technological domain is *lack of information acquisition, integration, maintenance and data management capabilities* (T3) with a value of 4.34%. According to Kim et al. (2018), organisations must have the innovativeness and data capability to adopt the DDT and harness its potential. They used the TOE framework and developed a research model explaining the factors affecting DDT adoption and innovation from the perspective of IT professionals. The findings suggest that perceived usefulness, perceived ease of use, organisation's innovativeness, organisation's data capability and applicability to managing data are important drivers of DDT adoption and innovation. Similarly, Haneem et al. (2019) also highlighted information complexity, top management support, technological competence and user demand as key factors affecting DDT adoption and innovation. They must be managed for holistic adoption. For this purpose, Sinaeepourfard et al. (2018) suggested using big data and fog to cloud data management. These capabilities and data handling skills can be improved through relevant training and skill development workshops where master trainers can provide adequate training to the real estate agents, managers and other key stakeholders to develop their digital skills and data handling abilities.

In the case of organisational barriers, the highest failure chance is due to a *lack of organisational willingness to invest in digital marketing* (O4) with a value of 5.24%. Low et al. (2020) insisted on the adoption of digital marketing. They discussed that creating real-time interactions, developing key performance indicators to measure digital marketing, personalisation and encouraging innovation in digital marketing paves the path for DDT usage and adoption. They argue that organisations using big9 technologies for digital marketing attract more business and users than their counterparts. Therefore, the investments must be increased in this domain (Kumar et al., 2019). According to Stone et al. (2018), a survey of 1,000 US households shows that six in ten American citizens are hoping to be smart city resident. They are generally used to giving high volumes of data and using data provided by others in their daily lives. They further understand the importance of acquiring and learning how to use many technologies that enable them to do this using smartphones and broadband. Accordingly, more and more organisations must invest in digital marketing to capture a more user base for their products and services. The lack of organisational willingness to invest in such digital technologies is associated with their lack of awareness of the potential benefits. Thus, these benefits must be highlighted and properly marketed by the Proptech developers, technology vendors and government officials to motivate the organisations to invest in these technologies. Adequate funding, incentives and motivation through recognition programs can also help motivate the organisations to invest in digital marketing and the adoption of associated technologies.

The second-highest failure cause in the organisational domain is *highly rigid firm-specific strategies and institutional constraints* (O2) with a value of 4.96%. According to Liang and Qi (2017), rigid organisations that do not want to leave their comfort zones regarding DDT and experimentation become obsolete. They used multiple case studies and developed an integrated model based on the DOI theory, TOE framework, TAM and technology task fit (TTF) to check the contextual influences on the adoption attitudes of the e-government cloud. They found that perceived benefit and perceived barrier from cloud technology characteristics and the organisational rigidity hinder the adoption of the e-government cloud and other technologies that must be addressed. In real estate organisations, Dooley (2017) highlighted routine rigidity as the main reason for the non-adoption of technologies. This routine rigidity is the persistence of following traditional methods and the failure to change the organisational processes. This must be changed if the real estate is to transform into smart real estate. For this purpose, flexibility is required on behalf of the real estate organisations and management. This can be induced through increased trust and proper marketing of the technologies. Awareness of benefits, increased productivity and emphasis on lower lifecycle and maintenance costs of these digital technologies can motivate the management to be flexible and adopt them.

The third highest barrier in the technological domain is *lack of management and lenders' trust in innovation and new technology adoption* (O1) with a value of 4.93%. Ho et al. (2017) claim that the trust of users, managers and stakeholders in the DDT dictates its adoption. This is reinforced by the perceived risk and subjective norms of stakeholders. Asadi et al. (2019) stressed eliminating reluctance through confidence-building measures and risk management to adopt digital technologies. They recommend stakeholders meetings, open communication and potential highlights of the benefits of technologies in addressing the reluctance of managers and investors to adopt new technologies.

Similarly, according to Thakor and Merton (2018), trust is asymmetric—it is more difficult to gain than to lose it. It enables lenders to have assured access to financing, whereas a loss of investor trust makes this access conditional on market conditions and lender reputation. It is due to trust development and maintenance that banks outperform Financial Technologies (Fintech) investors. Thus, for a holistic adoption, the management must first trust the technologies and then convince and motivate the investors to invest in them. This can be achieved through increased awareness of the technology benefits and increased stakeholder coordination and cooperation. For this, awareness seminars, targeted marketing and free trials of the technologies to have an insight into the potential immersive nature of these technologies must be arranged and provided. This can be supported through government funding and incentives, reduced interest rate, loans and establishments of venture capitals and organising awareness seminars and sessions to market the potential benefits, increased productivity and holistic advantages of going digital. This will open new avenues for DDT adoption and innovation for the managers and investors. While for the government, this will ensure moving towards holistic goals of industry 4.0, creating a win–win situation.

In terms of the statistical validations, the Cronbach alpha value was calculated to determine the internal consistency between the respondent's opinions related to the probabilities and impacts of the barriers in the current study, as discussed in the method section. The Cronbach alpha value was 0.961, which is well above the acceptable limits of 0.7. This verifies the consistency and reliability of the data for the analyses conducted in the current study.

Fig. 12 compares the fault trees developed for respondents with less than ten years of experience to those with more than ten years of experience in the Australian real estate sector. A consensus can be seen for two-third of the factors (14 out of 21) where the failure difference is less than 0.5%. However, for one-third of the factors, more than 0.5% of the variation is observed. The highest difference is observed for *lack of public demand for the selected technology* (E3). The less experienced managers have assigned it a score of 4.53% compared to 5.53% by the experienced managers. This highlights a lack of consensus related to public demand, which is evident from the discussion with younger managers. They claim that the senior managers, most of whom are in leadership roles, follow a traditional approach and unless a very strong public demand is generated for a DDT, which is only possible when the people know about that technology, the adoption remains elusive. Alternatively, the younger (less experienced) mangers are open to experimentation and assign this a lower score which is in line with Low et al. (2020).

The next factor with a variation of 0.81% between the respondent's groups is the *lack of management and lenders' trust in innovation and new technology adoption* (O1). The more experienced managers have assigned it a lower score compared to less experienced respondents. This shows a difference of opinion where the senior managers think they are open

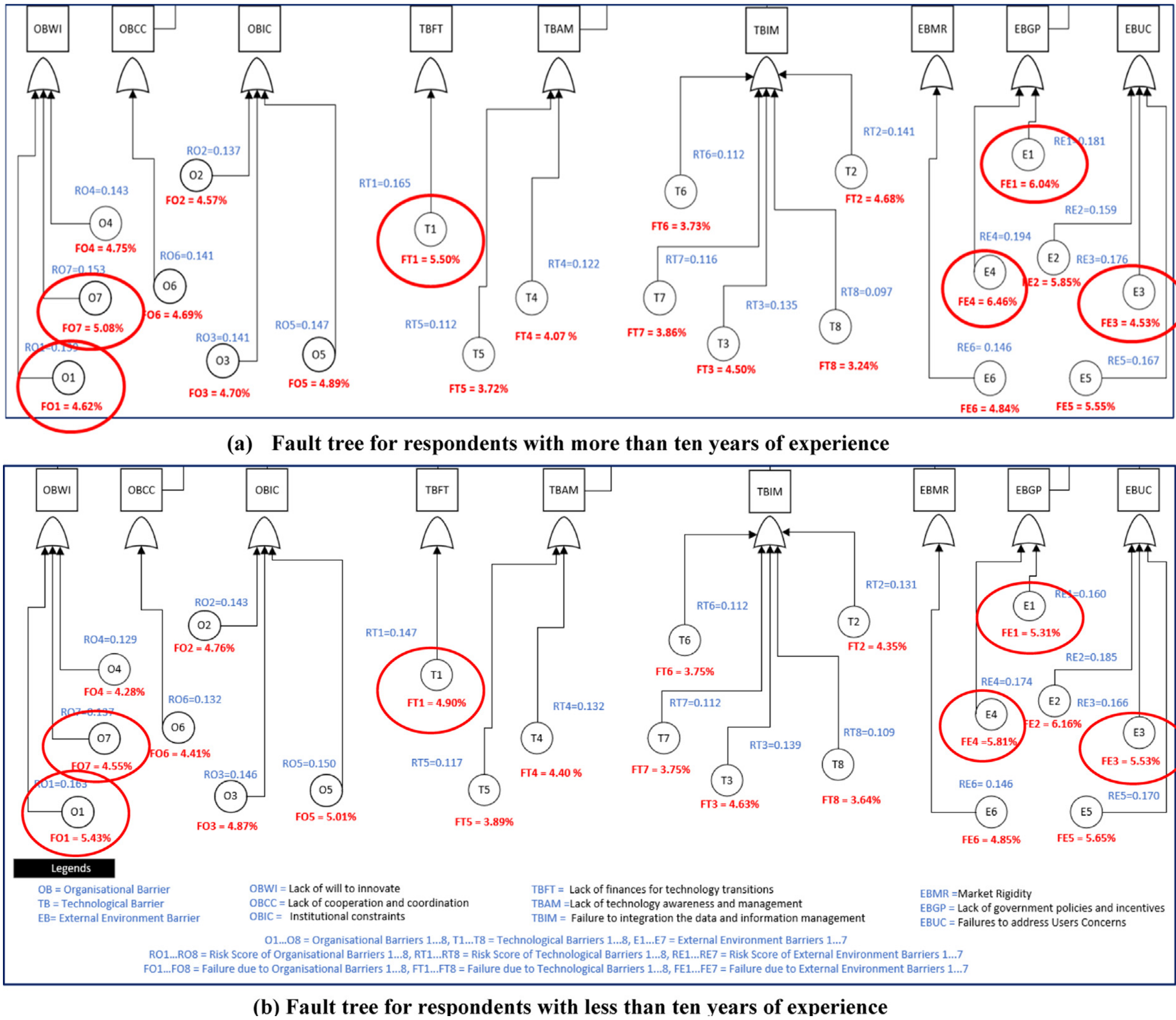

Fig. 12. Experience-based comparisons of fault trees.

to innovation. However, younger managers have a contradictory opinion. Accordingly, younger managers believe that senior managers are not much open to innovation and experimentation. A consensus can be developed through holistic institutional policies that take the opinion of everyone into account.

Similarly, other factors with less consensus include *high cost of software and hardware* (T1), *lack of government incentives, R&D support, policies, regulations and standards* (E1), *lack of trust in outsourcing the organisational data* (E4) and *lack of organisational willingness to shift from human intermediaries to ICT-based intermediaries* (O7). Overall, half of these factors (3 out of 6) are related to the trust and willingness of the organisations to innovate that can be effectively addressed through awareness seminars, incentives by the government and open discussions within the organisations. Regarding the reliability of the results, the Cronbach alpha values were 0.88 and 0.96 for respondents with greater than or equal to and lower than ten years of experience, respectively. Both these are above 0.7. Thus, the reliability of the data is acceptable for both cases.

3.5. Examples and reasons for non-adoption of disruptive technologies

At the end of the questionnaire, respondents were asked to provide any specific examples or additional details they want to share about barriers in adopting disruptive technologies in their organisation through an open-ended question: "Do you have any specific example or any additional details you want to share about barriers in adopting disruptive technologies in your organisation?". Further, the statement, "This can include barriers not discussed in this study, case-specific examples or other information you feel can help this study", was provided to help respondents remain to the point and concise. In response to this question, 31 respondents shared their thoughts and opinions. They highlighted the key legal issues, lack of industry standards, lack of integration or inability to integrate the technologies, DDT benefit awareness, lack of funding, higher costs of adoption and lack of external support, adaptability of staff/agents to new technologies and organisational reluctance, lack of user or public demands and client's interest in investing in new technologies and others. The following subsections summarise their opinions and provide pertinent discussions.

Legal issues, lack of industry standards and others

Lack of industry standards and the legal issues around DDT deployment are among the main hurdles facing DDT adoption and innovation in the Australian real estate sector, as discussed by ten respondents in their response to the open-ended question. A respondent stated, *"A reason for non-adoption is user education around digital execution methods being a compliant and legitimate form of contract and form completion. My experience is many people recognise the efficiency and customer experience benefits for ways to digitally execute things traditionally done manually, or in paper format - however, are always concerned about compliance and regulation requirements"*.

Similarly, other respondents stressed the need for well-defined and up to date industry standards around adopting technologies. A respondent stated, *"The absence of industry standards and regulations around these technologies hinders our organisational shift towards their adoption"*. Another respondent reinforced this and indicated the service complexity due to the lack of tools and standards hindering the adoption of disruptive technologies. A respondent stated the capabilities of the vendors to supply parts and key items on time as a hurdle to DDT adoption. Giving the example of 3D printing that they want to adopt in their organisation, the respondent stated, *"From a facilities management perspective, it is simply about [the] availability of parts, cost and delivery speed via the vendor network. This has the potential to reduce costs to clients and increase satisfaction, particularly in a complex and dispersed portfolio. However, the vendors usually fail to deliver these on time or [the equipment] is otherwise too costly to repair, thus making them think again about the adoption"*.

Other issues highlighted by the respondents include concerns about managing the assets and data, organisational readiness in terms of resources, lack of strategy, reliance on manual and outdated methods, etc. Similarly, a respondent stated, *"Data is intellectual property and everyone is trying to hold it. This creates a tension between the various organisation which discourage the sharing of data and information"*. Another respondent highlighted the pace of some Australian real estate markets and stated, *"Unfortunately, the Sydney market is so fast-paced the technology still lags and provides inaccurate data"*. Thus, there are concerns about the accuracy of the data and the inability to keep up with the pace of technological changes.

However, the will is there as stated by one respondent, *"We are a growing company, the company is trying to bring the latest technology … such as a well-structured platform to market ourselves and keep track of our sales and KPI"*. Similarly, another respondent stated, *"There are some companies in the Australian market that use disruptive technologies to assist with their property valuations"*. Such companies seem to be investment-oriented and use state of the art blockchain and Fintech platforms for their investment management in property sectors.

This is in line with the FTA findings, where the barrier *lack of government incentives, R&D support, policies, regulations and standards* (E1) is the topmost contributor to the failure to adopt technologies. The frequent mention of this barrier in discussion validates and verifies the FTA results. Accordingly, for a holistic adoption of technologies in the Australian real estate sector, the government must incentivise such technologies, provide R&D support and draft high-quality policies, regulations and standards through discussions with real estate leaders and key stakeholders. This will motivate the real estate organisations to invest in digital technologies, induce a willingness to shift from human intermediaries to ICT-based intermediaries and increase their trust in outsourcing the organisational data that will enable a holistic country-wide DDT adoption in line with industry 4.0 goals.

Lack of integration or inability to integrate the technologies

Eight out of 31 respondents reported examples or challenges to real estate DDT adoption as the lack of integration or inability to integrate the technologies. In this context, a respondent stated, *"Currently, we are finding that we have many technological options to implement or use. Our owner is a major investor in C2C and CRM development, where often the biggest challenge is the various platforms' inabilities to integrate or network. Further, few platforms seem to integrate well, so although the desire is there, various pieces of technology cannot interface"*. Reinforcing the above claim, another respondent stated, *"Integration of disruptive technologies with other platforms is often quite poor and requires many hours of paying skilled technicians to provide a solution. This is both time-consuming and expensive"*. These challenges cloud the management team's judgement and may avert them from adopting the technologies. Thus, to pave the way for holistic adoption of technologies, it is important to uplift and improve the existing systems for seamless integration of DDTs. Otherwise, financial incentives should be provided by the government to tackle the high costs of the required software and hardware. Training and awareness seminars should be provided to tackle the high complexity of the selected technology dissemination system and enable information acquisition, integration, maintenance and data management capabilities.

Another respondent stated, *"By far our biggest barrier to technological advancement is slow-moving regulation, legislation and compliance standards and also situations where [the] public sector, third parties and regulators (like Bond Boards and Centrelink/Centrepay) have archaic systems that we need to integrate with to complete an end-to-end process that can otherwise be fully and securely digitised"*. The same has been reinforced by another respondent who states that the lack of software partner integration and defencive platforms for integration hinders their organisational adoption of the smart real estate disruptive technologies. Further, the rapid evolution and associated upgrading or high-level maintenance requirement due to less efficient existing systems also add to the integration challenges. In this context, a respondent stated, *"The space is rapidly evolving; it is a never-ending process of maintaining/ updating/ upgrading these technologies to remain current"*.

These comments highlight the need to have proper regulations, legislation, standards and training for the managers and real estate key stakeholders to handle the pertinent digital technologies. These are in line with the three shortlisted top barriers for the external environmental group and two for the technology group. These are *R&D support, policies, regulations and standards* (E1), *high complexity of the selected technology dissemination system* (T2), *lack of information acquisition, integration, maintenance and data management capabilities* (T3). For addressing this concern, along with provisions of the legal frameworks supporting the adoption of the DDT, stakeholder coordination and cooperation and organisational willingness to shift from human intermediaries to ICT-based intermediaries are compulsory. These will enable the key stakeholders and real estate agents and managers to develop their skills and capabilities in sophisticated technologies and pertinent infrastructure for handling the associated data. Support from government and external organisations will enable a smoother transition in this context.

DDT benefit awareness

Awareness of the benefits of DDTs is a key focus of almost all theories presented in this study, including HDT, DOI, TAM, EU, CT and ROT. The lack of awareness of benefits is another reason for the non-adoption of digital technologies in the Australian real estate sector as discussed by six respondents. A respondent stated, *"For our organisation, it is awareness. Leaders are not aware of the power of technology and believe real estate is a relationship business. Cost is another issue and being a global firm, getting all countries to support initiatives is challenging".*

Similarly, another respondent highlighted the inability of Proptech vendors to emphasise the benefits of reduced costs and improved productivity. They stated, *"Most Proptech vendors miss being able to advise on how their technology can increase productivity; some is good but hard to show an improvement to make cost viable".* One of the respondents discussed providing proper training, education and awareness seminars targeted at highlighting the benefits and improved productivity of the new technologies can tackle these issues. Accordingly, organisational willingness to invest in digital marketing can be increased and trust in outsourcing the organisational data established to adopt the technologies at holistic levels.

A respondent who owns a successful business of ticket parking in real estate and commercial properties highlighted how the use of innovative technologies has helped them become the market leader in their domain. They stated, *"In 2010, I invested [in] the world's first ticketless parking system using license plate recognition technology in my garage for Lane Cove Council car park at Market Square, NSW Australia. For the next two years, I was unable to secure another sale, there was lots of resistance and every excuse was levelled at the company and product. From 'you are a small company' to 'people will not remember their license plate', 'people are used to getting a ticket, why do we want to change technology when this has served us well etc....', we heard them all. The biggest push back came from ticket-based equipment suppliers pedalling fear, doubt and uncertainty about the technology. We weathered the storms and have grown and increased our customer base from those early days. If not for COVID-19, we were going to be exporting our technology, looking forward to 2021 to travel overseas and export our technology".* Sharing such success stories and increased awareness is tantamount to adopting digital technologies in the real estate sector. Accordingly, incentives and seminars should be arranged and such successful entrepreneurs encouraged to share their success stories to highlight the benefits of adopting digital technologies.

Another respondent summed up the challenges of awareness as, *"The biggest barrier is being unaware of the art of the possible. It is difficult to stay up to date on all technological developments".* Thus, lack of awareness, coupled with the ever-changing technological demands and the need to uplift and maintain the critical infrastructure, hinder DDT adoption and innovation. This is in line with the *lack of awareness of improved productivity due to the technology* (O5) which is one of the key organisational barriers as per the FTA. Accordingly, awareness seminars must be arranged and the technologies should be properly marketed to highlight the benefits. Both vendors and government can take such initiatives. This will create more awareness that will increase the organisational willingness to invest in digital marketing and digital technologies and increase their willingness to shift from human intermediaries to ICT-based intermediaries, aiding DDT adoption and innovation.

Lack of funding, higher costs of adoption and external support

Funding has always been a critical concern for technological advancements, as evident from the views of six respondents. A respondent stated that lack of funding is hindering their organisational adoption of technologies. Another respondent indicated the high cost as the key barrier to DDT adoption and innovation in their organisation.

A respondent highlighted the absence of venture capitalists (VCs) in the Australian market coupled with government support and external funding that hinder their adoption of the latest technologies. The respondent stated, *"There are not as many VCs in Australia as in the US/Europe/Chia who invest [in] the PropTech/Property Financial Technologies (PropFinTech) companies. The whole real estate digitalisation ecosystem is not mature yet in Australia. For innovative real estate companies which aim to become the pioneer in the PropFinTech area, we need more funding and capital support from both the VCs and the government".*

However, a respondent on a positive note stated that *"There are many reasons for the lack of adoption to date, but that is now changing, tech is starting to solve real-world problems, easy to deploy and consumable for a small business like most real estate firms".*

Funding is a key concern for DDT adoption and is usually associated with the high costs of software and hardware. This is in line with the topmost ranked environmental barrier of *lack of government incentives, R&D support, policies, regulations and standards* (E1) and the second-ranked barrier of the technological barriers, *high costs of software and hardware* (T1) as per the FTA. These higher costs coupled with the high complexity of the selected DDT dissemination system, lack of information acquisition, integration, maintenance and data management capabilities and access to market data required for integrating the selected DDT with existing infrastructure hinder the DDT adoption and innovation in Australian real estate. To address this issue, legal frameworks supporting the adoption of the selected DDT, stakeholder coordination and cooperation and government incentives, R&D support, policies, regulations and standards must be provided to the real estate managers. Establishing more VCs and provisions of loans at lower interest rates will help address these barriers.

The adaptability of staff/agents to new technologies and organisational reluctance

Another reason highlighted by the respondents is the staff's adaptability or internal resistance to the DDT adoption and innovation, as discussed by five respondents. Two respondents highlighted the change management or getting people to do things differently to get a different result as one of the core issues for non-adoption of disruptive technologies. Another respondent supported this and argued that staff adaptability challenges hinder the DDT adoption and innovation in their organisation. A respondent, a Proptech manager, criticised the real estate agents for not adopting the technologies and claimed, *"Agents are threatened by technology and technologists"*. Another respondent argued that *"Resistance is also due to the late Industrial Age organisation structures that do not support fully digitalised environments and business interactions. Further, shoe-horning emerging/disruptive technologies into late Industrial Age business structures will only produce a minimum efficiency and effectiveness gain. A very tough but radical disruptive and strategic thinking is required to leverage the tech fully. The agents and managerial staff may not be in the position to take such tough decisions or maybe more risk-averse in general, as in the case of their organisation"*. This highlights the need to develop the capabilities and skills of agents and managers to fully leverage digital technologies. Incentives should be provided at both organisational and government levels to motivate the managers and agents to go for such training and uplift their skills. Awards, bonuses and other incentives should be introduced in the organisations to facilitate such skill acquisitions. This will address the poor digital communication skills among agents and uplift the state of the sector to facilitate digital transformation by minimising the rigid firm-specific strategies and institutional constraints. This is supported by a respondent who highlighted the staff's inadaptability to the new technologies and stated that this is easily addressable through proper training, educational seminars and increased awareness about the benefits.

Another respondent highlighted their organisational reluctance to experiment with new technologies and stated, *"The CEO and Board of our organisation have an attitude of "If it is not broke, do not try and fix it". They are set in more traditional ways of doing things and believe all of the property information can be gathered by walking the space and talking to people"*. Similarly, another respondent highlighted a lack of interest in new technologies on the part of their management where they are continuously shut through statements like *"this is not a priority at the moment"*, derailing the shift to new technologies. Due to such laggards as per the DOI, the adoption of technologies in the Australian real estate sector is slow.

These issues are in line with the barriers of *highly rigid firm-specific strategies and institutional constraints* (O2) and *lack of management and lenders' trust in innovation and new technology adoption* (O1) as per the FTA. Accordingly, these should be addressed through incentives, R&D support, legislations and support by the government agencies. Proper training and awareness sessions can help motivate the organisations towards digital transformation and help address rigid firm-specific strategies and institutional constraints, stakeholder coordination and cooperation and rigid market attributes of the real estate sector. This will also increase the trust of management and lenders in innovation and new DDT adoption that will facilitate the technological transformation of the real estate sector.

Lack of user or public demands and client's interest in investing in new technologies

User or public demand is another highly reported reason for the non-adoption of DDTs as discussed by four respondents. As per the HDT, user demand and value offered by the DDT dictate its adoption. A respondent highlighted the lack of confidence and confidentiality associated with DDT adoption and innovation as the main hurdle to user acceptance of these technologies. This, in turn, demotivates the management to invest in these technologies. Another respondent highlighted the market demand for the technologies and stated, *"In my view, the market drives the innovation where some company might create disruption and others would have to follow or would be at a disadvantage"*. Thus, to tackle this aspect, along with the awareness of users and the general public about the benefits of digital technologies, user safety and privacy concerns should be addressed to resolve the cognitive dissonance. This will address the lack of public demand for the selected DDT. Additionally, the real estate sector has to be more flexible and adaptive. It is possible through effective collaboration and coordination between stakeholders, flexing the highly rigid market attributes of the real estate sector.

Another respondent stated, *"We are a digital marketing agency and it is often the client's lack of understanding or willingness to invest that prevents adoption"*. Such clients need to be managed through ROT, DOI and EU principles, where the benefits must be explained to motivate them to invest in technologies. Awareness programs targeted at highlighting the accuracy of the estimated property value through DDTs and increasing the awareness of improved productivity, as a result, will induce organisational willingness to invest in these digital technologies. Another respondent, a CEO of a real estate organisation, emphasised the ability to realise and sell the benefits of a new DDT first to pave the way for its adoption. They stated, *"People are initially apprehensive about new technology. The task is to sell the benefits first and then progress implementation through simple training & education"*. An emphasis on the improved productivity and benefits of digital technologies through awareness and incentives by the government will help motivate the managers for DDT adoption and innovation.

A respondent stressed the need for user voice on disruption (in line with HDT) and stated that *"This will be a consumer-led disruption where the traditional agents will have to adapt or become less relevant to the whole real estate transaction"*. They provided the example of "Peg-ee", a proprietary SaaS-based free consumer platform where machine learning meets humanity through augmented intelligence. They also added, *"Agents will exist, but by deconstructing the process and empowering the property consumer at all stages of their individual property journey/cycle, they will demand an experience/outcome traditional agent cannot possibly deliver. It will be most of all, a transparent – trusted – proactive property platform"*. About the implementation part, they stated, *"We have figured out how to analyse the tangible and intangible to property values relative to the individual consumer property journey and transaction. It is far more than hard data alone. Our organisation is already moving to have someone in every suburb open and shut the door, but Peg-ee will bring them there ready to transact. The traditional industry is one of the least efficient and ineffective cottage industries. The consumers deserve a more certain and transparent process"*.

These issues are in line with the *high safety and privacy concerns by users* (E2), resulting in a *lack of public demand for the selected technology* (E3) as per the FTA. Trust building activities and being more transparent towards the users by providing more detailed and reliable information can help tackle these concerns. Thus, considering these comments, prioritising users and meeting their needs to address their safety and privacy concerns and associated cognitive dissonance will increase the public demand for the selected DDT to pave the way for DDT adoption and innovation in Australian real estate.

4. Conclusions, limitations and future directions

The current study investigated the barriers to adopting disruptive digital technologies in the Australian real estate sector from a managerial perspective through four key objectives. A three staged methodology was adopted where the relevant literature was retrieved using WoS and Scopus engines and reviewed to highlight pertinent barriers to the adoption of digital technologies in Australian real estate. A conceptual fault tree was developed using these barriers to DDT adoption and innovation and a comprehensive questionnaire was run to capture the views of 102 relevant real estate managers.

To address objective 1, i.e., to highlight the key barriers in digital DDT adoption and innovation in the Australian real estate sector, 72 articles were systematically reviewed to highlight 154 barriers. The results of the literature synthesis show that the keywords such as "technology adoption", "information technology", "technology acceptance", "construction management", "model", "real estate", "construction industry", "innovation", "sustainability", "economics", "energy conservation", "information technology", "investment" and "real estate development" were the most repeated in the retrieved papers highlighting the relevance of the papers to the DDT adoption in real estate and broader built environment, supporting their usage for detailed analyses. After this initial synthesis, a detailed review of the papers was conducted where the 154 identified barriers were narrowed down to 72 barriers and eventually 21 key barriers that are distributed into technology, organisation and environment (TOE) categories. The technology category houses eight key barriers: *high costs of software and hardware* , *high complexity of the selected technology dissemination system*, *lack of information acquisition, integration, maintenance and data management capabilities*, *lack of access to market data required for integrating the selected technology with existing infrastructure*, *lack of legal frameworks supporting the adoption of the selected technology*, *lack of understanding of smart/electronic contracts to use the selected technology*, *lack of ability to create and manage independent online portals supporting the selected technology* and *low accuracy of the estimated property value of the technology*. The organisational category houses seven barriers: *lack of management and lenders trust in innovation and new technology adoption*, *highly rigid firm-specific strategies and institutional constraints*, *lack of digital communication skills among agents*, *lack of organisational willingness to invest in digital marketing*, *lack of awareness of improved productivity due to the technology*, *lack of stakeholder coordination and cooperation* and *lack of organisational willingness to shift from human intermediaries to ICT-based intermediaries*. In comparison, the external environmental category houses six key barrier: *lack of government incentives, R&D support, policies, regulations and standards*, *high safety and privacy concerns by users*, *lack of public demand for the selected technology*, *lack of trust in outsourcing the organisational data, high resistance to the selected technology acceptance by the users (cognitive dissonance)* and *highly rigid market attributes of the real estate sector*.

The second objective was to develop a conceptual fault tree and link the barriers to the tree for a holistic assessment of the reasons behind DDT non-adoption. The conceptual fault tree was developed using the logics and relations of the barriers used in the reviewed study following the TOE categories. All the risk scores and failure values for the fault tree branches are calculated through probabilities and impacts assigned to the barriers by the 102 respondents. The associated fault tree analysis shows that the highest percentage of failure to adopt the DDT is attributed to *lack of government incentives, R&D support, policies, regulations and standards* , followed by *lack of trust in outsourcing the organisational data* and *high safety and privacy concerns by users* for the environmental group. The highest failure for the technological group is attributed to the *high complexity of the selected technology dissemination system*, followed by *high costs of software and hardware* and *lack of information acquisition, integration, maintenance and data management capabilities*. For organisational barriers, the barrier with the highest failure chances for DDT adoption and innovation is *lack of organisational willingness to invest in digital marketing*, followed by *highly rigid firm-specific strategies and institutional constraints* and *lack of management and lenders' trust in new technology adoption*.

The third objective was to investigate the awareness levels of Australian real estate managers regarding disruptive digital technologies. This was achieved through the questionnaire survey. For this purpose, the demographics of the respondents was assessed first, which shows that 55% of the respondents are classified as real estate agents, real estate/property web or IT managers and real estate/property manager/consultants. More than 54% of the respondents have more than ten years of experience in the real estate and property management fields. A comparison of the FTA for these two groups shows a consensus on 66.6% of the factors. The remaining 33.3% include *lack of public demand for the selected technology* (E3), *lack of management and lenders' trust in innovation and new technology adoption* (O1), *high costs of software and hardware* (T1), *lack of government incentives, R&D support, policies, regulations and standards* (E1), *lack of trust in outsourcing the organisational data* (E4) and *lack of organisational willingness to shift from human intermediaries to ICT-based intermediaries* (O7), respectively. For developing consensus on these factors, awareness seminars, open discussions in organisations and government incentives are required.

Further, over 90% of the respondents are located in the north-eastern regions of Australia. In terms of DDT awareness, 77.5% of respondents are aware of AI, followed by VR and Drones (72.5%). It is positive for the adoption of technologies. Further, 22.5% of respondents selected AI, followed by Big Data and VR (12.75%) as the most important DDT for their organisation not currently adopted. More than half of the respondents stated costs or expenses associated with the selected technologies as the main reason for non-adoption. Other reasons for non-adoption stated by respondents included company/organisation policies/practices, lack of awareness, DDT adoption and innovation reluctance, lack of understanding of technologies, reluctance to explore new techs, lack of people/user demand, barriers/issues/problems/risks in the integration of technologies, limited data management capabilities, lack of government support, proper use/leveraging abilities, valuation complexities, rigid business policies, need for the DDT and time required to adopt and understand it. The main reasons and examples provided by the respondents for non-adoption are related to lack of integration or inability to integrate the technologies, lack of user or public demands and client's interest in investing in new technologies, staff/agents' adaptability to the new technologies and organisational reluctance, DDT benefit awareness and lack of funding, higher costs of adoption and external support.

The final objective of the study was to develop a risk matrix and allocate the barriers to pertinent quadrants based on the risk scores. For this purpose, the risk scores in terms of probabilities and impacts were sought from the 102 respondents and PMBOK guidelines were used to develop the matrix. In terms of the risk scores assigned to the barriers, the highest mean probability score is observed for *high costs of software and hardware* followed by the *high complexity of the selected technology dissemination system*, *lack of information acquisition, integration, maintenance and data management capabilities* and *lack of trust in outsourcing the organisational data*. Similarly, the highest normalised mean impact score is observed for the *lack of organisational willingness to invest in digital marketing*, followed by the *high complexity of the selected technology dissemination system*, *lack of legal frameworks supporting the adoption of the selected technology*, *lack of ability to create and manage independent online portals supporting the selected technology*, *highly rigid firm-specific strategies and institutional constraints*, *lack of digital communication skills among agents* and *lack of government incentives, R&D support, policies, regulations and standards*. Overall, the highest risk scores are observed for *high costs of software and hardware*, *high complexity of the selected technology dissemination system*, *lack of government incentives, R&D support, policies, regulations and standards*. Similarly, the lowest risk scores are observed for *low accuracy of the estimated property value of the technology*, *lack of awareness of improved productivity due to the technology* and *lack of public demand for the selected technology*.

The current study has both theoretical and practical contributions. The study contributes to the body of knowledge by investigating the key barriers to DDT adoption and innovation in real estate and helps guide the body of knowledge towards a transformation of real estate into smart real estate by eliminating barriers to the adoption of digital technologies. The quantification of barriers is a novelty of the study where an unexplored area of DDT adoption and innovation in smart real estate has been investigated in details, the barriers identified and quantified to move towards a holistic adoption framework for smart real estate DDT adoption and innovation. Also, the developed risk matrix is a novel contribution to the smart real estate domain. The objective of the risk matrix in the current study is to enable the organisations to develop specialised risk responses to the barriers in adopting DDT in smart real estate.

In terms of the practical contributions, addressing identified barriers can help address the regrets of key users related to information accuracy and pave the way for provision using the big9 disruptive technologies to the real estate users. The quantification of risks in the form of risk scores (probability and impact) in the matrix can help the managers identify the most critical risk and develop risk-specific strategies in line with the risk management techniques. Thus, the matrix is a way forward to integrating project management techniques for smart real estate and property management that can be utilised by the managers. Accordingly, there are several benefits of having a specialised risk matrix for real estate management. These include help in approaching risks according to their level of urgency, simplifying the risk management process, spotting risk with little effort, showcasing risk mitigation efficiency of an organisation and effectively avoiding any undesirous impacts. These risks based on the level of urgency can help guide the real estate managers about which area to target and prioritise and gain a competitive advantage. Overall, the study is useful to both researchers and practitioners. The researchers can expand upon the list of barriers to DDT adoption and innovation in smart real estate and explore them in detail to propose holistic adoption frameworks. Similarly, the practitioners can adopt the suggested technologies by addressing the barriers to attract or retain more customers and hence more business.

Although the current study used a non-linear scale for questionnaire responses, the dynamic relationship between the barriers and the intra-relationship was not assessed, which is a limitation of the current study. This can be explored in a future study to expand upon the quality of the current study. For this purpose, system dynamics or DEMATEL techniques can be used. Another potential limitation, although unintentional, is that of most of the respondents belonging to north-eastern Australia, that may create a systematic bias of opinions. In future, a more evenly spread of respondents across all Australian states may produce different results that can be used to compare state-wise barriers for Australian real estate. Further, the current study is restricted to the Australian real estate sector that can be enhanced in the future to include other countries. A comparison with a developing country would be a useful addition to the body of knowledge in the era of industry 4.0 and moving towards smart real estate and a smart planet.

CRediT authorship contribution statement

Fahim Ullah: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing - original draft, Writing - review & editing. **Samad M.E. Sepasgozar:** Conceptualization, Project administration, Resources, Supervision, Validation, Visualization, Writing - review & editing. **Muhammad Jamaluddin Thaheem:** Conceptualization, Project administration, Supervision, Validation, Writing - review & editing. **Fadi Al-Turjman:** Validation, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. List of all barriers

Context	Risks/Barriers	f	Indexing	
			WOS	SC
Technological	High costs of software and hardware	10	✓	✓
	Lack of access to market data required for integrating the selected technology with existing infrastructure	8	✓	✓
	High complexity of the selected technology dissemination system	7	✓	✓
	Lack of information acquisition, integration, maintenance and data management capabilities	7	✓	✓
	Lack of legal frameworks supporting the adoption of the selected technology	6	✓	✓
	Lack of understanding of Smart/Electronic contracts to use the selected technology	6	✓	✓
	Lack of ability to create and manage independent online portals supporting the selected technology	6	✓	✓
	Low accuracy of the estimated property value of the technology	4	✓	✓
	Lack of Understandings of digital assemblages for new technologies	4	✓	✓
	Low technology efficiency	4	✓	✓
	Lack of updated, reliable and accessible information	4	✓	✓

Context	Risks/Barriers	f	Indexing	
			WOS	SC
	Incompatible, outdated systems and reliance on such outdated technologies	4	✓	✓
	Lack of remote management control	3	✓	✓
	Lack of understanding of blockchain transactions and blockchain land registration	3	✓	✓
	Lack of accurate digital records of relevant information	3	✓	✓
	Lack of understanding and usage of advanced automated valuation models	2	✓	✓
	High copyrights concern for property data and images	2		✓
	High proprietary data locking	2		✓
	Lack of technological integration and synergy	2	✓	
	High Use of non-integrated software	2	✓	✓
	Lack of digital property passports or data logbooks	2	✓	✓
	Lack of renewal of critical infrastructure	2	✓	✓
	Lack of reliability of infomediary sales channel	2	✓	✓
	Lack of accuracy of predictive analytics tools	2		✓
	Lack of a single pool of standardised property information	2	✓	✓
	High Incoherent human and machine interactions	2	✓	✓
	Lack of managing 24/7 customer interface	1		✓
	Low search engine rankings	1		✓
	Lack of ability to get timely firsthand project information	1		✓
	Lack of locally developed technologies, institutes and facilities	1	✓	
	Lack of ability to identify the correct digital parcel	1	✓	✓
	Lack of critical mass	1	✓	✓
Organisational	Lack of management and lenders' trust in innovation and new technology adoption	15	✓	✓
	Highly rigid firm-specific strategies and institutional constraints	7	✓	✓
	Lack of digital communication skills among agents	7	✓	✓
	Openness to invest in digital signages and advertisements	6	✓	✓
	Lack of organisational willingness to invest in digital marketing	6	✓	✓
	Lack of awareness of improved productivity due to the technology	6	✓	✓
	Lack of stakeholder coordination and cooperation	6	✓	✓
	Lack of organisational willingness to shift from human intermediaries to ICT-based intermediaries	6		✓
	Lack of adopting open data standards and revealing all information	4	✓	✓
	Lack of professional training applications	4	✓	✓
	Lack of channel-specific salespeople	4	✓	✓
	Lack of managements' technical knowledge about new technologies	4	✓	

Context	Risks/Barriers	f	Indexing	
			WOS	SC
	Lack of effective leadership for technology adoption	4		✓
	Lack of sales technologies understanding by lead management	3	✓	✓
	Lack of willingness of firms to openly share property data	3	✓	✓
	Lack of strategic management of the property resource	3	✓	✓
	Poor remote expert's management	3	✓	✓
	High delays in property registration	2	✓	✓
	Lack of administrative workload management	2	✓	
	Lack of collaboration between cluster enterprise	2		✓
	Highly inconsistent approaches to data rooms	1	✓	✓
	Higher levels of uncertainty pertaining to envisaged rates of return	1	✓	
External Environment	Lack of government incentives, R&D support, policies, regulations and standards	10	✓	✓
	High safety and privacy concerns by users	9	✓	✓
	Lack of public demand for the selected technology	6	✓	✓
	Lack of trust in outsourcing the organisational data	6	✓	✓
	High resistance to the selected technology acceptance by the users (cognitive dissonance)	6	✓	✓
	Highly rigid market attributes of the real estate sector	5	✓	✓
	Highly asymmetric risk information between originators and investors	4		✓
	Lack of coordination of land management documentation	3		✓
	Lack of public access to socio-spatial data	2		✓
	Legal aspects of open data usage	2		✓
	Lack of efficiency and effectiveness of housing regulations	2		✓
	High Disintermediation	2	✓	✓
	High legal challenges in collecting data from areas of limited use	2		✓
	Lack of regulatory acts establishing administrative boundaries	2	✓	
	High policy resistance by technology suppliers	2	✓	
	High subcultural dynamics	2	✓	
	High expected social benefits	2	✓	✓
	Highly under-resourced authorities and utility companies	2	✓	✓

Note: f means frequency, WOS means Web of Science and SC means Scopus.

Appendix B. List of 72 articles used in the current study

Authors	Title	Year	Source title
Chen Y., Wang M., Li L.	A Framework for the Contract Management System in Cloud-Based ERP for SMEs in the Construction Industry	2020	Journal of Property Investment and Finance
Chen Z.-L., Chen J.-Y., Liu H., Zhang Z.-F.	Present status and development trends of underground space in Chinese cities: Evaluation and analysis	2020	GREEN BUILDING IN DEVELOPING COUNTRIES: POLICY, STRATEGY AND TECHNOLOGY
Chow J.Y.J.	Policy analysis of third party electronic coupons for public transit fares	2020	JOURNAL OF HEALTHCARE ENGINEERING
Comerford D.A., Lange I., Moro M.	Proof of concept that requiring energy labels for dwellings can induce retrofitting	2020	JOURNAL OF CORPORATE ACCOUNTING AND FINANCE
Nelson, R; Howden, M; Hayman, P	Placing the power of real options analysis into the hands of natural resource managers - Taking the next step	2020	FACILITIES
Richardson K.	On the horizon at the port of San Diego	2020	JOURNAL OF PROPERTY INVESTMENT & FINANCE
Sun Y., Ifeanyi O.	A qualitative study of e-business adoption in the real estate sector in China	2020	Journal of Property Investment and Finance
Abdullah E.M.E., Rahman A.A., Rahim R.A.	Adoption of financial technology (Fintech) in mutual fund/ unit trust investment among Malaysians: Unified Theory of Acceptance and Use of Technology (UTAUT)	2019	Sustainability (Switzerland)
Abidoye R.B., Junge M., Lam T.Y.M., Oyedokun T.B., Tipping M.L.	Property valuation methods in practice: evidence from Australia	2019	PROPERTY MANAGEMENT
Al Abdallah G.M., Abou-Moghli A.A., Al-Thani A.H.	An examination of the e-commerce technology drivers in the real estate industry	2019	Geomatics and Environmental Engineering
Avdeev D., Kryakhtunov A.	Problems of introduction information about the limits of administrative and territorial units	2019	JOURNAL OF CLEANER PRODUCTION
Awuzie B., Monyane T.	Achieving sustainable construction in South Africa through digitalization: An exploratory study	2019	Journal of Enterprise Information Management
Darko, A; Chan, APC; Owusu-Manu, D; Gou, ZH; Man, JCF	Adoption of Green Building Technologies in Ghana	2019	Advances in Intelligent Systems and Computing
Elbeck, M; Dedoussis, EV	Arabian Gulf innovator attitudes for online Islamic bank marketing strategy	2019	Proceedings of 22nd International Conference on Advancement of Construction Management and Real Estate, CRIOCM 2017
Gopalakrishnan V., Ziv G., Bakshi B.R.	Role of Vegetation in Mitigating Air Emissions Across Industrial Sites in the US	2019	ADVANCES IN AFFECTIVE AND PLEASURABLE DESIGN
Javadpour L., Khazaeli M.	Business intelligence in the real estate industry and effect of data analytics adoption	2019	Proceedings of 22nd International Conference on Advancement of Construction Management and Real Estate, CRIOCM 2017

Authors	Title	Year	Source title
Mancini A., Clini P., Bozzi C.A., Malinverni E.S., Pierdicca R., Nespeca R.	Remote touch interaction with high quality models using an autostereoscopic 3D display	2019	ACS SUSTAINABLE CHEMISTRY & ENGINEERING
Sanderford, AR; McCoy, AP; Keefe, MJ	Adoption of Energy Star certifications: theory and evidence compared	2019	ACS Sustainable Chemistry and Engineering
Sazandrishvili, G	Asset tokenization in plain English	2019	Proceedings of the International Conference on Construction and Real Estate Management 2019
Shih Y.-Y., Chen C.Y., Wu C.H., Huang T., Shiu S.H.	Adopted intention of mobile commerce from tam perspective: An empirical study of real estate industry	2019	E3S Web of Conferences
Ullah F., Sepasgozar S.M.E., Wang C.	A systematic review of smart real estate technology: Drivers of, and barriers to, the use of digital disruptive technologies and online platforms	2019	E3S Web of Conferences
Demirkan H., Spohrer J.	Developing a framework to improve virtual shopping in digital malls with intelligent self-service systems	2018	Problems and Perspectives in Management
Fuerst F., Kontokosta C., McAllister P.	Determinants of green building adoption	2018	Espace Geographique
Grover P., Kar A.K., Janssen M.	Diffusion of blockchain technology: Insights from academic literature and social media analytics	2018	Energy Economics
Kuruzovich J.	Sales technologies, sales force management, and online infomediaries	2018	JOURNAL OF URBAN PLANNING AND DEVELOPMENT
Low S., Ullah F., Shirowzhan S., Sepasgozar S.M.E., Lee C.L.	Smart digital marketing capabilities for sustainable property development: A case of Malaysia	2018	MODELING INNOVATION SUSTAINABILITY AND TECHNOLOGIES: ECONOMIC AND POLICY PERSPECTIVES
Qi C.A., Liu L., Jupp J.	China's AEC industry and BIM adoption challenges: Understanding the influence of positive and negative mindsets	2018	Journal of Urban Planning and Development
Saull A., Baum A., Braesemann F.	Can digital technologies speed up real estate transactions?	2018	Sustainability (Switzerland)
Sawyer S., Crowston K., Wigand R.T.	Digital assemblages: Evidence and theorising from the computerisation of the US residential real estate industry	2018	Journal of Advanced Research in Law and Economics
Yong K.C., Cheah B.E., Song W.C., Ain M.F.	Signaling scheme for high speed die-to-die interconnection in multi-chip package (MCP) technology	2018	BUILDING RESEARCH AND INFORMATION
Etim A.S., Huynh K., Ramaswamy S., Greer A., Higdon T., Guevara I.	Educating project managers in the 21st-century economy: A field study on the adoption of social and collaborative tools as low-cost alternatives for project communication	2017	Proceedings of the International Conference on Construction and Real Estate Management 2017

Authors	Title	Year	Source title
Lahiry A., Kaeli D.	Dual dictionary compression for the last level cache	2017	Journal of Emerging Technologies in Accounting
Magdaniel F.C.	Technology campuses and cities: A study on the relation between innovation and the built environment at the urban area level	2017	2017 IEEE 35TH INTERNATIONAL CONFERENCE ON COMPUTER DESIGN (ICCD)
N'Diaye O., Aveline-Dubach N., Le Goix R.	The adoption of smart grid technology by Japanese developers: A real estate perspective on the smart city [L'adoption du smart grid par les promoteurs japonais: une perspective immobilière sur la smart city]	2017	CREATIVE CONSTRUCTION CONFERENCE 2017, CCC 2017
Niemi M.I.	Electronic conveyancing of real property in Europe: Two models, the English and the Finnish one	2017	Procedia Engineering
Pereira, D; Mestre, S	Sustainability of Large Real Estate Projects: Case Study of Vila Nova de Santo Estevao	2017	AUGMENTED REALITY, VIRTUAL REALITY, AND COMPUTER GRAPHICS, AVR 2017, PT II
Sanderford A.R., Overstreet G.A., Beling P.A., Rajaratnam K.	Energy-efficient homes and mortgage risk: crossing the chasm at last?	2017	Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)
Willey M., Srinivas D., Varadarajan S., Porter D., Srinivasan E., Hausmann D., Henri J., Kang H., Trivedi M., Mountsier T.	Enabling robust copper fill of high aspect ratio through silicon vias	2017	Transfer of Immovables in European Private Law
Wofford L., Wyman D., Starr C.W.	Do you have a naïve forecasting model of the future?	2017	Proceedings - 35th IEEE International Conference on Computer Design, ICCD 2017
Yang J., Sun J., Zhao H., Xi J., Li X.	Spatio-temporal differentiation of residential land for coastal town: A case study of Dalian Jinshitan	2017	RENEWABLE & SUSTAINABLE ENERGY REVIEWS
Chartres L.	The linkage between competitive and operational advantage and entrepreneurship within Australian real estate franchises	2016	OPTICS EXPRESS
Gopalan R., Sreekumar S., Satpathy B.	Evaluating the Indian retail service quality enablers using interpretive structural modelling	2016	Asia Pacific Business Review
Pałubska J.	The issue of the influence of limited use areas on real estate value2 [Problematyka wpływu obszarów ograniczonego użytkowania na wartość nieruchomości]	2016	CHINESE GEOGRAPHICAL SCIENCE
Salifu Osumanu I., Aigbavboa C.O., Thwala D.W.	Examining the relationship between lean adoption and housing finance in Ghana	2016	International Journal of Business Performance Management
Vimpari J., Junnila S.	Evaluating decentralized energy investments: Spatial value of on-site PV electricity	2016	Chinese Geographical Science

Authors	Title	Year	Source title
Yang, J; Song, LC; Yao, XY; Cheng, Q; Cheng, ZC; Xu, K	Evaluating the Intention and Behaviour of Private Sector Participation in Healthcare Service Delivery via Public-Private Partnership: Evidence from China	2016	A+BE Architecture and the Built Environment
Alaerts G.J.	Financing for water-Water for financing: A global review of policy and practice	2015	Environment Systems and Decisions
Attota R.K., Weck P., Kramar J.A., Bunday B., Vartanian V.	Feasibility study on 3-D shape analysis of high-aspect-ratio features using through-focus scanning optical microscopy	2015	American Journal of Environmental Sciences
Khan Z.	FAI: An ounce of prevention, worth a pound of cure	2015	International Journal of Strategic Property Management
Doddavula S.K., Kaushik M., Jain A.	Implementation of a fast vector packing algorithm and its application for server consolidation	2014	Journal of Retailing and Consumer Services
Everett G., Lamond J.	Green roof perceptions: Newcastle, UK CBD owners/occupiers	2014	35th International Conference on Information Systems "Building a Better World Through Information Systems", ICIS 2014
Ireland B.	Growing pains: Despite an increase in the software's adoption, the electrical industry is still experiencing barriers with BIM...	2014	Pacific Rim Property Research Journal
Jiang, H; Payne, S	Green housing transition in the Chinese housing market: A behavioural analysis of real estate enterprises	2014	New Technology, Work and Employment
Nanyam V.P.S.N., Basu R., Sawhney A., Vikram H., Lodha G.	Implementation of Precast Technology in India-Opportunities and Challenges	2014	Transportation Research Part A: Policy and Practice
Shih Y.-Y., Chen C.-Y.	The study of behavioral intention for mobile commerce: Via integrated model of TAM and TTF	2014	NEW TECHNOLOGY WORK AND EMPLOYMENT
Darko, A; Chan, APC; Yang, Y; Shan, M; He, BJ; Gou, ZH	Influences of barriers, drivers, and promotion strategies on green building technologies adoption in developing countries: The Ghanaian case	2013	Construction Innovation
de Lara Pires P.D.T., Peters E.L., Zeni D.M., Gaulke D.	The use of Brazilian tributary legislation on the araucaria forest biome [O bioma florestal com araucária e a legislação tributária brasileira]	2013	JOURNAL OF PERSONAL SELLING & SALES MANAGEMENT
Donahue E.J.	Integration of microgrid technology into real estate development for a sustainable future	2013	Quality and Quantity
Montealegre R., Iyengar K.P., Sweeney J.	Toward a process model of IT adoption ambidexterity: A revelatory case-study	2013	QUALITY & QUANTITY
Temirzhanova L.A., Imangaliev N.K., Syzdykov A.Z., Eshnazarov A.A., Sagymbekov B.Z.	Improving the mechanism of countering certain types of fraud in the Republic of Kazakhstan	2013	SMT Surface Mount Technology Magazine

Authors	Title	Year	Source title
Wong A.K.D., Zhang R.	Implementation of web-based construction project management system in China projects by Hong Kong developers	2013	Journal of Personal Selling and Sales Management
Zhang M., Kong X.X., Ramu S.C.	The transformation of the clothing industry in China	2013	JOURNAL OF ENVIRONMENTAL MANAGEMENT
Zhang, L; Wu, J; Liu, HY	Turning green into gold: A review on the economics of green buildings	2013	PROCEEDINGS OF THE 2013 IEEE 15TH ELECTRONICS PACKAGING TECHNOLOGY CONFERENCE (EPTC 2013)
Alberto G.	Inverter/modules AID energy, appliance, PV and motor sectors	2011	Floresta
Gao, S; Pheng, LS; Tay, W	Lean facilities management: preliminary findings from Singapore's international schools	2011	Power Electronics Technology
Appelbaum D., Nehmer R.A.	Using drones in internal and external audits: An exploratory framework	2010	CYBERPSYCHOLOGY BEHAVIOR AND SOCIAL NETWORKING
Gusakova E., Romanova E.	Using group decision support systems in the preparation of real estate development projects	2010	PICMET 2010: TECHNOLOGY MANAGEMENT FOR GLOBAL ECONOMIC GROWTH
Iotti M., Bonazzi G.	Life Cycle Flow (LCF) application to evaluate the real estate investment in residential buildings with tax benefit incentives in cases of positive externalities	2010	Cyberpsychology, Behavior, and Social Networking
Jin Z., Xia B., Li V., Li H., Skitmore M.	Measuring the effects of mergers and acquisitions on the economic performance of real estate developers	2010	43rd International Symposium on Microelectronics 2010, IMAPS 2010
Kretz D., Neumann T., Kretzschmar M., Junghans S., Teich T.	Modular System Development for Flexible Adoption of Ubiquitous Challenges in Energy Management and Control	2010	GEO: connexion
Pleyers G., Poncin I.	Non-immersive virtual reality technologies in real estate: How customer experience drives attitudes toward properties and the service provider	2010	EC and M: Electrical Construction and Maintenance
Sanford C., Oh H.	The role of user resistance in the adoption of a mobile data service	2010	INTERNATIONAL JOURNAL OF STRATEGIC PROPERTY MANAGEMENT

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