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Challenges for implementing biophilic strategies in Australian building design

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ABSTRACT

Although biophilic design, particularly, direct nature integration (DNI) strategies like green roofs and green walls are associated with multiple benefits including building occupants' well-being and carbon sequestration, their adoption in building design is limited in some developed countries like Australia. Architects and building sustainability consultants significantly influence design decisions; however, research focused on exploring DNI adoption barriers from their perspective is limited. Therefore, this research aimed to investigate the challenges limiting adoption of DNI strategies in Australia through the lens of innovation adoption theories. Semi-structured interviews with 24 architects and sustainability consultants focused on identifying barriers stemming from "organisation", "building client", "designer", "innovation", and "socio-political influencers". Like in previous studies, "budget constraints" and "maintenance burden" were identified as key barriers in this research, thus, affirming their persisting negative impact on DNI adoption. However, the innovation adoption framework led to identifying new barriers like "builder influence" (socio-political influencers), "employment circumstances" (designer), and "business constraints" (organisation). The new barriers discovered in this research may be relevant to other countries; however, further studies are needed to identify dimensions relevant to other contexts. These studies will benefit from the research framework developed in this research.

1. Introduction

Biophilic design posits that humans have an inherent affinity for nature and benefit from a connection with natural elements in the built environment [1,2]. This approach to design seeks to incorporate nature (e.g., plants, stone, and view of nature) into the design of spaces to promote human well-being as reported in several studies [1]. For instance, Sadick and Kamardeen [3] found that embedding biophilic design strategies in workplaces would enhance employees' cognitive restoration, health, stress-coping, motivation and well-being. Similarly, Ghaziani et al. [4] and Peters and D'Penna [5] observed improved stress control and cognitive stimulation among students due to improved vegetation access and nature inspired pattern in educational buildings. Moreover, Miller and Burton [6] reported that landscaped courtyards in aged-care facilities generate a sense of meaning and peace in residents. Nitu et al. [7] showed that retrofitting residential buildings with landscaped backyard and courtyard improves energy performance. These studies highlight the multifaceted benefits of biophilic design; however, urbanised societies have limited nature interactions, which leads to diminished health and well-being [8]. Therefore, biophilic design could be a cost-effective strategy to reverse building occupants limited nature interactions and enhance their health and well-being [9].

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Several biophilic design frameworks have been proposed in the last decade [e.g., 1, 2, 10, 11. By integrating concepts from these frameworks, Zhong et al. [12] proposed a holistic framework to foster nature incorporation into buildings. The framework comprises three design principles ("nature incorporation", "nature inspiration" and "nature interaction") and 18 elements as shown in Table 1.

As shown in Table 1, "nature incorporation" suggests bringing in natural elements like plants and water to enable multisensory experiences of nature for occupants. Additionally, "nature inspiration" involves imitating nature by embedding natural features into buildings. Furthermore, "nature interaction" is achieved by arranging spaces to provide nature-like environments and establishing place-base connections. Direct nature integration (DNI) in this research aligns with "nature incorporation" with emphasis on elements like plants, water, and landscape. Additionally, DNI also includes aspects of "nature interaction", particularly "connection to place" and "connection of spaces" where building occupants' direct access to nature is the focus. Consequently, DNI in this research refers to biophilic design strategies that seek to provide opportunities for building occupants to touch, feel, or experience natural elements like plants, animals, water, and landscape in proximity. DNI therefore is an integration of "nature incorporation" and aspects of "nature interaction".

Table 1
Biophilic design framework.

Biophilic design element	Design strategies
A) Biophilic principle 1: Nature incorporation	
1. Water	• Build waterscapes such as fountains, constructed wetlands, ponds, water walls, rainwater spouts, aquaria, etc. • Access to natural water features such as waterfalls, rivers streams, oceans, etc.
2. Air	• Increase natural ventilation using operable windows, vents, narrower structures, etc. • Simulate natural air & ventilation through operable windows, vents, airshafts, porches, clerestories, HVAC systems, etc.
3. Daylight	• Bring in natural light via glass walls, clerestories, skylights, atria, reflective colours/materials, etc. • Mimic the spectral and ambient qualities of natural light by arranging multiple low-glare electric light sources, ambient diffused lighting on walls/ceiling, and daylight preserving window treatments
4. Plants	• Bring vegetation indoors by potting plants and indoor green walls • Incorporate plants into buildings by using green roofs, green walls and facades, large atria with park-like settings, green pockets, etc.
5. Animals	• Create spaces like ponds and aquariums to accommodate animals. • Build animal-friendly living areas nest boxes, gardens, green roofs/walls to attract animals.
6. Landscape	• Build landscapes in the sites such as constructed wetlands, grasslands, prairies, forests and other habitats. • Create interior landscapes in atria, courtyards, entry areas, hallways, etc. • Provide window views of natural landscapes like forests, seascapes and water motifs
7. Weather	• Enhance exposure to weather through operable windows, porches, balconies, terraces, courtyards, etc. • Enhance awareness of meteorological conditions by using transparent roofs, rainwater collectors and spouts, etc. • Simulate the experience of weather like sunlight, airflow, humidity, temperature and barometric pressure.
8. Time and seasonal change	• Provide views of seasonal changes in plants • Present views of the building façade and appearance that change due to exposure to nature
B) Biophilic principle 2: Nature inspiration	
9. Forms and shapes	• Imitate the contours and motifs of organisms (biomorphic design) in building forms, structural systems, components and interior spaces • Biomorphic elements could be botanical/animal motifs, shells, spirals, eggs, oval, tubular forms, arches, vaults, domes, etc.
10. Patterns & geometries	• Adopt fractals, hierarchically organised ratios and scales in designs • Use the Fibonacci series (0,1,1,2,3,5,8,13,21,34) or Golder Ratio (1:1.618) • Choose the intermediate ratio (1:1.3–1.75)
11. Mechanisms	• Learn from other species to meet the functional needs (Biomimetic or Biomimicry) such as termites and spiders inspired the efficiency of climatic controls and the structural strength of building materials.
12. Images	• Presents natural scenes, plants, animals, water, landscapes or geological features in paintings, photographs, videos and fabrics. • Natural images should include a rich variety of species, landscapes or human survival experiences in nature.
13. Materials, texture & colour	• Adopt natural material like wood, bamboo, rock, stone, clay etc. • Consider textures beyond materials such as light, colour and sound • Use natural colours such as blue, green and others
C) Biophilic principle 3: Nature interaction	
14. Prospect & refuge	• Conceive spaces with two complementary characteristics: open views/vistas (prospect) and under sheltered/safe environments (refuge) • Achieve inside and outside experiences through window views and balconies, courtyards, colonnades, etc. • Use controllable lighting to design spaces with refuge effects
15. Complexity & order	•Arrange rich details and diversity in an orderly manner •Consider natural forms, patterns and geometries, especially in exposed building structures, facades and details •Choose materials with specific textures and colours or carefully arrange the variety and placement of plants
16. Enticement (peril & mystery)	• Generate 'peril' using cantilevers, infinity edges, transparent facades, pathways under/over water, scenes defying gravity, etc. • Create 'mystery' through winding paths, translucent materials, imperceptible sound sources, obscuring/curving the edges, etc.
17. Connection to place	• Provide views of prominent landmarks, landscapes, waterscapes, geological forms, etc. • Use indigenous materials and native plant varieties • Apply landscape features to define building forms or dedicated landscape design such as savanna-like environments
18. Connection of spaces	• Conceive interior-exterior connections in transitional spaces such as porches, patios, balconies, courtyards, pavilions, gardens, entry areas, foyers, atria, etc. • Consider mobility in spaces like entrances, exits, corridors, stairs, high glass elevators, etc.

(Source: Adapted from Zhong et al. [12])

Of the three biophilic design principles, “nature incorporation” is predominantly associated with significant occupants' health and well-being benefits [3,8,13,14]. However, “nature incorporation” strategies like green roofs, green walls, and court yards have been associated with high implementation costs which impedes their adoption [15,16]. Although these strategies have high implementation cost, they have additional sustainability benefits like atmospheric carbon sequestration, reducing heat island effect, and reduced building energy consumption due to improved thermal insulation [17]. These benefits have motivated significant DNI adoption in buildings in Europe and North America; however, Australia lags behind in this endeavour [18]. Additionally, studies that have investigated DNI adoption barriers in other countries have reported limited availability of DNI adoption incentives, knowledge of DNI benefits among architects, developers, and clients and implementation cost as the key barriers [12,19–21]. However, several of these studies [12,19,21] were based on systematic literature reviews of previous studies and not based on primary research that leveraged the professional experience of key stakeholders like architects and building sustainability consultants. These stakeholders play key roles in translating clients’ project briefs into buildable designs and therefore have significant impact on design decisions that can influence DNI adoption. These stakeholders (architects and building sustainability consultants) are also involved in coordinating activities between clients and other stakeholders. However, there is limited empirical research focused on DNI adoption challenges based on the professional experiences of architects and building sustainability consultants. Therefore, this research aimed to investigate the challenges of implementing DNI strategies in Australia drawing from the experience of architects and building sustainability consultants. Consequently, this research employed a qualitative approach involving interviews to gain deep insights into the challenges inhibiting DNI adoption in Australian buildings.

2. Literature review

A literature review was first conducted to examine the reported challenges for DNI adoption, and the findings are reported here. Despite the reported benefits of DNI in the literature, the levels of adoption in different countries varies significantly [18]. However, there has been limited empirical studies focused on investigating the challenges limiting DNI adoption in different countries. Table 2 highlights some of the key DNI challenges from the few sources in literature that have explored this topic.

Table 2 presents a range of DNI challenges related to either specific stakeholders (e.g., designers, developers, and clients) or the broader society. The predominant specific stakeholder challenge is limited DNI knowledge among designers, developer, and clients who are the key decision makers at the design and construction phase. Hence, their limited knowledge of DNI is more likely to limit adoption. Additionally, societal level challenges like the lack of systematic mechanisms for DNI implementation suggest that any efforts geared towards accelerating DNI adoption should not be limited to the core project stakeholders. The fact that a developed country like Australia lags behind other developed countries in the adoption of DNI [18] suggest that adoption challenges would vary due to contextual differences. The cities of Stuttgart and Berlin in Germany have a combined green roof area of over 4 million m^2 [25] while Toronto in Canada is approaching 1 million m^2 [26] and Chicago is approximately 520,000 m^2 [27]. In contrast, Sydney, the largest city in Australia currently has 155,000 m^2 of green roof [28]. The reduced adoption of DNI in Australia poses many global warming related outcomes. Australia's global warming rate of 0.042 °C pay year is 40% higher than the global average of 0.03 °C per year and resulted in increasing the number of extremely warm days and cooling degree days in Australia [29]. On 24–25 January 2019, 200,000 households were without electricity due to increased demand for cooling resulting from extreme temperatures [29]. Additionally, the risk of flooding in Australia is estimated to be 18% higher than the global average [29]. The benefits of green roofs including absorbing rainwater to minimise risk of flooding and improving the insulation properties of buildings to minimise energy demand for cooling can contribute to increasing Australia's climate change resilience [30]. Workplace stress is estimated to cost Australian employers approximately $6.3 billion per annum [31]. DNI strategies are associated with enhancing stress-coping and cognitive stimulation [3,5]; hence, they can contribute to overcoming the socio-economic impact of workplace stress in Australia. Given that there has been limited research focused on understanding why Australia lags other countries, empirical research would lead to uncovering contextually relevant challenges that would enrich the literature on DNI challenges.

Table 2
DNI implementation challenges.

Source	DNI challenges
Zhong et al. [12]	• Designers limited multidisciplinary knowledge inhibits their ability to choose appropriate biophilic design strategies for specific buildings and climate
Andreucci et al. [19]	• Limited knowledge of DNI benefits has resulted in a “nice to have but dispensable” attitude among clients
Clancy [20]	• Deficit of biophilic design implementation knowledge • Limited understanding of benefits among clients and developers • High capital and maintenance cost perception among clients and developers • No incentives in several countries to encourage adoption for new development and renovations
Gunderson [22]	• Society's fixation with non-living things like digital technologies and gadgets which limits DNI exposure opportunities
Parsaee et al. [23]	• Lack of DNI recommendations and a systematic design framework applicable to extreme cold climates
Abdelaal [24]	• Lack of systematic DNI implementation mechanism
Kellert et al. [2]	•Large-scale urbanisation with DNI integration as an afterthought

3. Research methods

The interpretivist exploratory research strategy, supported by semi-structured interviews was deployed to discover DNI adoption barriers in Australia. Interpretivist exploratory research is a qualitative research approach that focuses on understanding human experiences in a particular context to gain insights and develop a deeper understanding of the experience [32]. This approach therefore aligns with the aim of this research given that DNI barriers were based on the professional experience of architects and building sustainability consultants. Semi-structured interviews involve using open-ended questions for detailed exploration of a topic, and follow-up questions are asked based on participants responses. Further, the use of predefined open-ended questions minimises the risk of off-topic discussions and ensures the collection of rich and relevant information [32]. Given the limited research on DNI barriers in Australia, semi-structured interview was preferred to collect detailed and contextually relevant information from participants.

3.1. Research framework

Wisdom et al. [33] analysed innovation adoption theories and proposed a framework that integrated innovation adoption dimensions from the predominant theories. Consequently, the framework proposed by Wisdom et al. [33] harnessed the strengths of multiple innovation adoption theories to provide a consolidated framework that addresses the limitations of individual theories. Table 3 depicts an adapted version of the framework, which identifies five innovation adoption characteristics. The framework includes categories for external stakeholder influences (e.g., government, and professional associations) and key internal stakeholders (e.g., project clients, designers, and design organisations). Hence, in relation to the construction industry, the socio-political influencers refer to external factors that the industry has limited control over (e.g., requirements of building codes for design and construction). The innovation category focuses attention on the inherent characteristics of the innovation of interest that can inhibit its adoption. Although DNI strategies like green roofs and green walls are not new, their adoption is limited in Australia. Therefore, this research leveraged the adapted innovation adoption framework as a lens for detailed exploration of DNI adoption barriers in Australia to inform the development of innovative strategies that may boost adoption.

(Adapted from Ref. [33]).

3.2. Data collection and analysis

The semi-structured interviews in this research were based on interview questions developed to align with the five innovation adoption categories (representing five DNI barrier categories) in Table 3. Open-ended questions were developed to initiate discussions on DNI barriers relevant to each category. A description of DNI was developed to contextualise the discussions. The interview guideline, invitation documents and sampling strategies received ethics approval from the authors' institution. Please see Appendix 1 for the interview questions used in the study. A purposive sampling approach via three recruitment methods was employed in this research. Firstly, potential participants were contacted via information from the authors colleagues. Secondly, publicly available contact information on LinkedIn was used to contact potential participants. Lastly, participants were requested to refer the research team to potential participants. Participant recruitment was always initiated using an approved contact email with attached plain language statement, consent, and withdrawal of consent form. Only participants who returned a signed consent form were engaged further. Interviews were conducted via Zoom and were audio recorded with a digital recorder; hence, the Zoom video was not recorded. Participants were informed before starting the audio recording. Each interview lasted between 45 and 60 min. Participants read the DNI description at the start of the interview. The audio recordings were transcribed for thematic analysis which was conducted concurrently with the data collection. After the 15th interview, significantly new themes were not identified for any of the five barrier categories.

Table 3
Adapted integrated innovation adoption framework.

Category	Descriptors
Socio-political influencers	• Positive external influences, like a physical environment of development and growth; regulations, and accreditation standards supportive of innovation; incentives, and supportive social environment promote adoption. • Lack of these external influences hamper innovation adoption.
Organisation	• Leadership support for and experience with adoption leads to better adoption; however hierarchal top-down leadership may hinder adoption. • Organisations with a research infrastructure, and additional resources facilitate adoption. • Positive external environment, social climate and interactions with innovation developers are useful. • Organisational culture that focuses learning responsibility on individuals is more effective.
Innovation	• Easy-to-use, better-than-current-practice, observable, cost-effective, adaptable, evidence-based, compatible with organisational and user norms, relevant, low-risk innovations would be embraced. • Innovations that engender resistance, unfamiliar to staff, and without reliable evidence would not be adopted.
Designer	• Individuals' attitudes and motivation for adoption, particularly positive attitudes toward change, the need for change, and quality improvement are important for successful adoption. • Feedback on the adoption process is useful in increasing adoption • Social networks of individuals, skills, experience, innovativeness, ambiguity tolerance, and risk tolerance are associated with increased adoption. • Social networks of individuals are associated with adoption. • Short job tenure and skills deficit negatively impact adoption.
Building client	• Client attitudes, beliefs, and readiness toward change are all associated with better adoption.

Hence, data saturation was practically achieved [32], and participants recruitment was closed with a total of 24 participants. Fig. 1 presents the demographic information of all 24 participants.

The hybrid thematic analysis process (Fig. 2) employed in this research integrates Braun and Clarke [34] adapted phases of thematic analysis (Manual) and natural language processing (NLP) techniques (Automated). The NLP component of this research was completed using the Python version 3.8 programming language. The initial coding step involved manually reviewing transcripts to identify data fragments capturing DNI barriers related to the five categories. Afterwards, the initial codes were pre-processed to remove newline characters and lowercasing of all texts to ensure that "Risk" and "risk", for example, would have the same representation in the next step. The embedding step involved translating pre-processed codes into semantic vector representations utilising "SentenceTransformers," a deep learning Python library for vectorizing sentences and paragraphs [35]. Additionally, "all-mpnet-base-v2″, the best sentence embedding model at the time of this research was used to produce the vectors. To reduce the chance of conflicting clusters, the semantic vectors for each barrier category were grouped using the agglomerative clustering algorithm with a distance threshold of 0.3. Since there is no need to pre-define the number of clusters, the agglomerative clustering technique was favoured over K-means. Subsequently, the clusters were manually reviewed and clusters representing different dimensions of a barrier were merged and labelled.

A semantic network graph was developed using the Force Atlas 2 algorithm to explore interrelationships between the five barrier categories. The five categories were the nodes, and the edge weights were the semantic similarities between the nodes. Semantic simi-

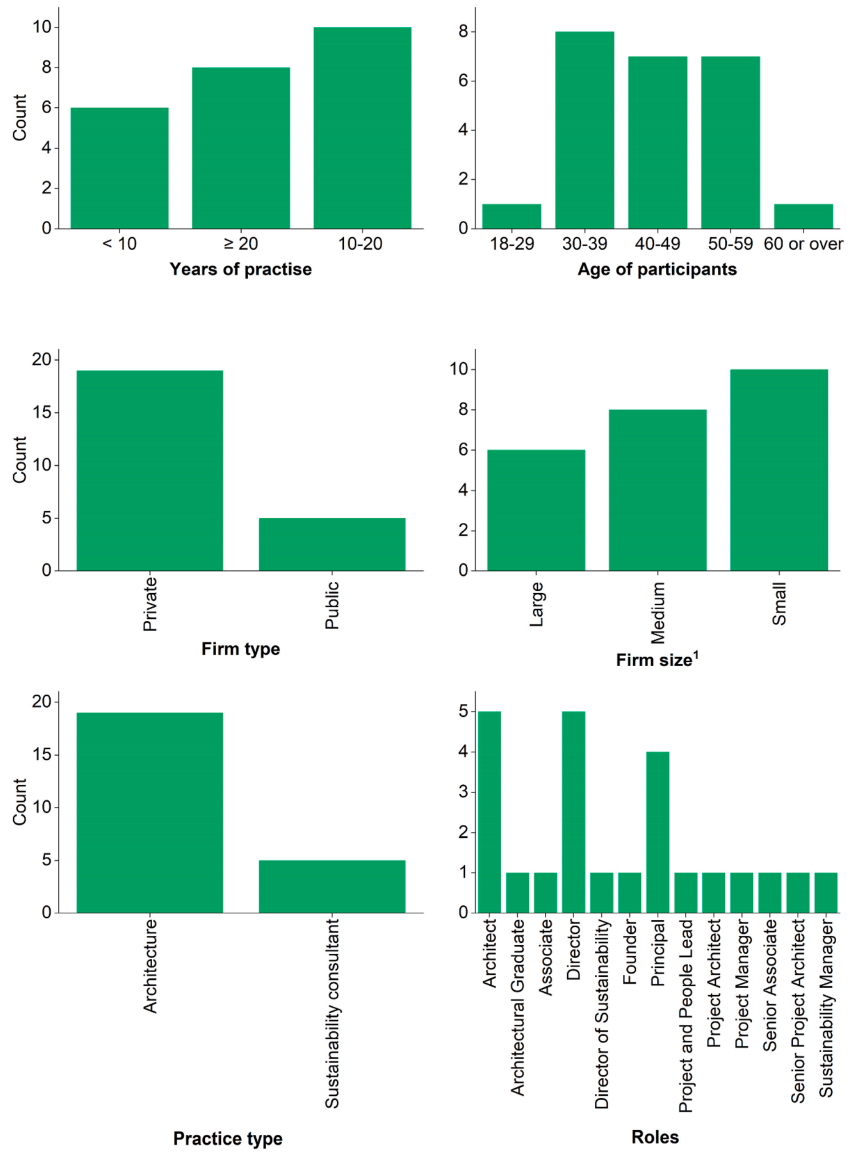

Fig. 1. Participants demographic information.
[1]Samll (less than 20 employees); Medium (20–199 employees); Large (200 or more).

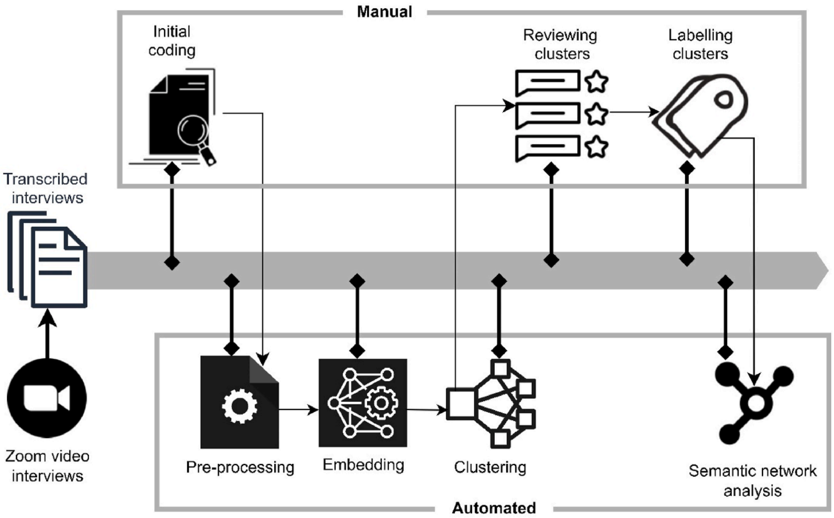

Fig. 2. Hybrid thematic analysis process.

larity was calculated using the “cosine_similarity” function from the “scikit-learn” Python library using the vector representations of the interview texts coded to the five categories as the inputs. Cosine semantic similarity ranges from 0 (lowest similarity) to 1 (highest similarity). The nodes and edge weights were written to a CSV file which was imported into the OriginLab software version 2022b to generate the semantic network graph.

4. Findings

The study discovered many challenges for the implementation of DNI strategies in building design in Australia. The barriers are discussed under five broad categories, including “building client”, “innovation”, “organisation”, “designer” and “socio-political influencers”. Fig. 3 shows a concept map of the five categories and the specific barriers discovered in this research.

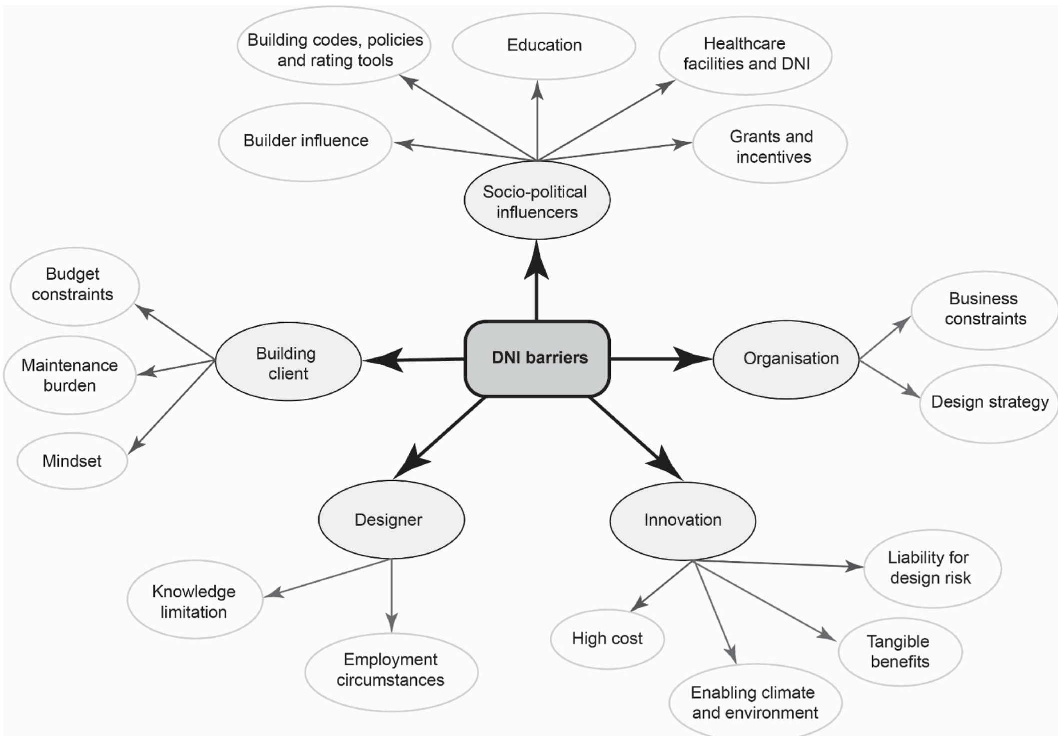

Fig. 3. Concept map of DNI barrier categories and specific barriers.

4.1. Building client

4.1.1. Budget constraints

Construction clients' budget constraint is a regular project limitation that sometimes leads to project decisions like scope reduction, time overrun and project termination. In this research participants identified budget constraints as a key roadblock impeding clients' willingness to the inclusion of DNI strategies in their projects.

DNI strategies like green walls and green roofs are not regular components in most buildings; hence, their associated capital costs are not fundamental cost components in clients' budget. Therefore, their inclusion in a project would be perceived as an additional cost on top of the conventional core budget components like earthworks, concrete works, and plumbing. Consequently, the budget constraint leads to a situation where the inclusion of DNI strategies competes with other needs. Participants highlighted that DNI is mostly not among the primary objectives of some clients and therefore dropped out of consideration in the conundrum of competing needs. Participants further opined that the limited prioritisation of DNI by clients is likely due to their limited understanding of the added value of including these strategies in their project. The tangible value of including DNI in projects is likely perceived to be lower compared to the opportunity cost of their exclusion. This perception is supported by the limited empirical research focused on exploring the tangible financial benefits of DNI to clients. Given the budget-orientation of most clients in making project decisions, participants advocated for holistic DNI value research, especially for economically motivated investment projects like commercial buildings. Additionally, participants highlighted the scarcity of value management examples demonstrating DNI value and opportunity cost trade-offs in the local industry as a key roadblock. Without information on tangible benefits, project consultants like Architects would have a difficult task in convincing clients to accept DNI strategies.

4.1.2. Maintenance burden

Besides the capital cost, the ongoing maintenance of strategies like green walls, green roofs, and aquariums was alluded as a major concern for clients and tenants. However, a more strategic maintenance barrier is the concern over how to effectively manage DNI strategies to ensure their long-term resilience. Most commercial and institutional buildings would have matured protocols for ongoing maintenance of building systems like heating, ventilation, and air conditioning. However, green roofs and green walls are the exception in most buildings; hence, existing maintenance strategies may be unsuitable. Although this concern may be unfounded, it is justified given that DNI strategies are alien to most commercial and institutional buildings. Additionally, there is limited research focused on providing contextualised DNI maintenance guidelines and best practices in Australian commercial and institutional buildings.

4.1.3. Mindset

Mindset refers to a person's beliefs that influences their behaviour, attitude or outlook of people, places, and ideas. In this research, mindset implies the beliefs, perceptions and attitudes of clients that inform their development strategy and DNI decision-making. Two key mindsets were identified in this research, "reluctance" and "extremes". Feedback is a key decision-making variable in all industries including construction. Therefore, positive, or negative feedback on any project aspects based on clients' previous experience would influence future project decisions. Both positive and negative feedback on DNI strategies would aid further research and development; however, negative feedback would fuel client reluctance and thwart promotion efforts. The reluctance dimension of the mindset barrier is connected to negative feedback on DNI strategies that makes clients less open to employing those strategies on new projects irrespective of contextual differences.

The extremes dimension refers clients' attitudes, beliefs, and perceptions of DNI on a mindset continuum. "Maintaining status quo" is an extreme where clients resisted unconventional design ideas like DNI. Accordingly, "… *if the client is set in their ways and wants a certain thing, it is difficult to change their mind*". This resistance can be heightened by negative feedback on the performance or capital and operating cost of DNI strategies, and thus, links the maintaining status quo extreme with the reluctance tendency. Additionally, maintaining status quo is potentially a client risk aversion strategy to eliminate the perceived risks associated with DNI strategies like green roofs and green walls. The other extremes dimension is the "nice to have, not essential" client view of DNI and other sustainable design strategies. Clients' who harbour this mindset would not prioritise the design and construction cost of DNI strategies in their project budget. Further, the perceived high maintenance cost of these strategies will further entrench the nice to have mindset and contribute to derailing DNI promoting and adoption in all building types. This nice to have mindset may be predominant among private clients; however, local government organisations are not immune. Hence, a policy-driven approach to DNI adoption in new projects would mitigate this mindset in government projects.

4.2. Innovation

4.2.1. High cost

Participants indicated that the construction and maintenance cost of DNI strategies like green roofs and green walls are higher compared to traditional alternatives. Clients' budget constraints coupled with the perceived high cost of DNI strategies lead to a selection bias favouring traditional options. Additionally, this bias seems to be an industry-wide issue. The limited adoption of DNI strategies implies that economies of scale cannot be leveraged to fuel adoption. Conversely, growing adoption due to the multifaceted benefits of DNI strategies will drive further research and development that would reduce capital and ongoing cost due to increased demand.

4.2.2. Enabling climate and environment

Green roofs, green walls, and living plants either indoor or outdoor need enabling conditions to ensure their long-term survival. Providing and sustaining this enabling condition would account for a significant proportion of the ongoing cost associated with these strategies. Regardless of cost, different plants would have different water, temperature, and soil depth requirements. However, the complexity of providing enabling conditions can be taken for granted. Therefore, *"… anyone can kind of plant something in the ground and hope that it grows. I think because it's so accessible, maybe we ignore that it is complex at the same time."* For embedded DNI strategies, ignoring the complexity of enabling conditions that are needed for ongoing care will gravely hamper their long-term survival. Another key aspect of enabling conditions is the climate, especially in countries like Australia that have diverse climatic conditions across states. In a multi-climate environment, aligning the choice of DNI strategies with climatic conditions is imperative given that tropical climate plants may not survive in a temperate climate. Getting the climate right was highlighted as a challenge by several participants.

Choosing the right plants for a given climate will remain a challenging task if there are no contextually relevant materials to facilitate the process. This challenge will be further compounded on projects where the design team does not include members with expertise in this area. Furthermore, the client's preference can also aggravate this "right choice" issue if they insist on a particular plant or vegetation that is unsuitable for a particular climate. Participants also highlighted the difficulty in controlling outdoor environmental conditions; this is particularly essential for DNI strategies that are integrated into a project externally. Making the right choice is more critical in this situation compared to DNI strategies integrated indoors.

4.2.3. Liability for design risk

Construction projects are risk prone, considering the number of stakeholders needed to achieve a collective project goal. Risk management is, therefore, one of the key project management functions needed on construction projects to eliminate or mitigate negative project outcomes like cost and time overrun. Design risks (e.g., wrong material specification and missing information) are very detrimental to construction projects given that the construction stage is based on the design and would therefore inherit design risk. Most participants in this research were architects; hence, it is not surprising that several participants raised issues of design risks associated with DNI and particularly green roofs.

There was a particular concern among the participants around the design detailing of green roofs given the likelihood of defects related to waterproofing, water leakage and its associated defects like mould growth due to dampness. This risk is likely attributable to the lack of standardised information to facilitate design detailing of DNI strategies like green roofs. Besides being detrimental to project success, design risks can have a significant impact on responsible stakeholders including professional liability and reputational damage that could diminish the chances of securing future projects. Additionally, the consequences of these risks would contribute to negative feedback on DNI and fuel adoption reluctance among designers.

4.2.4. Tangible benefits

Construction clients embark on projects to achieve defined objectives; hence, project requirements and ultimately design and construction decisions would be project objectives oriented. For commercial projects, design decisions and building elements that would yield tangible benefits like increased lettable area and investment returns will be budgeted and prioritised. The most investigated and popularised benefits of DNI are the health and well-being gains for building occupants, with limited focus on tangible benefits to project clients. The occupants' health and well-being benefits of DNI can create a positive image for a project in the operation phase that could yield tangible benefits like tenant retention. However, these "soft" benefits (e.g., positive image, reputation) are not easily quantifiable; hence, they have less bearing on project cost-benefit analysis at the planning stage. Considering the budget constraints on most projects and the need for cost-benefit certainty, there is a need to develop methods and tools that will aid benefits quantification, especially at the planning stage where key budget decisions are made. Undoubtedly, the tangible benefits of DNI strategies will be connected to their long-term resilience given that short-lived benefits will undercut clients' trust in these strategies.

4.3. Organisation

This section presents the three organisation barriers and their dimensions.

4.3.1. Business constraints

The work of architecture and building sustainability firms is directly tied to the market; consequently, the business environment would significantly influence how these organisations operate. Four dimensions of this barrier were discovered, namely, "competitive market", "organisational support", "research resources", and "risk aversion".

The construction industry is an inherently "competitive market" where consulting and construction firms are constantly competing to secure projects to sustain and grow their business. The need to secure projects may cause some organisations to quote lower fees for competitive bidding purposes. Additionally, the desire to submit a competitively priced bid may lead to excluding DNI-related costs if the project brief and tender documentation did not directly call for it. Consequently, lower fees due to price competition can stifle design innovation where organisations would avoid proposing DNI strategies to eliminate its associated design cost. Not all construction projects are secured through competitive bidding. Particularly, private clients without a binding procurement policy may prefer to single source project design services either based on previous experience or recommendation. Although price competition would not be applicable in this situation, the need to secure projects coupled with client's primary objectives and budget constraints can lead to the strategic exclusion of DNI ideas from design considerations. Additionally, some architecture and building sustainability firms (particularly small ones) may be less daring in proposing DNI ideas in the absence of direct competition to avoid losing a project and client. Consequently, the need to stay in business in a "competitive market" can derail active promotion of DNI ideas to clients.

The second dimension of business constraint is "organisational support". Organisations, irrespective of industry, seek to achieve their primary objectives and would therefore provide employees with the requisite resources and support to achieve them. Secondary, and non-specified objectives would receive less or no support. Without organisational support, employees would be less motivated to promote DNI to project clients. In the same vein, architecture and building sustainability organisations that do not consider the promotion and adoption of DNI as part of their practice would not support employees interested in pursuing that objective. Organisational support for promoting a "supposedly risky" idea like DNI to clients, may include resources (e.g., project examples, cost-benefit information, technical specifications), training (formal and informal training on DNI and biophilic design) and leadership (mentoring, senior management support). Providing these supports would incentivise employees to take the initiative in promoting DNI ideas to clients, knowing that they are not standing alone. Additionally, organisational support like funding DNI (or biophilic design) training would encourage employees to acquire the knowledge and skills needed to internalise DNI as a core organisational strength. However, many organisations do not provide professional development support related to biophilic design. Small practices with limited projects and resources may not support employees in acquiring knowledge and skills related to DNI strategies given that most buildings do not include green roofs, and green walls. However, if DNI strategies are to become the norm, active promotion and adoption cannot be relinquished to medium and large firms only. Besides limited resources, most small practices have either one or a few senior managers which can lead to limited leadership support for DNI ideas if the managers are not in favour of promoting this idea. Consequently, employees would be less willing to consider DNI ideas in their designs which will subsequently lead to stagnation or retrogression in DNI knowledge and skills development.

Given that DNI strategies like green roofs and green walls are employed on a few buildings only, several architecture and building sustainability organisations would not have a repository of technical information on these design ideas. Therefore, the availability of "research resources" is a key dimension of the business constraints barrier given that most design teams would need to locate the essential information required to support design elaboration and technical detailing. The resources available for DNI research would vary relative to the size of organisations, with small practices most likely at the lower end of that spectrum. The challenges of securing clients and projects to sustain a small practice imply that they would be less likely to promote DNI ideas to clients whose design brief did not have those ideas. Consequently, the research resources limitation faced by small practices, directly impedes their ability to support employees to acquire the knowledge and skills needed to confidently incorporate DNI ideas in their design. On the other spectrum, employees of medium and large practices reflected on how their organisations leverage research resources to gain a competitive advantage in the market. Besides their financial strength, medium and large practices also leverage their significant employee numbers to distribute the research and development workload. Medium and large practices would be responsible for most of the large-scale developments where there may be limited reluctance to adoption of DNI ideas. However, that volume is insignificant to fuel DNI adoption when compared to the non-DNI developments in the industry.

The last dimension of the business constraints barrier is "risk aversion", the tendency for people to prefer outcomes with low uncertainties. Considering the perception of design and construction risk associated with DNI strategies like green roofs and green walls, risk aversion may be an effective strategy for architecture and building sustainability firms looking to minimise risk exposure and its associated consequences including reputational damage. Hence, "*you have some companies that would not … adopt those things, because they don't want to put themselves out there from.. the risks side of things*". This points to one extreme end of the risk aversion strategy where firms would eliminate the risk by excluding DNI ideas as parameters in their design equation to completely insulate them from the potential consequences of DNI design and construction risks. The opposite of the complete avoidance strategy is the cautious promotion strategy where firms may suggest DNI ideas to clients without actively leading them towards adoption. The cautious promotion strategy aims to transfer the risk of adoption decision to clients. Arguably, complete risk elimination may be preferable to small practices with limited resources while practices with limited DNI experience may prefer cautious promotion. Although the cautious promotion strategy will generate discussions on the topic, it would not encourage adoption due to its passive nature.

4.3.2. Design strategy

Architecture and building sustainability firms would have a strategy, either explicit or implicit, that guides their design work. These strategies would affect design decisions and materialise in completed projects, thereby generating visual signatures that distinguish the designs of various practices. Explicit inclusion of DNI in design strategies would encourage employees to actively promote these ideas to clients. As pointed out by a research participant, DNI is excluded from tender submission documents if they are not explicitly enshrined in a design strategy or included in a request for tender. The non-inclusion of DNI ideas in tender submissions implies that they would be precluded from discussions at the critical planning stage where key design decisions are made. Moreover, another factor that significantly influences a design strategy is the client's project objective and risk appetite. Considering the cost perception associated with DNI strategies like green roofs and green walls, clients' risk appetite can significantly shape design strategies and lead to exclusion of DNI ideas irrespective of the design teams' initial intent.

Besides the client's influence, another dimension of the design strategy barrier is "ideological differences" within a practice. Participants emphasises how a generational gap within an architectural practice can lead to ideological differences that can negatively impact contextualised development and implementation of a design strategy for a specific project. There are *" … some older members of staff and management that because they've done the tried and tested, almost brute force way of … clear everything and then build new"*. However, existing acclimatised vegetation on-site can be leveraged to enhance the long-term resilience of DNI strategies. Hence, the potential impact of ideological differences on design with respect to the promotion and adoption of DNI ideas cannot be overemphasised.

Another dimension of the design strategy barrier is the age-old "silo design culture" most prevalent in traditional procurement where the architectural design will be completed and passed on to other design stakeholders to complete their respective tasks. Silo designs often lead to increased cost due to constructability issues where, for example, a concrete column may disrupt the location of power points. Similarly, silo designs would make a green roof, green wall or living plants look out of place. Considering clients' reluctance towards DNI adoption, poor integration will derail DNI promotion given that would not yield the desired occupants' health and well-being benefits.

The last dimension of the design strategy barrier is "collaboration influences". The building design process may involve several stakeholders including architects, structural engineers, electrical engineers, and environmentally sustainable design (ESD) consultants. Each stakeholder plays a key role needed to yield a safe, liveable, and building code/regulation-compliant design. Irrespective of the procurement strategy employed, collaboration is a key feature of the design process; however, the nature of this collaboration depends on the procurement strategy. Design-build-oriented strategies encourage parallel collaboration from ground zero while traditional procurement leads to delayed and staggered collaboration. Notwithstanding the procurement strategy, "managing multiple priorities" of the stakeholders involved in the design process can lead to tensions that need to be strategically managed. Unilateral inclusion of DNI strategies by architects may heighten the tension. Another challenge related to collaboration influences is non-aligned priorities of design team members. A participant commented that they "*work with a range of other sustainability advisors* … some of them … *they're really just about reaching a sort of minimum benchmark and according to whatever tool you're required to meet*". Most building rating tools do not stipulate DNI ideas like green roofs and green walls in their minimum requirements. Hence, building sustainability consultant who prioritises the minimum benchmark may not favour green roofs and green walls, which could cause tension with others who favour those ideas. The result of this tension could be poor integration of DNI ideas into the overall project design strategy.

4.4. Designer

This category focuses on DNI adoption barriers that are directly related to employees. The two key barriers identified are presented below.

4.4.1. Knowledge limitation

DNI is a subset of biophilic design; therefore, anyone knowledgeable in biophilic design principles and strategies would have a good understanding of DNI. Architecture and sustainable building design education generally happen at the tertiary level in universities. Architecture education integrates knowledge from diverse fields including arts, engineering, and science. However, participants claimed that a significant proportion of architects seem to be "arts bias" by being overly inclined to the arts component of architecture. This arts inclination is not surprising given that the most recognised outputs of architects are design drawings and models (hard copy or digital). Biophilic design belongs to the science component of architecture and is embedded in visually appealing art. Clients will see the art and not the science that informed it. It is however not clear if this arts bias is a personal preference or emanates from the design of the architectural education curriculum. Formal and informal training related to biophilic design was not specifically investigated in this research; however, participants raised concerns that topic related to the benefits of biophilic designs are rarely discussed in formal architectural education and institutional professional development programs. They further indicated that most design professionals are aware of DNI benefits; however, they are not certain if their implementation know-how is on the same wavelength as the level of benefit awareness. There is also a scarcity of biophilic design professional development activities. Consequently, a significant proportion of architects have limited exposure to biophilic design knowledge and would therefore be less confident to employ DNI ideas in their designs.

4.4.2. Employment circumstances

The "employment circumstances" barrier relates to work conditions (like compensation and workload) and general industry trends that influence employees' willingness apply DNI strategies. Like other industries (e.g., manufacturing and agriculture) where investors seek to protect their investments, clients investing into construction projects would seek a guarantee for their expected returns. Professional liability is a big deal for clients given that it protects them from damages resulting from negligent works of professionals like architects and engineers. Considering the perceived design risk associated with DNI strategies and the likelihood that a significant proportion of architects may have limited knowledge of biophilic design, professional liability may deter several architects from employing these ideas. Project failures resulting from DNI strategies like green roofs will lead to insurance claims, which in turn will increase professional indemnity premiums.

Although the balance between job demand and reward is not the only key determinant of employees' satisfaction and performance, that balance would significantly influence satisfaction and performance. Participants indicated that although architects spent a relatively higher number of hours on projects to meet client needs and deadlines, it is not a very high-paying job. This imbalance will not incentivise architects (especially those in small practices) to promote DNI ideas to clients whose brief did not include them. Additionally, the quick turnarounds required will provide employees in small practices with limited opportunities to develop DNI expertise.

4.5. Socio-political influencers

This category relates to barriers attributable to stakeholders other than project clients, architecture, and building sustainability firms and their employees. Five main barriers discovered, are presented below.

4.5.1. Builder influence

Builders are essential stakeholders in the property development process irrespective of project type and size. Additionally, builders are heavily involved in the construction stage where the project budget is expended. Hence, builders have significant influence over project cost given that their activities consume the greatest proportion of the client's budget. Builders have a wealth of practical construction experience and can provide substantial cost-saving advice. However, builders are not designers; hence some of their cost-saving advice may distort design and lead to unanticipated long-term consequences. In this light, cost-saving suggestions provided by builders that leads to modifying DNI strategies would fuel the high-cost perception associated with those ideas.

Design-build contracts are attractive given that builders can leverage their construction knowledge to eliminate buildability issues at the design stage and save cost. However, many architects do not recommend this contract type due to the tendency of projects becoming the "*vision of the contractor who has signed up to a preliminary design and then has the licence to do whatever they want as long as they meet the principal project requirements.*" Consequently, if DNI strategies are not included as principal requirements under a design-build contract, builders can legally exclude them as a cost-saving option for clients without the architect's explicit consent. Therefore, builders' influence during the construction stage can unintentionally derail DNI promotion efforts if the necessary safeguards are not in place.

4.5.2. Building codes, policies, and rating tools

This barrier has three dimensions including "building codes", "building/planning policies" and "building rating tools. Building codes are the primary references in most countries for the minimum expected performance of buildings; therefore, compliance is a prerequisite for development approvals. Code compliance can therefore be leveraged to promote the adoption of design ideas that would have large-scale positive impact on society. However, participants indicated that the Australian building code do not strongly promote DNI ideas. Hence, sustainability and resilience-oriented ideas like DNI may not be adequately integrated into building designs to yield desired sustainability objectives.

A participant mentioned that the Australian building codes stipulate requirements for "*the amount of fresh air that is in a building, the percentage of daylight that enters classrooms and so on",* which are related to DNI. However, it is not certain if these requirements were intended to promote DNI adoption. The intent of a code requirement is significant because it informs policies at the regional and local government levels to facilitate the realisation of the code's intent. Making building code changes to specifically promote DNI adoption may be a good idea. However, "*in Australia, it's not very easy to just come across an organization that will give you a full on detailed, …as to how you're going to achieve that green roof*", and therefore points to limited expertise on how to achieve code compliant DNI strategies.

Council planning and other subsidiary policies are key in realising the primary intent of a building code given that they provide further compliance information typically unavailable in building codes. Consequently, these policies allow councils to contextualise code requirements to meet local needs. Considering that these policies are derived from building codes, it is logical to expect that they will inherit code weaknesses. In this regard, several participants indicated that planning and other subsidiary policies do not strongly promote DNI adoption. They further raised concerns over the ambiguity of some policy requirements that can be destructive to vegetation. If a policy stipulates a requirement for incorporating existing vegetation and other nature elements into new building design, this will expedite DNI adoption.

Research participants opined that introducing building codes and planning policy requirements to promote DNI may not guarantee quality design; however, DNI would become a principal project requirement that will not be precluded as a cost-saving measure. For example, the city of Toronto in Canada has a green roof by-law that has made it one of the global leaders in green roofs. Hence, building codes and regulations can play a significant role in accelerating DNI adoption. Some participants observed that regional and local authorities in Australia are cautiously encouraging DNI ideas, especially on large development projects. Furthermore, the authorities are mindful of "*what the market can afford as far as investment, and, what the authorities enforce*". Although this assertion is understandable, it also points to potential lobbying by key stakeholders whose established business norms would be significantly impacted by code and policy changes.

The last dimension of this barrier is building rating tools like Green Star that are not mandatory but could contribute to DNI adoption. According to some participants, Australian Green Star system awards "*two or three points for increasing the amount of indigenous diversity, in the landscape, another couple of points for natural ventilation and some points for innovative use of water. But this is only a small fraction out of 75 points*". Green Star and similar rating tools operate a points-based system that allows design teams to choose their target points which may or may not include DNI strategies. Therefore, the adoption of DNI strategies through voluntary building rating tools would be subject to the decisions of clients and project teams. Points chasing to achieve a target certification level can lead to poor integration of DNI strategies given that the rating tools seem to award points for inclusion and not integration.

Besides Green Star, there are other building rating tools like the National Australian Built Environment Rating System (NABERS) and the Nationwide House Energy Rating Scheme (NatHERS). Although the different tools may have different purposes, the plurality of rating tools can be a roadblock for the adoption of DNI as they may have different requirements, which could be a source of confusion as professionals seek to meet the needs of different stakeholders with different rating tool preferences. Participants implicitly advocated for the standardisation of building ratings to ease the professionals' burden of information overload.

4.5.3. Education

This barrier refers to education-related issues that are beyond the control of staff and organisations that this research focuses on. Two dimensions of this barrier were identified, "mode of training" and "training resources". Architecture and building sustainability are applied professions; hence, the educational programs need to reflect that reality. Some participants claimed that formal architecture education is theory focussed; hence, students have limited practical exposure to ideas like DNI. Moreover, when choosing project examples for architectural education, universities and professional associations tend to use high-profile buildings that most architects will never design in their career. Using high-profile project examples will distance non-conventional ideas like DNI from trainee architects and make them less confident to employ them in their professional practice. Architects are not expected to be ESD (environmentally sustainable development) specialists; however, to ensure effective collaboration and integration of ESD ideas, it is essential for architects to under the science and language of ESD. Participant suggested that "*if the specification of ESD was simplified, then the impacts of green roofs, green walls, etc, would be easier to educate from an architectural perspective*". Non-contextualised ESD specifications will make the science and language of ESD less accessible to most architects who work under short project turnaround times and have limited time to digest complicated specifications; this would be more pronounced for small practices with limited research and training resources.

4.5.4. Grants and incentives

Grants and incentives from government or non-government bodies can be effective means of driving the adoption of desired strategies. Research participants indicated that current government grants are largely focused on renewable energy and energy savings. These energy-centric grants are likely due to the government's objective of reducing building energy consumption to meet climate change goals. Although these are laudable objectives, participants believe that leveraging ideas like the passive design to minimise buildings' energy needs, can eliminate or significantly minimise reliance on solar panels to achieve climate change goals. This would effectively free up government funds to support non-conventional ideas like green roofs and green walls. The astronomical increase in solar panels in Australia in recent years can partly be attributed to grants that eased the cost of acquiring this system. Hence, it is logical to anticipate that similar support for DNI ideas like green roofs and green walls would accelerate their adoption. However, participants cautioned that "*any incentive or reward programme is subject to abuse, unfortunately, the incentives and rewards can go to the wrong people for the wrong reasons*". Hence, poorly administered schemes may promote quantitative adoption of DNI ideas without quality outcomes.

4.5.5. Healthcare facilities and DNI

Healthcare buildings are a special typology given the wide range of occupants that use them. Design ideas that can lead to unhealthy indoor environmental conditions could worsen the health conditions of patients. Considering the potential benefits of DNI on the health and well-being of patients and the healthcare system at large, it is logical to expect the healthcare buildings subsector to take a leading role in DNI adoption. However, the participants who predominantly work in the healthcare buildings subsector indicated that there is a reluctance to adopt DNI strategies like green walls and living plants in Australian healthcare buildings due to limited adoption examples that resulted in beneficial outcomes to users. The limited availability of successful adoptions will fuel the perception of design and construction risk associated with DNI, particularly in healthcare buildings where negative outcomes could have dire consequences for users and the reputation of design consultants and contractors involved. Additionally, the participants hinted at an entrenched risk aversion attitude towards DNI strategies due to the few examples where strategies like green roofs and green walls resulted in negative outcomes. The risk-averse mindset also impedes opportunities for further research aimed at exploring the benefits of these strategies in the healthcare setting. Additionally, participants espoused another dimension of this barrier, the lack of space for DNI elements due to the plethora of services required in healthcare rooms. This barrier could be effectively resolved through careful integration of all services by leveraging the user experience of clinical staff. However, this will be less plausible in the presence of entrenched risk aversion towards DNI.

4.6. Semantic network graph

Fig. 4 shows a weighted undirected network graph of the five DNI barrier categories. The edge weights ranged from 0.53 (O-SPI) to 0.76 (O-D) which shows that the barriers were substantially related; however, each had its own unique focus and thus affirm the consistency of the manual interview transcript coding. The O category is the central network node and is logical given that architecture and building sustainability organisations who interface with the other barriers were the central focus of this research. Additionally, the highest semantic similarity (0.76) is between O and D nodes which highlights the close connection between organisation and designer-related barriers. The outstanding pattern of the network graph is the grouping of nodes. Based on the findings presented above, the four nodes at the top (O, D, BC, and SPI) are largely human-centred while the bottom node focused primarily on DNI. Hence, the five barrier categories can be further categorised into two as "soft barriers" (O, D, BC, and SPI) and "hard barriers" (I). Additionally, efforts to address the barriers discovered in this research can be strategically devised per the two broad categories to leverage interdependences for efficient and impactful outcomes.

5. Discussion

This research aimed to investigate the challenges of implementing DNI strategies like green roofs and green walls in Australia based on the experience of architects and building sustainability consultants. Using an adapted innovation adoption framework, this research identifies DNI barriers related to "building client", "innovation", "organisation", "designer" and "socio-political influencers". Table 4 shows barriers found in this research that are like previous studies and new barriers that adds to the literature or significantly extend the dimensions of similar barriers in literature. The similar barriers identified in this research including "high cost", "tangible benefits", "maintenance burden", and "knowledge limitation" shows that these barriers are persisting in impeding DNI adoption. Hence, further studies are needed to devise contextually relevant strategies to overcome these barriers in countries like Australia and others where DNI adoption is low.

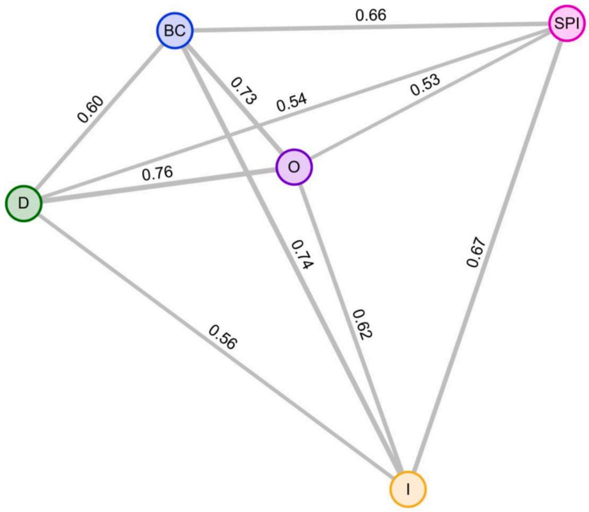

Fig. 4. Semantic network graph of barrier categories (O – organisation, BC – building client, D – designer, I – innovation, SPI – socio-political influencers).

Table 4
Similar and new barriers.

Similar barriers	New barriers
Budget constraints (BC) [20]	Employment circumstances (D)
Maintenance burden (BC) [20]	Business constraints (O)
Knowledge limitation (D) [12]	Design strategy (O)
High cost (I) [12]	Builder influence (SPI)
Enabling climate and environment (I) [2]	Healthcare facilities and DNI (SPI)
Tangible benefits (I) [19,21]	Liability for design risk (I)
Mindset (BC) [21]	
Building codes, policies, and rating tools (SPI) [24]	
Grants and incentives (SPI) [20]	
Education (SPI) [12]	

O – organisation, BC – building client, D – designer, I – innovation, SPI – socio-political influencers.

Previous studies [12,20] reported that capital and maintenance cost of DNI were among the key barriers limiting their adoption in other countries including the USA and England. In this research, "budget constraints" and "maintenance burden" were two building client barriers identified which aligns with the previous studies. Additionally, this research identifies new barriers in other categories that explicates the capital and maintenance cost challenge. Firstly, "business constraints" was discovered as a multifaceted barrier in the organisation category where for example market competition leads to excluding DNI from bid proposals to lower fees for competitive bidding purposes. This competitive bidding strategy may lead to securing projects by lowering client's capital cost; however, it will harm the promotion of DNI strategies by limiting the opportunity for clients to consider them as viable options in their project. Lastly, "employment circumstances" were one of two designer barriers identified in this research. A key dimension of this barrier is the mismatch between job demands and rewords for architects which will not incentive some of them to promote DNI to unwilling clients. These cost-related barriers complement the building client barriers of "budget constraints" and "maintenance burden" in worsening DNI adoption. Additionally, these complimentary barriers demonstrate some of the intricacies of DNI implementation cost in Australia that may not be directly relevant to other countries but will serve as a reference for contextual exploration.

Architects are the initiators of building design based on clients' brief and therefore have significant influence on design decisions. Zhong et al. [12] concluded that architects need multidisciplinary knowledge to choose appropriate biophilic design strategies based on project context. However, this research shows that the multidisciplinary knowledge challenge with respect to DNI is multifaceted. In this research, "knowledge limitation" was identified as a designer barrier which affirms the previous conclusion [12]. However, in the socio-political influencers category, the "education" barrier was identified with two dimensions, "mode of training" and "training resources". "Mode of training" emphasises the theoretical nature of formal architecture education while "training resources" showed that DNI training resources in formal and informal settings in Australia are less comprehensive. Consequently, the knowledge limitation of some architects is attributable to inherent weaknesses in available formal and informal architecture education.

Evidently, the previous section and above discussions shows that the innovation adoption framework employed in this research resulted in enriching the exisitng knowledge on DNI barriers by discovering new dimensions of existing barriers not discussed in previous studies. However, the framework also resulted in discovering new barriers that expands current knowledge of DNI barriers. Firstly, "liability for design risk" was identified in the innovation category where design detailing of green roof was highlighted as a major risk source that can diminish DNI adoption efforts. This new barrier sheds more lights on barriers like limited design knowledge and lack of systematic design framework mentioned in previous studies [12,23] by highlighting the direct consequences of these barriers to designers. Secondly, “design strategy” was identified in the organisation category with several dimensions including “clients' influence” and “collaboration influences”. DNI is mostly excluded from tender submission documents if they are not explicitly included in client briefs and request for tender, thus, alluding to clients' influence on design strategy. Additionally, design decisions are made in view of the multiple priorities of stakeholders involved in the design process. Lastly, “builder influence” and “healthcare facilities and DNI” were identified in the socio-political influencers category. The “builder influence” barrier highlights builders’ ability to influence DNI decisions at the construction stage with cost-saving advice that leads to eliminating DNI strategies or significant modifications that erode DNI benefits. The “healthcare facilities and DNI” barrier illuminated the risk-based reluctance and constrained space in healthcare rooms as key dimensions limiting DNI adoption in Australian healthcare buildings. These new DNI barriers would enrich the literature and contribute to devising comprehensive strategies to boost adoption of DNI in different building types.

The semantic network graph developed in this research resulted in categorising the five DNI barrier categories into “soft barriers” and “hard barriers”. Soft barriers (organisation, building client, designer, and socio-political influencers) are mainly human-centred while hard barriers (innovation) emanate from the core attributes of direct nature including their need for ongoing care. The shared characteristics of the barriers within each of these two broad categories can be leveraged to develop complementary strategies to fast-track DNI adoption. From Fig. 4, the strongest semantic connection to the socio-political influencers was with the innovation category. This connection shows the key role that parties like government (national, regional, and local), professional associations, building rating organisations, and educational institutions can play to accelerate DNI adoption. Governments employ financial incentives like grants to drive adoption of initiatives like photovoltaic (PV) installation. Government PV rebates in Australia has resulted in about 20% of all dwellings having PV installation; thus, making Australia one of the leading countries in PV installations [36]. Therefore, addressing the “grants and incentives” barrier in the socio-political influencers category could drive DNI adoption. However, further research will be needed to develop effective evaluation and monitoring methods given that DNI design is not structured, and some benefits are intangible (e.g., human well-being impact).

“Building code, policies, and rating tools” was a key barrier in the socio-political influencers category. Building codes and subsidiary polices dictates the primary requirements of buildings and can therefore be used to promote DNI adoption. However, some participants opined that regulating DNI is not necessary given that architects are generally inclined to produce quality designs. Notwithstanding this justifiable position, the “builder influence” barrier suggest that quality designs can be unintentionally subverted in the absence of safeguards like regulation. Although building rating tools are generally non-mandatory, they can significantly contribute to driving DNI adoption given that building owners seek to leverage the value-adding potential of rating tools to maximise their investment. However, there needs to be harmonisation of building codes, policies, and ratings tools to ensure seamless integration of requirements from these sources in producing quality designs with DNI as a principal requirement.

6. Practical implications

Passive design strategies like insulation, shading, orientation, and terminal mass can significantly improve the thermal performance of buildings and reduce energy needed for heating and cooling. These strategies however will not contribute to reducing heat island effect resulting from global warming in Australia which is higher than the global average [29]. Additionally, considering the cost of workplace stress in Australia ($6.3 billion per annum [31]), overcoming the adoption challenges of DNI strategies like green roofs and green walls would have significant socio-economic benefits. The findings of this research have both global and local significance. First, DNI barriers like “high cost”, “tangible benefits”, “knowledge limitation”, and “maintenance burden” identified in this research are similar to barriers identified in other countries like England, USA, and Canada [19,20,24]. Therefore, the findings of this research affirm the currency of these barriers and suggest that they should be considered by other countries seeking to increase adoption of DNI strategies. However, considering contextual differences like governance style, building regulations, and climate differences between countries, further research may be needed to devise relevant local strategies for overcoming these challenges. Second, this research also identified new barriers including “business constraints”, “builder influence” and “healthcare facilities and DNI”. The latter barrier in particular highlights the local significance of this research. This barrier highlights the resistance to DNI adoption in Australian healthcare buildings due to the limited availability of Australian examples that demonstrates DNI benefits. Additionally, this barrier emphasises the strategic importance of local and contextual evidence in allaying fears of DNI adoption in healthcare considering the potential consequences of negative outcomes in these building type. Therefore, key Australian stakeholders including government, health authorities, designers, and researchers need to collaborate in increasing the availability of successful Australian examples of DNI adoption with positive outcomes. Although the “healthcare facilities and DNI” barrier in this research highlights the Australian context, it may also be relevant to other countries with significant risk aversion towards DNI adoption in healthcare buildings. However, this barrier will need further exploration in those countries to identify the dimensions that are relevant to the context.

Findings of this research shows that DNI adoption barriers are not confined to the construction industry and project clients. Hence, a multistakeholder approach is needed to accelerate DNI adoption. Additionally, the findings suggest the need for contextual DNI benefits research to catalyse multistakeholder adoption efforts. The limited DNI adoption in Australia suggests that there are limited trades persons with the requisite knowledge and skill of DNI construction and maintenance. Hence, training programs to aid DNI adoption should focus on both designers and trades to minimise design and construction risks associated with DNI. This will create new employment opportunities and ensure successful DNI adoption. In the short-term, stakeholders like the construction industry, governments, and educational institutions can use the findings of this research to develop preliminary strategies to promote DNI adoptions. For example, architecture firms can use the organisational and designer barriers to develop internal strategies that will strengthen DNI design capability and client communications. Additionally, there is a need for DNI benefits research in special building typologies like healthcare and prisons.

7. Conclusions

This research aimed to investigate the challenges of implementing DNI strategies like green roofs and green walls in Australia based on the experience of architects and building sustainability consultants. The barriers found in this research included "budget constraints" and "maintenance burden" that are like findings of previous studies. However, the innovation adoption framework used in this research resulted in discovering barriers for five categories namely "organisation", "building client", "designer", "innovation", and "socio-political influencers". This research therefore provides a broad and detailed outlook of DNI adoption barriers compared to previous studies. The new barriers discovered in this research include "builder influence" (i.e., socio-political influencers category), "employment circumstances" (i.e., designer) and "business constraints" (organisation). Additionally, the semantic network graph developed in this research showed that the five barrier categories can be sub-divided into two, "Soft barriers" (organisation, building client, designer, and socio-political influencers) and "hard barriers" (innovation). The former is human-centred, and the latter emanates from the core attributes of DNI including their need for ongoing care.

This research contributes to knowledge by identifying new barriers of DNI adoption based on empirical research. Although these new barriers are based on primary data from Australia only, they would be relevant to other countries seeking to accelerate DNI adoption. However, the dimensions of new barriers like "business constraints", "builder influence", and "employment circumstances" discovered in this research may be limited to the Australian context. Therefore, further research is needed to uncover dimensions of these barriers that are contextually relevant to other countries to aid strategic development of adoption solutions. The innovation adoption framework adapted for this research resulted in identifying DNI barriers across five distinct and interrelated categories. The five categories of the adapted framework facilitated a broad coverage of DNI barriers which will contribute to developing comprehensive strategies to accelerate DNI adoption in Australia. However, the adapted framework and interview questions developed in this research can be used in future studies to aid consistency and tracking the evolution of DNI barriers across multiple contexts. Participants were either architects or building sustainability consultants; hence, the findings are limited to the professional experiences of these stakeholders. However, these stakeholders are responsible for coordinating the building design process and interface with other key stakeholders as is manifested in the scope of barriers identified. Further studies are needed to explore DNI challenges from the viewpoint of other key stakeholders like clients, developers, the builders, and government agencies. This research conducted semi-structured interviews with 24 participants that may limit generalisation of the findings. However, data saturation was practically achieved after the 15th interview while some correlations were found between findings of this research and previous research. The DNI adoption challenges identified in this research can be used to develop questionnaire surveys to elicit the views of a larger sample of architects and sustainability consultants for generalisation purposes. Additionally, research focused on detailed exploration of DNI benefits is needed to galvanise multi-stakeholder adoption efforts.

Author statement

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Declaration of competing interest

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

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

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