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Article

Accelerating the Delivery of Low-Carbon Buildings by Addressing Common Constraints: Perspectives from High-Rise, High-Density Cities

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Abstract: The delivery of low-carbon buildings (LCBs) in high-rise, high-density cities is still hindered by various common and interdependent constraints. However, a study that developed innovative strategies to address the common constraints to delivering LCBs focusing on traditional high-rise, high-density cities could not be identified in the previous literature. Therefore, this study aimed to identify potential strategies for accelerating the delivery of LCBs in high-rise, high-density cities by addressing relevant common constraints that were identified in recent studies. Accordingly, potentially relevant strategies were identified through eight semi-structured interviews with well-experienced experts in industry and academia. Consequently, 71 strategies were identified under six categories, i.e., policy implementation, building energy/carbon data utilisation, awareness raising/training, technology advancement, incentives, and organisational level commitments. This also required closer collaboration with different stakeholders/stakeholder classes in implementing these strategies, who were, therefore, also identified. An SNA-based analysis was also conducted to explore the connections between constraints and strategies. The strategies related to energy/carbon policy development, standardisation, codes and certifications, mandatory regulations, financial incentives, and technology adoption showed the ability to address a majority of the driving constraints related to policies and technologies. These study findings will assist policymakers and other relevant stakeholders in the arena of the project and asset management in accelerating the delivery of LCBs by adopting an innovative approach to prioritise potential strategies in order to suitably address and synergise the complex interdependencies among the constraints.

Keywords: constraints to low-carbon building; strategies to accelerate low-carbon building; high-rise, high-density cities

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1. Introduction

1.1. Carbon Emissions and Buildings in High-Rise, High-Density Cities

Buildings significantly contribute to global climate change. As a worldwide average, buildings consume 35–40% of the annual energy produced and emit 30–40% of annual carbon emissions [1,2] Ahmed et al. [3] emphasised that embodied carbon emissions of buildings account for about 11%, while operational carbon emissions from buildings account for about 28% of global carbon emissions annually. Accordingly, 'building stock' can be identified as an important focal point for initiating energy management and carbon emission reduction programmes [4].

Highly urbanised countries/regions with high-rise, high-density cities should implement effective policies and procedures to reduce energy consumption and carbon emissions from buildings since these highly dense cities consume about 80% of energy and emit about 75% of carbon in the country/region [5,6]. Nevertheless, more cities will grow vertically and become highly dense in future due to the rising building demand and migration of the population to urban areas [7]. UN DESA [8] predicted that about 68% of the global population will live in cities and urban areas by 2050.

Having identified the environmental threat from building stock due to the high energy consumption and carbon emissions, a majority of the countries with high-rise, high-density cities are continuously attempting to reduce the carbon emissions from their building stock [9,10].

Taking a few examples, Hong Kong initiated a 'climate action plan 2030+' to achieve the goals of the 'Paris Agreement' [11]. The UK government has initiated plans to achieve an 80% reduction in carbon emissions by 2050 compared to the emission levels in 1990 [12]. In Australia, several states have initiated plans to achieve the certifications of the Commercial Building Disclosure (CBD) programme and the National Australian Building Energy Rating System (NABRES) [13]. The 'national climate change plan of the UAE 2017–2050' also includes targets for reducing emissions from buildings [14]. 'Singapore green building masterplan' [15] targets to increase the percentage of green buildings up to 80% by 2030.

Despite the above initiatives, notable carbon emissions reduction from the buildings sector is not evident [16]. Moreover, about three billion m^2 of building floor area is being constructed yearly without complying with energy/carbon policies and procedures [17]. Indeed, databases clearly indicate, and scholars further highlight, how the rapid increase in carbon emissions and energy consumption from buildings in highly dense regions constitute a significant threat to the environment. This should raise a clarion call for the immediate attention of responsible stakeholders [10,16,18]. This situation demonstrates that the evolution of building carbon and energy reduction programmes is not keeping pace with the rapid growth in high-rise, high-density cities.

1.2. Low-Carbon Buildings (LCBs)

With increased rates of urbanisation, 'environmental sustainability' aspects are frequently incorporated into building construction, operations, and management activities throughout the world [19,20]. Accordingly, many scholars have emphasised that delivering LCBs is one of the highly supportive strategies to ensure the sustainability of buildings and the built environment [9,21].

LCBs are buildings which are specifically engineered with GHG reduction in mind. By definition, an LCB is a building which emits significantly less GHG than regular buildings [22]. An LCB typically includes energy-efficient features. However, a building with energy-efficient features does not necessarily mean that the building is an LCB [23]. The low-carbon concept covers a wide spectrum that transcends being just energy efficient. Accordingly, building orientation, structure, building envelope materials, window size, location and glazing, the efficiency of heating, ventilation and air conditioning (HVAC) systems, usage of materials with minimum GHG emissions while production, usage of onsite renewable energy, emission reduction in building systems, adapting low-carbon behaviour, reusing or recycling at the end of the lifecycle, compliance, minimising overall carbon footprint, etc. contribute to delivering an LCB.

To align with global carbon reduction efforts, all countries should implement efficient programmes to deliver LCBs. Further, yearly low-carbon intensive new building construction should improve up to 4 billion m^2 of floor area (the current level is around 250 million m^2 per year). Moreover, at least a 30–50% improvement in energy performance should be achieved through effective policies and technology adoption when renovating existing buildings [17].

Pan and Pan [9] emphasised the importance of delivering LCBs in high-rise, high-density cities/regions in order to minimise the carbon emissions from the building stock. Various action plans are being proposed and implemented for carbon emission reduction from buildings in most of the high-rise, high-density cities throughout the world, especially in countries with stable/developed economies [24]. However, these attempts could not achieve a noteworthy reduction in carbon emissions /energy usage in these cities [16,25]. This may arise from a number of constraints (related to policies and regulations, technologies, social conditions, geographical conditions, and financial status) that hinder the delivery of LCBs [26,27].

1.3. Constraints to Delivering LCBs and Strategies to Accelerate the Delivery of LCBs

Figure 1 shows a summary of constraints reported in the previous literature between 2011 and 2020. Accordingly, it is evident through the blue coloured lines that more studies reported the constraints related to financial level, policy/regulatory level, technology level, and knowledge. The number of reported constraints is also high for these categories.

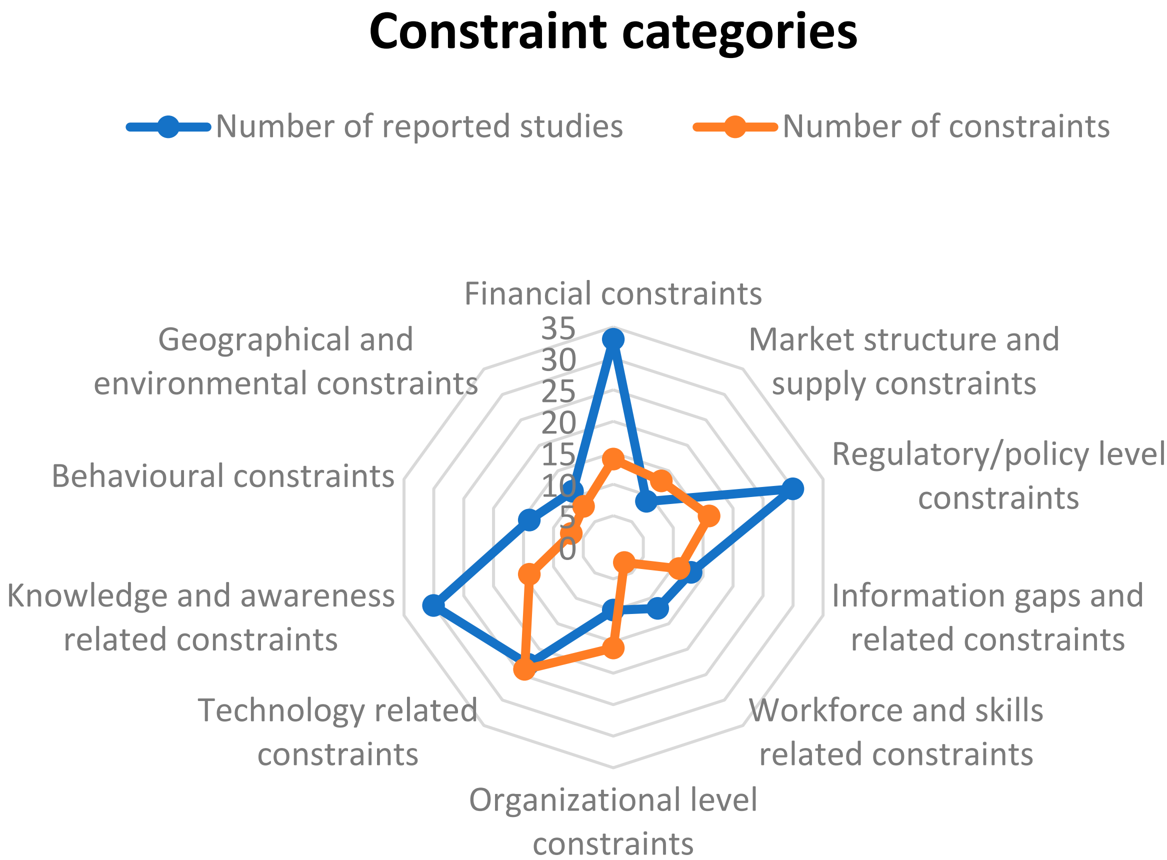

Figure 1. Constraint categories.

Many of these constraints show interdependencies and interrelationships among each other [28]. A clear identification and analysis of these interdependencies among constraints would be beneficial for relevant stakeholders to determine effective strategies to overcome the constraints [29]. Accordingly, developing strategies to address the driving constraints (significant constraints which generate other constraints) should be given a higher priority. Addressing the driving constraints upfront would ease the efforts in mitigating the dependent constraints [10,29].

Government involvement and policy intervention are regarded as essential and effective ways to promote building energy efficiency and low-carbon measures by overcoming common constraints [30–32]. Formulating policies for developing standards and designs of building materials as well as buildings, is crucial in accelerating the adoption of low energy/carbon buildings [31,33]. Design criteria should be duly supported by innovative and creative research methodologies and advanced technological support [33]. All future designs of buildings should ideally include the use of sustainable and energy-efficient materials. The development of such sustainable, eco-friendly, and energy-efficient building materials should be supported and promoted by the government, related institutions and departments [34,35]. Furthermore, effective collaboration among the industry, regulatory bodies, and academia should be maintained to facilitate the customised and effective research and development of feasible technological advancements [36]. Strict regulations should also be imposed on energy and carbon compliance documentation and reporting [34,37]. Furthermore, market-based incentive schemes are thought to be effective and cost-efficient instruments to support and enhance the low carbon and energy-efficient building investments [38,39].

Furthermore, carbon emissions and energy usage should be assessed throughout the life cycle of buildings [40]. Life cycle assessment should be supported by providing suitable calculation tools, technology, expertise, and training [33,39,41]. Relevant institutions, including government departments, should promote the new energy-efficient and low-carbon building development by setting examples by implementing pilot projects with measurable benefits [33]. Awareness raising, training, and skill development of the building professionals and the community, in general, should be considered as a long-term strategic approach to drive towards a sustainable built environment [42,43].

1.4. Research Gap and the Aim of the Present Study

Although many previous studies have identified the constraints to delivering LCBs from different dimensions and explored the strategies to accelerate the delivery of LCBs, a detailed exploration of strategies to address common constraints to delivering LCBs in high-rise, high-density cities could not be found in the previous literature. Although the constraints to delivering LCBs show complex interdependencies, none of the previous studies attempted to analyse these interdependencies and explore innovative methods to accelerate the delivery of LCBs by synergising with these interdependencies. Moreover, less attention has been paid in the literature to identifying and exploring the constraints and strategies for delivering LCBs by focusing on high-rise, high-density cities.

Therefore, this study aimed to identify the potential strategies to accelerate the delivery of LCBs by addressing the common and significant constraints to delivering LCBs in high-rise, high-density cities. The list of common and significant constraints to delivering LCBs in high-rise, high-density cities was adopted from a precursor study by the authors of this paper [29]. This precursor study explored the common constraints to Hong Kong, Singapore, Australia (Sydney and Melbourne), UAE (Dubai and Abu Dhabi), and Qatar (Doha). The present study summarised the findings of Madhusanka et al. [29] and identified suitable strategies to accelerate the delivery of LCBs by addressing the constraints. Moreover, the present study mapped and analysed the connections between constraints and strategies using an Interpretive Structural Modelling (ISM) based structure and a Social Network Analysis (SNA) based on a two-mode network. These analyses provided a clear view of the significance, centrality, and interdependencies of the identified strategies. Furthermore, the necessary involvement and collaboration of different stakeholders in implementing the identified strategies are also identified and discussed in the present study.

2. Methods

This section discusses the research methods chosen to suit this study. Accordingly, methods followed to identify and analyse the constraints, methods of identifying strategies and mapping with constraints, and the SNA approach utilised in this study are elaborated in Figure 2 and the sub-sections below. Some inputs to the present study were adopted from the precursor studies of the same authors of this paper. In Figure 2, the specific tasks covered in the present study are indicated by a dotted line.

2.1. Methods Used for Identifying and Analysing the Constraints

The list of common and significant constraints to delivering LCBs in high-rise, high-density cities and the interdependencies among these constraints were published in precursor studies by the authors of this paper [10,29]. The present study adopted a summary of these precursor studies and explored suitable strategies to accelerate the delivery of LCBs by addressing the constraints identified in the precursor studies. Madhusanka et al. [10] and Madhusanka et al. [29] identified the common and significant constraints to delivering LCBs from the perspectives of five high-rise, high-density regions through a comprehensive literature review followed by a questionnaire survey. Subsequently, the interdependencies among the identified constraints were analysed by using ISM and Matriced' Impacts Croise's Multiplication Appliquee a UN Classement (MICMAC) analysis approaches.

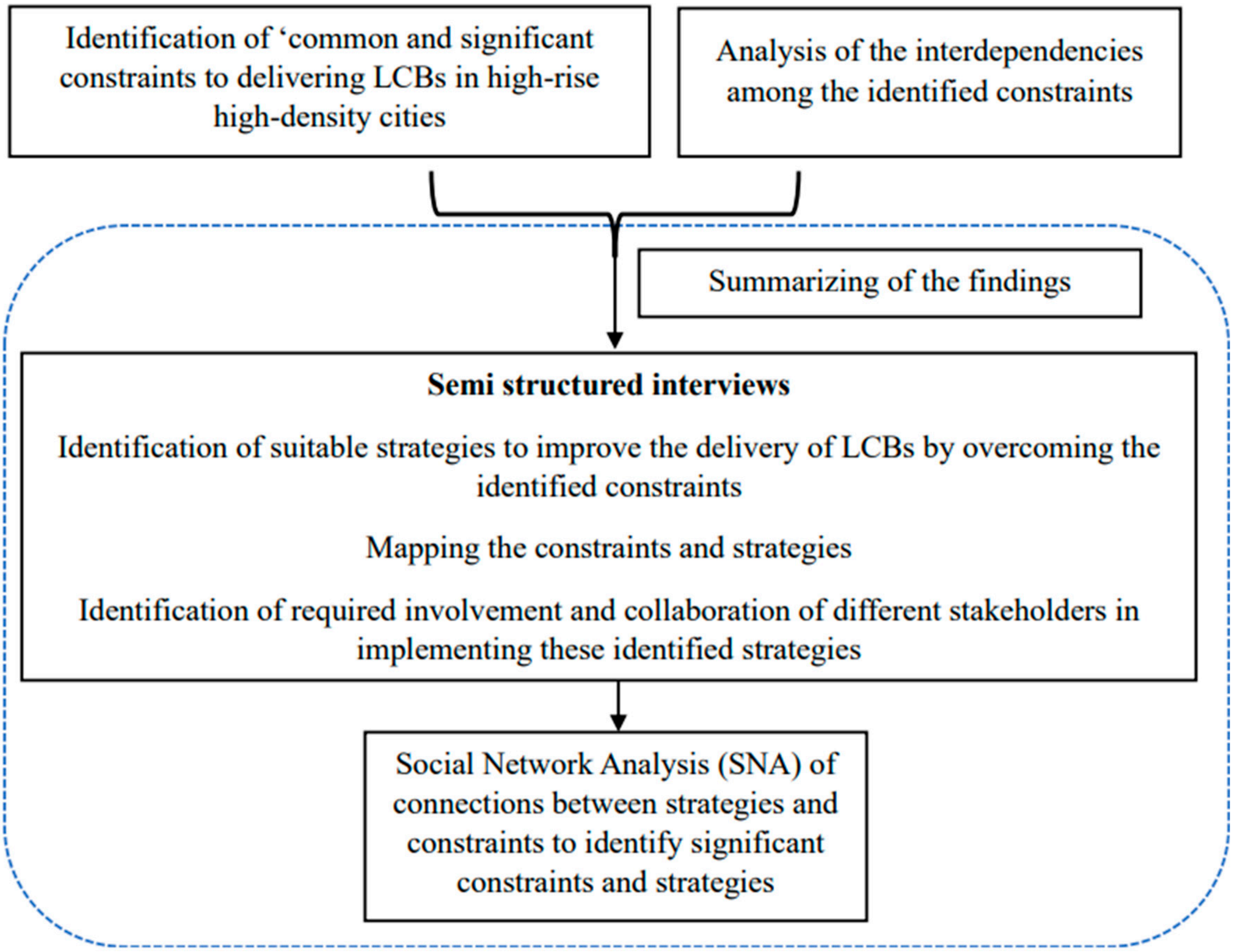

Figure 2. Research methods.

ISM approach is used to systematically reveal the relational links and interdependencies among a set of factors by placing the considered factors in a hierarchical model [44]. MICMAC analysis is used to categorise and prioritise a set of factors based on their driving/dependence nature [45]. Accordingly, these factors ('constraints' in the present study) can be categorised into four groups [46]: (1) autonomous barriers (weak driving power and weak dependence); (2) dependent barriers (weak driving potential but strong dependence); (3) linkage barriers (strong driving power and dependence); and (4) independent barriers (strong driving power but weak dependence).

2.2. Methods Used for Identifying Strategies

This step contributed to achieving the core target of this study. Accordingly, semi-structured interviews were conducted to identify suitable strategies to improve the delivery of LCBs by overcoming the identified constraints. A summary of the findings on constraints and their interdependencies was presented to each interviewee, who was asked to provide recommendations by referring to the summary of the findings where possible. The interview guidelines were sent to the interviewees beforehand to be prepared for the interview. Accordingly, the respondents were asked to state the constraints which could be addressed (or mitigated) through the strategies suggested by them. Furthermore, they were asked to indicate the required involvement and collaboration of different stakeholders in implementing these identified strategies.

In-depth semi-structured interviews were conducted with eight experts in the industry and academia, who were approached through personal contacts. Accordingly, three senior academics at different universities and in different countries (all of them were involved in research and teaching on low-carbon buildings, building energy efficiency, green buildings, and sustainable construction and built environment management), two senior facilities managers (who had relevant experiences in managing and carrying out facility management procedures in low-carbon/green buildings), a quality and compliance manager (involved in environmental and energy compliance in buildings), a government official (working in a senior management position at an energy/sustainability-related authority), and a senior quantity surveyor (who had experiences in constructing/costing the construction process of low-carbon buildings and green buildings) were interviewed. All the interviewees had more than 10 years of experience in relevant fields. Accordingly, a sample of experts with relevant exposure and experience covering different sectors could be approached for the semi-structured interviews.

The interviews were transcribed, and a written record was prepared. As there were only eight interviews, this task was performed manually without getting the support of any transcription software. Subsequently, the data were organised to easily understand the 'strategies to accelerate the delivery of LCBs by addressing the constraints', 'categories of the identified strategies', 'connections among strategies and the constraints', and 'required stakeholder involvement and collaboration in initiating the strategies'. Furthermore, the collected data from different interviewees were comparatively analysed, redundancies and repetitions were eliminated, and the list of strategies was finalised by utilising the most inclusive and appropriate suggestions of interviewees. Furthermore, detailed descriptions provided by the interviewees were utilised when interpreting and discussing the strategies. Accordingly, it was ensured that a clear and concise representation of the interviewees' opinions was incorporated in preparing the list of strategies, mapping the constraints with strategies, and discussing the findings. Furthermore, the identified strategies (through interviews) were further discussed with the literature support from several publications. The above steps were followed to ensure the reliability and validity of the collected data.

Methods Used for Social Network Analysis of Constraints and Strategies

SNA incorporates mathematical, statistical, and informational methodologies to analyse a specific set of linkages among a defined set of entities arranged into a network structure [47]. This study utilised an SNA two-mode (bipartite) network structure to map and analyse the connections among two sets. Accordingly, 'strategies' and 'constraints' were used as the two types of nodes in the social network. The links between strategies and constraints were identified through the semi-structured interviews, and the network of these identified links was developed through the UCINET social network software package.

The developed two-mode network was statistically analysed through the 'degree centrality' network analysis measure. This measure is suitable for analysing the nodes in a network in terms of their structural positioning and connectedness [47]. Further, this measure provides an indication of the significance of the nodes in terms of the number of connections.

Degree centrality (DC) indicates the number of connections of a node in the network. Accordingly, a node with a higher degree of centrality value has many direct links with other nodes in a network [48]. Thus, holding a centralised position in the network and acting as a hub [49]. In the present study, the DC of a strategy represents the number of constraints which can be addressed by the considered strategy. Similarly, the DC of a constraint represents the number of strategies which can contribute to addressing the considered constraint.

DC can be measured by using Formula (1).

$$DC(i) = \sum_{j}^{N} x_{ij} \quad (1)$$

Index i indicates the considered node for calculation; j refers to the nodes in the other category of the two-mode data set, and x represents the adjacency matrix. x_{ij} is the element of the ith row an jth column of x. Similarly, the DC of node type j can be calculated.

3. Results and Analyses

3.1. Constraints to Delivering LCBs and the Interdependencies among the Constraints

Figure 3 shows a summarised representation of the findings of the precursor study by the same authors [29]. Accordingly, the 21 common and significant constraints that were identified, are presented in a hierarchical structure of 12 levels (ISM hierarchical structure). The constraints placed at the bottom levels of the structure are significant and driving constraints which affect the other constraints in the middle and upper levels of the structure.

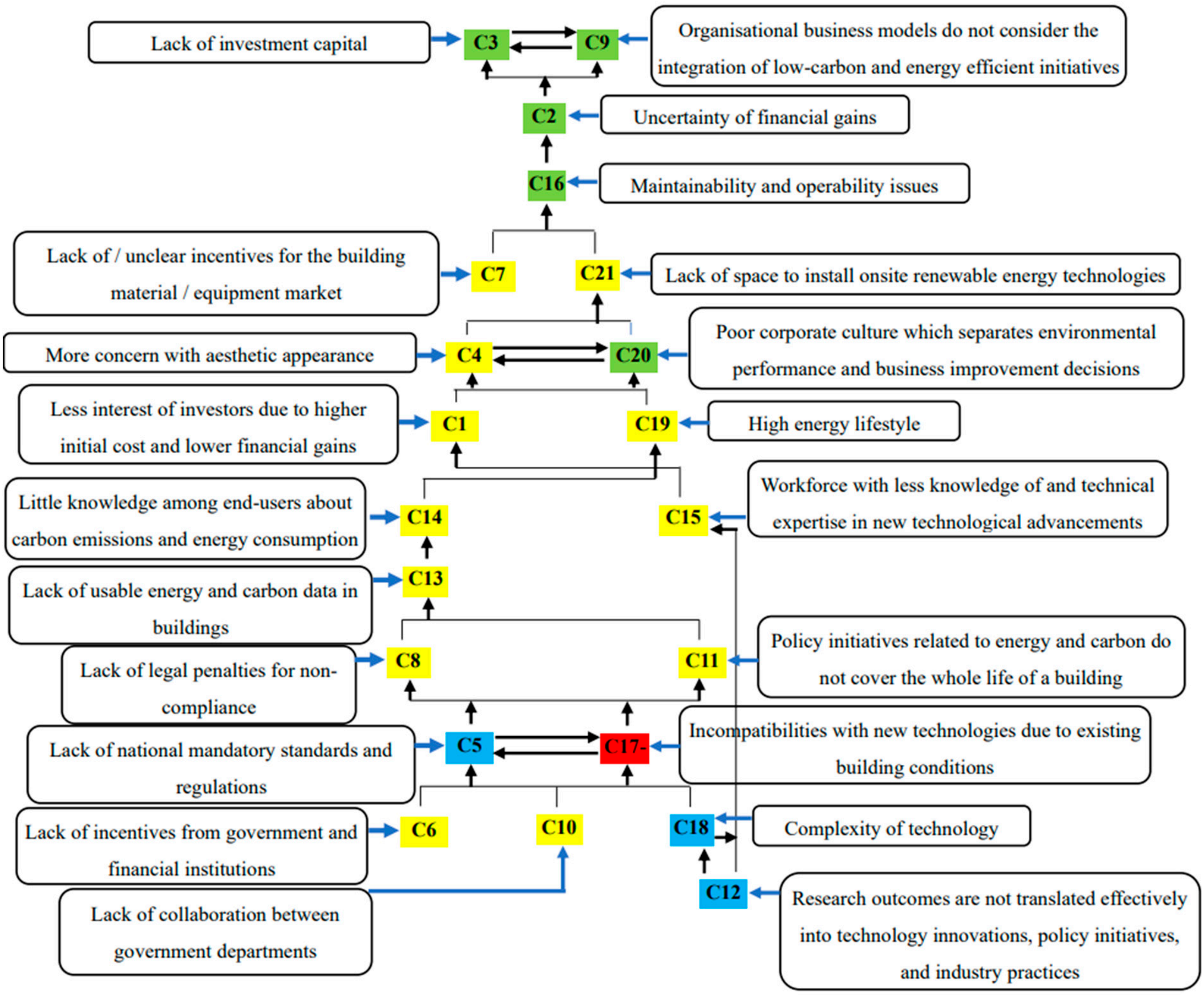

Figure 3. A summary of constraint interdependencies.

MICMAC technique and ISM approach are often used together to analyse the hierarchical structure among a set of barriers along with their driving/dependence nature [50,51]. Accordingly, constraints to delivering LCBs in high-rise, high-density cities were categorised and prioritised to identify the significant constraints which should be targeted when deciding strategies to accelerate the delivery of LCBs. According to the MICMAC analysis, the constraints were categorised into four different categories based on their driving and dependence nature. These four categories are highlighted by different colours in Figure 3, i.e., yellow—autonomous constraints with weak driving power and weak dependence, blue—independent constraints with strong driving power and weak dependence, red—linkage constraints with strong driving power and strong dependence, and green—dependent constraints with weak driving power and strong dependence.

According to the ISM hierarchical structure, the constraints C5 (lack of national mandatory standards and regulations), C6 (lack/unclear incentives towards owners and developers), C8 (lack of legal penalties due to non-compliance), C10 (lack of coordination, communication and collaboration between government departments to initiate building energy and carbon policy initiatives), C11 (policy initiatives related to energy and carbon do not cover the whole life of a building), C12 (research outcomes are not effectively translated into technology innovations, policy initiatives, and industry practices), C17 (incompatibilities with new energy efficient and low-carbon technologies due to existing building conditions), and C18 (complexity of technology) were identified in the bottom levels of the hierarchy (levels 9–12). Accordingly, these constraints can be identified as having a comparatively high driving power and significance. The MICMAC results also provide an indication of the significance of these constraints. Accordingly, it was evidently established that addressing these driving constraints upfront can effectively contribute to addressing and mitigating the other dependent constraints. Five of these eight significant constraints are related to the policy and regulatory level; one is related to research and the industrial applications of research outcomes, while the other two are related to technical constraints. Nevertheless, policy and regulatory actions will be the key to improving the practical applicability of research and also to introducing feasible low-carbon technologies to the building industry. Therefore, policy and regulatory sector stakeholders can be identified as having the highest influencing ability in overcoming the constraints of delivering LCBs.

3.2. Strategies for Accelerating the Delivery of LCBs

This section discusses the strategies to accelerate the delivery of LCBs by addressing the constraints identified through eight semi-structured interviews conducted with experts in industry and academia. Moreover, the required contributions of stakeholders in implementing the identified strategies are briefly discussed together with the identified strategies. Suitable strategies were identified to accelerate the development and delivery of LCBs under six categories. The discussions in this section are based on the findings from the in-depth semi-structured interviews.

Policy and regulatory constraints and technology-related constraints were identified as the most significant and driving constraints to delivering LCBs in the selected set of countries/regions. The interviewees also acknowledged that the policy and regulatory level strategic influences and effective technology advancements/adoption as the most significant driving forces in accelerating the delivery of LCBs. In addition to the identification of suitable strategies to accelerate the delivery of LCBs, the interviewees were requested to indicate the constraints which can be influenced through the identified strategies. Accordingly, Table 1 provides a summarised presentation of the strategies identified by the interviewees, and Figure 4 shows the connections among the identified strategies and the list of 21 'common and significant' constraints, as identified by the interviewees. Furthermore, Figure 4 provides an indication of the significance of the strategies based on their connections with driving, dependent, and intermediate constraints.

Table 1. Summary of identified strategies.

Categories	Strategies
P1	Decentralising the generation of electricity by proper urban planning
P2	Implementing regulations on phasing out the systems, equipment, and materials with high-carbon emissions and less energy efficiency
P3	Implementing national level realistic emission reduction policies and targets
P4	Integrated policy initiatives for urban development
P5	Mandating low-carbon retrofitting/refurbishment
P6	Standardising construction and building materials
P7	Implementing penalties, such as taxes for non-compliance, environmental tax, etc.
P8	Introducing city or state-based energy benchmarks and fines for not achieving the benchmarks
P9	Introducing regulations for building deconstruction and disposal
P10	Introducing/updating the mandatory building energy codes
P11	Labelling and certifying the new and existing buildings
P12	Labelling (energy/carbon) for building materials, equipment, and systems
P13	Introducing Life Cycle Analysis (LCA) regulations for building materials
P14	Mandating the required minimum energy/carbon performance levels of appliances and equipment
P15	Implementing regulations on thermal performance and embodied carbon emissions of building materials
P16	Ensuring proper inspection of major refurbishments
P17	Mandating structural provisions for onsite-renewable energy generation for new constructions
D1 (A,T)	Creating more opportunities for pilot projects, real-world examples, and sharing of performance data and evidences to build trust among investors
D2 (P)	Making energy audits compulsory for existing buildings and standardising the reporting procedures
D3 (P)	Mandating the disclosure of energy usage and carbon emissions
D4 (P)	Mandating LCA for major investments in the public sector
D5 (P,T)	Encouraging and supporting life cycle assessment (LCA) by providing relevant expertise and calculation tools
D6 (P)	Continuous improvement and reviewing of standards based on real world data
A1	Raising awareness of the general public through various media platforms
A2(O)	Raising end-user awareness, encouraging behavioural changes, and influencing changing their attitudes
A3	Including education on sustainability/emission reduction/energy efficiency to the school curriculums from primary education
A4	Training and certification of energy managers and energy auditors through a regulatory body
A5	Training relevant government sector officials
A6	Training organisations to develop sustainable business models
A7	Providing specialised training on relevant products, tools, systems and technologies
A8 (D)	Establishing databases/websites for relevant information sharing on energy-efficient and low-carbon initiatives (materials, equipment, technologies, suppliers, construction/installation methods/times/costs, energy/carbon performance data of materials/equipment/systems, payback information, important results of occupancy surveys/audits)
A9 (P)	Maintaining a pool of qualified energy and carbon auditors in the government sector
T1	Demonstrating, prototyping, and providing examples of developed advanced energy efficient materials, equipment, and technologies
T2	Exploring co-generation capacities and energy recovery opportunities
T3 (P)	Mandating the maintenance and servicing contracts with specialised and authorised service providers
T4 (P)	Ensuring the availability of globally applicable maintenance and servicing procedures for systems and equipment
T5 (P)	Assessing new constructions in terms of their potential for renewable energy generation and energy recovery
T6 (P)	Planning and implementing construction waste sorting and recycling facilities by the government or supporting the private sector to implement these facilities
T7 (P)	Implementing effective guidelines for building deconstruction and waste sorting
T8 (O)	Integration of BIM and utilisation of advanced tools at the design stage
T9 (P)	Validating the performances of new developments and evaluating the compliance with other requirements, such as safety and fire regulations

Table 1. *Cont.*

Categories	Strategies
T10 (P)	Conducting research on reusing/recycling materials and minimising the usage of important natural resources
T11 (O)	Adopting building management systems with integrated controls
T12 (O)	Ensuring timely standardised maintenance and servicing of high energy-intensive systems and equipment
T13 (P)	Obtaining international-level assistance for technology advancement for LCBs
T14 (P)	Industry, academia, and government collaborations in research and technology adoption
T15 (I,P)	Financing the conversion of research and development (on technical advancements of materials, products and equipment) into manufacturing (through tax incentives, providing grants, etc.)
T16 (P)	Providing suitable research grants to universities
T17 (P)	Ensuring the support of the government for manufacturers and producers (who develop advanced high-efficient technical solutions) to bare the risk of entering into new markets
T18 (O)	Obtaining the best performances of the systems through following proper (standardised) installation, maintenance, and operational procedures
T19 (P)	Promoting circular design approaches for buildings
I1	Offering attractive interest rates and longer tenure periods, incentives, such as grants, loans, and tax rebates, for low-carbon/energy efficient investments
I2 (A)	Raising awareness of financial institutions on financing low-carbon, energy efficient, and green building initiatives
I3	Offering incentives to encourage the building owners to consider more decentralised power generation options
I4 (P)	Establishing policies to finance the onsite renewable energy generation in buildings
I5	Providing attractive tariff rates for feeding power to the national grid through renewable energy generation in buildings
I6 (P)	Link financing procedures with the building energy/carbon certifications and standards
I7	Financing for low-carbon initiatives through energy service providers/companies (ESCOs) by initiating performance-based contracts
I8	Offering long-term warranties for the systems and equipment
I9 (T,P)	Offering incentives for manufacturing industries to invest in productive research and development
I10 (P)	Providing incentives, such as rebates for taxes and loans for energy efficient/low-carbon product development
O1	Establishing and following internal compliance procedures and energy/carbon policies in organisations
O2	Establishing an energy-efficient/low-carbon culture within organisations
O3	Developing organisational internal funding models to support investments in energy-efficient and low-carbon initiatives/procurement procedures to consider LCA, LCC
O4	Delegation of responsibilities for low-carbon, energy-efficient, and sustainability-related initiatives within organisations
O5	Generating, processing, and analysing the building-level data related to energy usage, carbon emissions, behaviour patterns, equipment/system performances, etc.
O6	Adopting sustainable maintenance procedures
O7	Incorporate energy saving and carbon reduction into their internal business models
O8 (D)	Determining building-specific initiatives (e.g., phasing out less efficient systems, demand management, load shedding, adjustment of operational procedures, investments in new energy/carbon efficient systems, adopting energy management systems) based on the generated data and information through building-level audits/surveys
O9	Implementing effective energy management procedures in buildings

In Table 1, 'P' indicates the strategies related to policies, regulations, standards, codes, and certifications; 'D' indicates the strategies related to the effective utilisation of building energy/carbon data; 'A' indicates the strategies related to awareness raising, training, and information dissemination; 'T' indicates the strategies for technology advancement; 'I' indicates the strategies related to providing incentives for low-carbon adoption, and 'O' indicates the organisational level strategies to accelerate the low-carbon adoption. Some strategies are difficult to mention under one specific category. Therefore, these strategies are mentioned (and numbered) under the most relevant category, and other relevant categories are mentioned within brackets. For example, 'D5 (P/T)' indicates that the relevant strategy relates to the data utilisation (D). Yet, it can also be related to policy and technology-related sectors.

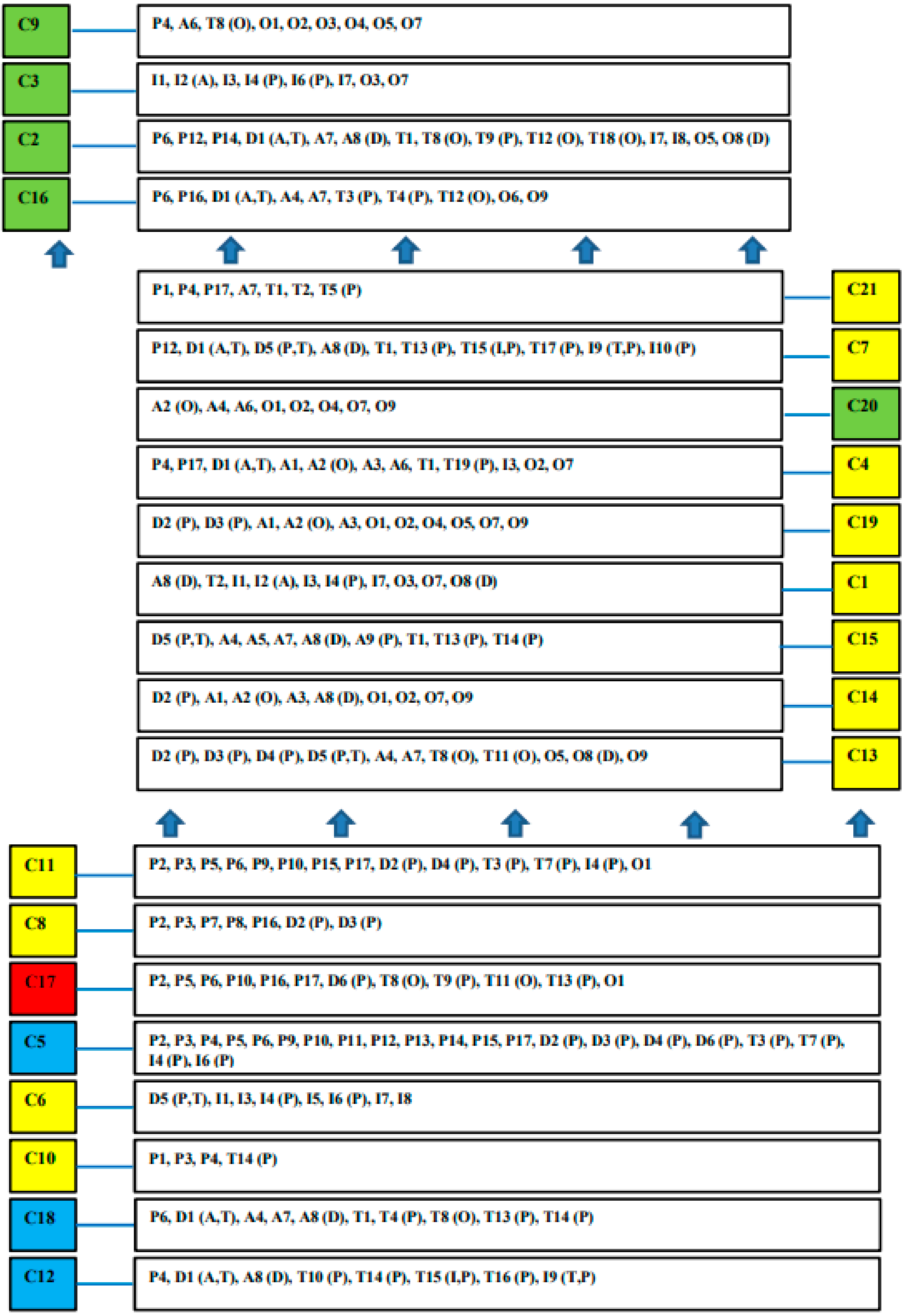

Figure 4. Connections between strategies and constraints.

Figure 4 is finalised with the 'summarised list of strategies' and 'connections between strategies and constraints', as identified by the interviewees. Moreover, the ISM and MICMAC findings of the precursor study [29] are incorporated into this figure to provide an indication of the significance of the constraints and strategies.

The constraints in Figure 4 above are coloured according to whether they are autonomous (yellow), independent (blue), linkage (red), and dependent (green) in nature (corresponding to the MICMAC analysis in Figure 3). Furthermore, the set of constraints in the bottom cluster (C11, C8, C17, C5, C6, C10, C18, and C12) are placed in levels 9–12 of the ISM hierarchical structure, indicating a higher driving power. Accordingly, the strategies targeting these driving constraints can also be considered significant driving strategies that could have a higher impact towards accelerating the delivery of LCBs by addressing the driving constraints. Accordingly, it is evident that the policy and regulatory level strategies, strategies to provide incentives, and strategies related to technology advancement are mostly linked with the driving constraints in Figure 4. The middle cluster in Figure 4 shows the connections of strategies towards the constraints placed in levels 4–8 of the ISM hierarchical structure (C21, C7, C20, C4, C19, C1, C15, C14, C13). Most of these constraints show both driving and dependence characteristics. The constraints placed in the upper cluster of Figure 4 show the highest dependent characteristics. Accordingly, these constraints are placed in levels 1–3 of the ISM hierarchical structure (C9, C3, C2, C16). The strategies related to the areas of knowledge and awareness, organisational commitments, and data utilisation are mostly influencing the constraints at middle and upper clusters. Accordingly, this implies that these strategies also depend on policy, technology, and incentive-related strategies.

3.3. SNA-Based Mapping and Analysis of Constraints and Strategies

In addition to the above analyses, a two-mode social network structure (Figure 5) was constructed to visualise the connections between the constraints and strategies. Accordingly, the red-coloured nodes show the identified 21 common and significant constraints to delivering LCBs in high-rise, high-density cities. Blue-coloured nodes show the identified strategies for accelerating the delivery of LCBs.

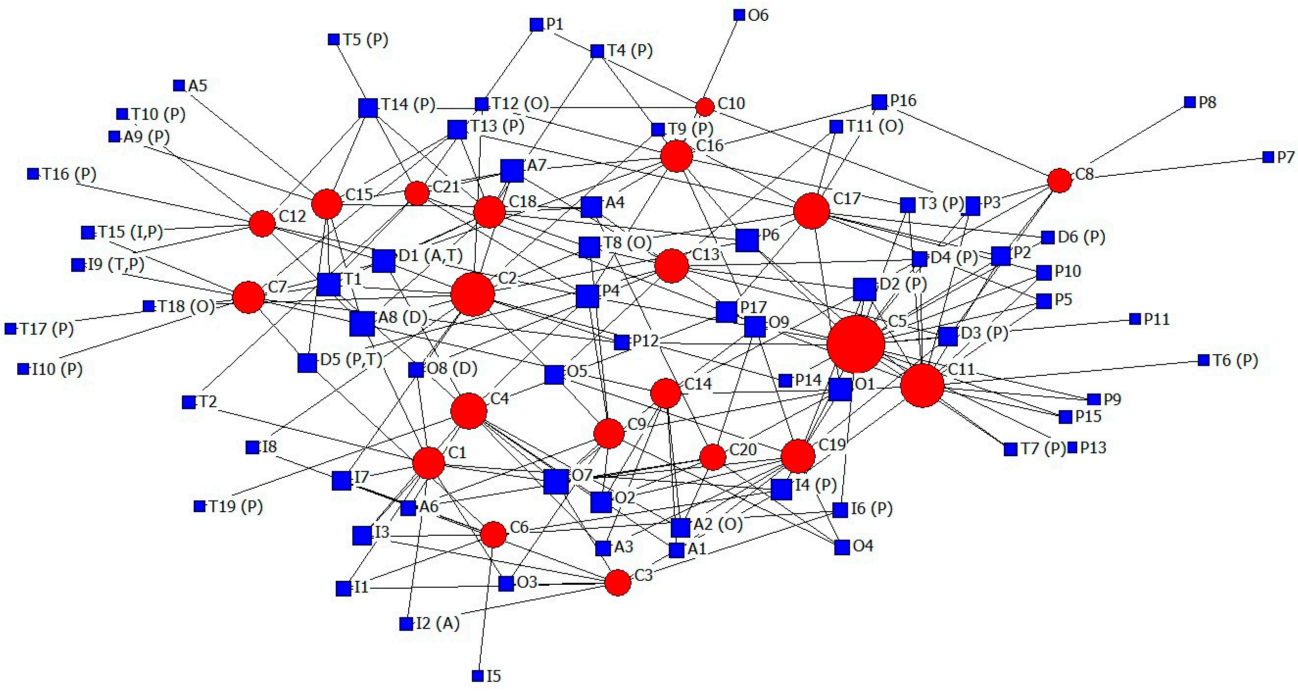

Figure 5. Two-mode social network of constraints and strategies.

The size of each node proportionally represents the 'degree centrality' value of the node. Furthermore, the significant nodes (which have a higher number of links) are clustered to the centre of the network structure, while the nodes with fewer connections are scattered around the network. Table 2 shows the degree centralities (DC) of 'strategies' and 'constraints'.

Table 2. Degree centralities of 'strategies' and 'constraints'.

Strategy ID	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
DC	2	4	4	6	3	6	1	1	2	3	1
Strategy ID	P12	P13	P14	P15	P16	P17	D1 (A,T)	D2 (P)	D3 (P)	D4 (P)	D5 (P,T)
DC	3	1	2	2	3	5	6	6	4	3	4
Strategy ID	D6 (P)	A1	A2 (O)	A3	A4	A5	A6	A7	A8 (D)	A9 (P)	T1
DC	2	3	4	3	5	1	3	6	7	1	6
Strategy ID	T2	T3 (P)	T4 (P)	T5 (P)	T6 (P)	T7 (P)	T8 (O)	T9 (P)	T10 (P)	T11 (O)	T12 (O)
DC	2	3	2	1	1	2	5	2	1	2	2
Strategy ID	T13 (P)	T14 (P)	T15 (I,P)	T16 (P)	T17 (P)	T18 (O)	T19 (P)	I1	I2 (A)	I3	I4 (P)
DC	4	4	2	1	1	1	1	3	2	4	5
Strategy ID	I5	I6 (P)	I7	I8	I9 (T,P)	I10 (P)	O1	O2	O3	O4	O5
DC	1	3	4	2	2	1	6	5	3	3	4
Strategy ID	O (6)	O (7)	O8 (D)	O9							
DC	1	7	3	5							
Constraint ID	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
DC	10	15	8	12	21	8	10	7	9	4	15
Constraint ID	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	
DC	8	11	9	9	10	12	10	11	8	7	

Accordingly, the strategies P4 (integrated policy initiatives for urban development), P6 (standardising construction and building materials), D1 (A,T) (creating more opportunities for pilot projects, real-world examples, and sharing of performance data and evidences to build trust among investors), D2 (P) (making energy audits compulsory for existing buildings, and standardising the reporting procedures), A7 (providing specialised training on relevant products, tools, systems and technologies), A8(D) (establishing databases/websites for relevant information sharing on energy-efficient and low-carbon initiatives (materials, equipment, technologies, suppliers, construction/installation methods/times/costs, energy/carbon performance data of materials/equipment/systems, payback information, important results of occupancy surveys/audits)), T1 (demonstrating, prototyping, and providing examples of developed advanced energy efficient materials, equipment, and technologies), O1 (establishing and following internal compliance procedures and energy/carbon policies in organisations), and O7 (incorporating energy saving and carbon reduction into their internal business models) show the highest number of connections (more than six) with constraints. This implies that these strategies could address many 'common and significant' constraints to delivering LCBs identified in this study.

Among the list of constraints, 21 strategies could contribute to addressing and overcoming constraint C5 (lack of national mandatory standards and regulations). C2 (uncertainty of financial gains) and C11 (policy initiatives related to energy and carbon do not cover the whole life of a building) are connected with 15 strategies, while the constraints C4 (more concern with aesthetic appearance) and C17 (incompatibilities with new technologies due to existing building conditions) are connected with 12 strategies. This indicates that the attention and commitment of multiple sectors are required to address and overcoming these constraints. Moreover, it can be highlighted that the centralised strategies with relatively higher degree centrality values in the SNA two-mode structure have the ability to address a majority of driving constraints (driving constraints could be identified from Figures 3 and 4). Once these driving constraints are effectively addressed and mitigated, it contributes to mitigating the connected dependent constraints (in upper levels of ISM structure) without much effort.

4. Discussion

This section discusses the strategies under the six main categories presented in Table 1. In addition to the identification of strategies and mapping them with constraints, the interviewees were asked to provide their views on the required involvement and collaboration of different stakeholders/stakeholder classes in implementing the identified strategies. Accordingly, the significant constraints, strategies to address the constraints and accelerate the delivery of LCBs, and the required involvement and collaboration of different stakeholders in implementing the strategies are discussed in detail in this section. This discussion is also supported by the literature where possible.

4.1. Formulating and Implementing Adequate Policies, Regulations, Standards, Codes, and Certifications

The lack of mandatory standards and regulations (C5) was identified as a common constraint in the considered countries and regions. Policy initiatives related to energy and carbon do not cover the whole life of a building (C11), and a lack of legal penalties due to non-compliance (C8) was also identified as a significant constraint hindering the effective delivery of LCBs. Accordingly, sufficient actions are required to strengthen the policies and regulations. Implementing national-level realistic emission reduction policies and targets for buildings and providing detailed step-by-step guidelines on moving towards the targets are needed [13], and this should be led by the government and standards and accreditation bodies. Academia and professional bodies should also be proactively involved in supporting policy development. Policy implementation needs to be accelerated by providing adequate incentives to the owners/clients, manufacturers, and contractors to adhere to the relevant guidelines. Policy implementation could start with putting mandates to retrofitting first and then moving into the areas, such as standardising construction and building materials, and then targeting zero environmental impact/zero-carbon buildings as long-term plans [33]. As an initial attempt, initiating regulations on phasing out the systems, equipment, and materials with high carbon emissions and less energy efficiency can be made. This can be achieved by introducing the minimum energy and carbon performance requirements for building retrofitting and refurbishment [52,53]. Energy efficient/low-carbon retrofitting policies can be developed specifically for cities/high-density urban areas, focusing on the facilities managed by the government sector. Subsequently, the best practices and procedures can be used as examples for the private sector to implement sustainable/green/low-carbon retrofitting and maintenance procedures. Implementing mandatory energy-efficient/low-carbon refurbishment requirements based on the age of the building (e.g., 25–30 years) could be pursued. Customised standards could be implemented for refurbishment. Proper inspection of the major refurbishments should be performed by the relevant regulatory authorities in the building sector. Market penetration of low-carbon/energy-efficient materials, equipment, and systems should be supported simultaneously through incentives (incentives are discussed in a separate section below).

Integrated and consistent policy development is another crucial requirement. Developing policies for multi-level governance in accelerating the development and delivery of LCBs in urban areas is a major required commitment of policy-makers and regulators [52]. Furthermore, integrated master plans should be developed for low-carbon high-rise, high-density city development. This initiative should be led by the government by involving the governmental authorities relevant to urban development, sustainability, energy, transportation, etc. The involvement and collaboration of owners/clients, contractors, NGOs, public and community bodies, and education and research institutes are also crucial in developing such a master plan [52]. The main responsibility in initiating policy initiatives is with the government, relevant departments, and authorities. Nevertheless, proper communication channels should be established with the academia, private sectors and industries, and public and civil societies to be successful in developing policies with the win–win scenarios. Furthermore, the governmental departments responsible for the environment, power generation and supply, industry relations, finance, buildings/built environment, and urban development should establish proper communication and collaboration channels with each other to achieve integrated approaches for decarbonising cities/regions as a whole. When it comes to high-rise, high-density cities, the main priority should be for buildings since they consume the majority of generated electricity and emit a significant amount of carbon. Lack of collaboration and coordination among relevant government sector authorities (C10) was also identified as a common and significant constraint to the considered set of countries/regions in the present study. Initiating the above actions could also help in enhancing collaboration among governmental entities, hence also facilitating innovative project management and asset management on building projects and project portfolios [54].

Government, with the collaboration of research entities, utility suppliers, industries, and building owners, should implement programmes to decentralise the generation of electricity through proper urban planning [52]. The buildings sector should be encouraged and supported for onsite renewable energy generation and feeding to the grid (net metering) based on the generation capacity. Mandates can be introduced to include structural provisions in buildings for onsite-renewable energy generation for the new constructions.

Government should also play a key role in providing policy support throughout the process of product development, starting from research and development, material extraction, processing, market penetration, financial incentives, and performance certification. There are multiple sectors which should be involved, such as researchers, manufacturers, financial institutions, and suppliers. Government agents should play the coordination role and driving role in this process. This should be performed until the technology or product is established in the market and gets matured/saturated in the market.

It is also possible to introduce city or state-based energy benchmarks and introduce fines and penalties for non-compliance [33,52]. Subsidies and tax incentives should be implemented prior to the implementation of penalties for non-compliance. Subsequently, penalties, such as taxes for non-compliance and environmental tax, can be introduced as penalty measures in the long run. Simultaneously, rewards or grants should be provided to the facilities with better energy and carbon performances.

4.2. Effective Utilisation of Building Energy and Carbon Data

Lack of usable energy and carbon data in buildings (C13) is another constraint commonly identified in the selected contexts. Effective policy interventions, skill development of professionals, and technological support are important in addressing this constraint. Mandatory energy audits for existing buildings should be supported by standardised reporting procedures and database maintenance [33]. The audits should be conducted by targeting different phases of the building life cycle. The operational phase audits should be conducted on a time scale. Audits can also be performed to identify the energy/carbon performances for mandatory compliance requirements. Accordingly, Gupta et al. [33] highlighted that life-cycle assessment (LCA) should be encouraged and supported by providing relevant expertise, regulatory support, comparative studies, and calculation tools. This can start with the public sector by mandating LCA for major investments.

Adequate training and certification programmes should be introduced for energy auditors and energy managers. Mandating the disclosure of energy usage and carbon emissions, including embodied carbon emissions, is an important step towards initiating a data-driven culture in decision-making for building energy efficiency improvement and carbon emission reduction. For this, energy/carbon performance data and audit results should be easily accessible to the relevant government sectors, academia and other relevant professionals at the project level, organisational level, and wider project portfolio levels. Continuous improvement and review of standards and regulations should be pursued based on the available real-world data. Standardisation and accreditation bodies and the governmental authorities are the primary responsible parties for this, while contractors, consultants, organisational-level energy managers, facility managers, and clients should actively engage and collaborate in arranging data generation and sharing at the project/organisational level.

Actual expenditures and payback period-related information on energy-efficient systems and equipment should be made available for the reference of investors and owners. Universities can focus on carrying out research projects and educational programmes to analyse the payback (return on investment) potentials of major energy-efficient installations and refurbishments. This helps to eliminate the uncertainty in energy saving potential/financial gains associated with low-carbon and energy-efficient investments in the buildings sector (C2). Furthermore, the information on actual construction/installation times, costs, and the amount of energy saved/reduction in carbon emissions should be published on easily accessible platforms (designated websites, media). Alam et al. [13] suggested creating websites to share the details of successful projects, awareness, training programmes, and research findings. This information is important in providing real-world evidence and examples for relevant stakeholders (owners, investors, material and equipment manufacturers, and relevant regulatory bodies) to make informed decisions on energy/carbon efficient investments and required improvements to the systems. Accordingly, Cristino et al. [55] also emphasised the importance of having a strong policy framework to disseminate relevant information on building energy-efficient technologies.

The data gathered through energy management systems (EMS) and building management systems (BMS) can be effectively utilised for decision-making on required improvements. These data could also effectively contribute towards deciding energy-saving strategies, evaluating compliance with policies and regulations, benchmarking, record keeping, and certifying. Therefore, the regulatory bodies should take appropriate measures to encourage/mandate the installation of these systems for new constructions.

4.3. Awareness Raising, Training, and Information Dissemination

It is important to develop and maintain proper databases of energy-efficient materials, equipment, technologies, and respective suppliers. This will create opportunities for comparison and selection of adequate materials, systems, and technologies. Moreover, databases should be developed with carbon and energy information on building materials, construction methods, construction projects, etc. Accordingly, new developments could benefit from past information.

Little knowledge among end-users about the consequences of their actions on carbon emissions and energy consumption (C14), high-energy lifestyle (C19), and more concern with aesthetic appearance (C4) are identified as constraints that are common to the selected countries/regions. End-user awareness raising, behavioural changes, and influencing changing their attitudes are important steps in addressing these constraints. Accordingly, Cristino et al. [55] also emphasised the importance of conducting education and training programmes for the occupants of the buildings and improving the awareness of occupants about the building energy-efficient programmes. Proper education should also be provided for occupants on changing their energy-use behaviour [53]. As an initial step, detailed occupancy surveys should be conducted to clearly identify the energy usage patterns and attitudes of the end-users and occupants. Subsequently, end-user-targeted awareness-raising programmes should be implemented to make them aware of the multiple benefits of low-carbon initiatives (the information gathered through the occupancy surveys could be used as the baseline for designing these awareness programmes in a particular country/region). Government and academia can collaboratively design uniform occupancy survey guidelines. Facility managers, energy managers (with the support of owners), and relevant government representatives can carry out the surveys while the relevant government sector authorities and academia can design suitable training and awareness-raising programmes. Furthermore, incentive schemes for adopting low-carbon/energy-efficient behaviours can be introduced at the organisational level.

Importantly, the overall awareness of the general public should be raised to self-motivate them in selecting low-carbon/sustainable alternatives available in the built environment sector. The public should be educated and encouraged to adopt sustainable behaviours. This is a long-term process since behaviour changes must be preceded by mindset changes. Therefore, this should start with primary education and continue through secondary and tertiary education, timely awareness programmes, training programmes, media support, etc.

A workforce with less knowledge and technical expertise in new technological advancements (C15) was identified as another significant constraint. Therefore, efficient training and accreditation systems should be implemented for the professionals engaged in the sectors of low-carbon construction, auditing, energy management, building maintenance and retrofitting. IEA [52] suggested implementing accreditation systems for professionals engaged in low-carbon construction and management as a feasible solution to enhance the quality, skills, and expertise of the workforce. Implementing specialised training on relevant products, tools, systems, and technologies is also an important step [26,33]. This will enable obtaining the best performances of these systems through proper installation, maintenance, operations, etc.

Government sector officials in relevant authorities and departments should also be provided with adequate training and accreditations. Cristino et al. [55] also emphasised the importance of providing adequate training to regulators and legislators. Accordingly, providing training and certifications and employing a qualified set of energy and carbon auditors in the government sector will be important to maintain the uniformity of energy/carbon auditing, comparison and further decision-making on policy initiatives for energy usage and carbon emission reduction in buildings. Accordingly, Alam et al. [13] highlighted the importance of developing a pre-qualified set of energy auditors. Moreover, training and certification of energy managers through a regulatory body should be conducted to facilitate the implementation of effective energy management procedures in buildings. Necessary training should be provided for organisations to support the development of their business models by including sustainability aspects in their operations and facilities.

4.4. Technology Advancement

Incompatibilities with new technologies due to existing building conditions (C17) and complexity of technology (C18) are identified as commonly prevailing constraints in the selected contexts. In order to adopt feasible technologies, the policy-makers and regulators should target obtaining international-level assistance for technology advancement for LCBs. This should be performed by considering the current social, economic, and technological status of the country.

Priority should be given to supporting the manufacturing of locally produced low-carbon building materials. Incentives should be given to relevant manufacturing industries to invest in productive research and development in developing low-carbon alternatives. Demonstration, prototyping, and examples of developed advanced energy-efficient materials, equipment, and technologies should be promoted through the sponsorship of the government [53,55]. This could help in building the trust of investors and clarifying the uncertainties associated with low-carbon and energy-efficient investments (C2).

Validating the performances of new developments and evaluating compliance with other requirements, such as safety and fire regulations, should be effectively supported and carried out with the involvement of relevant government authorities before the commercialisation of the materials and products. Furthermore, the cost-effectiveness of these alternatives should be assessed. For this, the manufacturers, relevant national-level laboratories and research institutions, such as universities, should work in collaboration. Initial market penetration of such innovative products should be supported with demonstrations, case studies, etc. Government, research institutions, academia, manufacturers, and the media should also work collaboratively to penetrate these markets with technological advancements. Government support is needed for the manufacturers during this transition to help bear the risk of entering into new markets. Financial institutions should also work collaboratively in providing incentives for promoting these technological advancements.

Useful research outcomes not being translated effectively into technology innovations, policy initiatives, and industry practices (C12) is also identified as a significant and common constraint. Research and development could be initiated by research institutions, such as universities or research and development sections of industries. The construction industry, government sector, and academia should collaboratively commit to addressing this constraint. Government should encourage and provide suitable research grants to universities and other institutions to initiate research centres and carry out research projects on developing cost-effective, low-carbon, and energy-efficient alternatives [33,55]. Research and development should be encouraged in exploring construction methods to minimise the usage of increasingly scarce natural resources, e.g., sand, and to increase the usage of recycled materials. Government should also provide incentives for industries to invest more in research and development.

Financing the conversion of research and development into manufacturing through tax incentives, providing grants, etc., should also be made with the support of government and financial institutions. Industry, academia, and government collaboration and information exchange should also be promoted through joint workshops, seminars, conferences, and exhibitions. Industries, energy generation, supplying sector, and the buildings sector should work collaboratively in researching and exploring co-generation capabilities of electricity and recovery of power through heat recovery at the industrial level. Government, academia, and industry-based research and development sectors should collaboratively target circular design approaches for innovative buildings, their materials, and equipment. This helps reduce the embodied energy/carbon of materials, increase the efficiency of construction, operation, and maintenance phases, and also increase the opportunities for reusing and recycling at the end of life.

Appropriate energy simulation, integration of BIM, and utilisation of advanced tools at the design stage effectively contribute to identifying energy-saving opportunities beforehand, thereby constructing a building with optimum energy efficiency and minimum carbon emissions [52]. Furthermore, all new constructions should be assessed in terms of their potential for renewable energy generation and energy recovery (solar electricity, solar thermal, geothermal energy, waste heat recovery, etc.). Accordingly, mandatory requirements should be introduced to plan and design buildings to ensure decentralised energy generation.

'Interoperability and compatibility' of building systems is another major concern (C17). For example, the daylighting control mechanism and HVAC system should have integrated controls. Fire safety systems and HVAC systems should also have proper integration. Therefore, adopting building management systems with integrated controls is important in enhancing the integration of different systems. The usage of different types of sensors and automated controllers and integrating them with building energy-management systems or building-management systems should be encouraged for all new constructions. This will ensure optimum energy utilisation, facilitate decision-making on maintenance, and also help optimise indoor environmental quality, while performance can also be monitored and logged for future decision-making.

Carrying out timely standardised maintenance and servicing of high energy-intensive systems and equipment is important to ensure their performance and efficiency. This can be performed by mandating maintenance and servicing contracts with specialised and authorised service providers. This also ensures the optimum energy/carbon performance of relevant systems and equipment. Availability of globally applicable maintenance and servicing procedures for the systems and equipment should be ensured at the point of installation [33].

Greater attention should also be paid to construction waste management, repurposing of buildings, recycling of materials, and reusing of materials [52]. Accordingly, the government should plan and implement construction waste sorting and recycling facilities or support the private sector to implement these facilities by providing adequate financial incentives and technical guidance. Development of effective guidelines for building deconstruction and waste sorting is another important initiative which could help in streamlining the recycling/reusing process.

4.5. Incentives for Low-Carbon Adoption

Incentives are important for material and equipment manufacturers, producers, and suppliers to survive and thrive in the market as well as for owners and investors to invest in LCBs. Lack of investment capital (C3), lack of incentives for the building material/equipment market (C7), and lack of incentives from the government and financial institutions towards owners and developers (C6) were identified as significant common constraints to LCB adaption in the selected countries and regions. Accordingly, government and financial institutions hold the primary responsibility for introducing adequate financial incentives. Government should initiate awareness raising of financial institutions on financing low-carbon, energy-efficient and green building initiatives [56]. Developing policies to finance onsite renewable energy generation in buildings is another important step towards delivering LCBs. Accordingly, Cristino et al. [55] highlighted the importance of developing a systematic method (pattern) for providing economic incentives.

Manufacturers of low-carbon materials and equipment should be supported with subsidies, such as rebates for taxes, loans, and incentives for research and development. Importers and distributors should also be supported by providing incentives for importing energy-efficient/low-carbon equipment and material by granting tax rebates. Implementing new technologies and developing new products/materials require significant capital and also require access to technology and expertise. More importantly, the manufacturers need a guarantee of the return on investment. Due to the many risks, private investors are less willing to pioneer such developments. Adequate incentives and support from government and financial institutions are required for manufacturers and investors until the end product saturates the market.

Banks can initiate providing financing support, such as mortgages, for buildings with high energy efficiency and less carbon footprint. Moreover, banks can offer attractive interest rates and longer tenure periods for loans which target low-carbon and energy-efficient investments. Furthermore, the incentives, such as grants, loans and tax rebates, can be provided based on the energy/carbon performance levels of developments [52]. A revolving loan fund mechanism can also be considered a feasible option for financing low-carbon and energy-efficient investments [13]. This provides the opportunity for the borrower to repay the loan through the cost savings achieved through the investments made for energy-efficient building retrofits. Additionally, the energy efficiency improvement/carbon emission reduction projects can be financed through the support of national or state level (local government level) budgets. Accordingly, governments could offer financial incentives for private developers to adopt low or zero-carbon initiatives for buildings [53]. UNECE [56] emphasised tax incentives and low-interest loans as the most appropriate methods to increase the viability of investing in energy-efficiency improvement projects. Furthermore, investors' trust can be enhanced, and the uncertainty of return on investment (C2) can be minimised by providing long-term warranties for energy-efficient /low-carbon systems and equipment.

Another feasible option is to link financing procedures with the building energy/carbon certifications and standards. More attractive incentives could be provided according to the ratings or certification levels. Providing attractive feed-in tariff rates for feeding power to the national grid through renewable energy generation in buildings also helps to encourage the building owners to consider more decentralised power generation options [52].

Financing can be made through an energy service provider/company (ESCO) for energy-efficient and low-carbon initiatives in buildings through performance-based contracts. This can be identified as a budget-friendly option for energy efficiency improvement. Accordingly, owners can enter into an energy performance-based contract with an ESCO to upgrade the building with energy-efficient features. The required capital for the improvements can be totally or partially from ESCOs. The relevant payments for the services and the investment of ESCOs are made based on the energy savings of the implemented retrofits and upgrades. In addition to the private sector, public sector facilities can also implement this energy-performance-based contract mechanism and help promote such initiatives in collaboration with ESCOs [52].

4.6. Organisational Level Commitments and Policy Initiatives

C9 (organisational business models are not considering the integration of low-carbon and energy-efficient initiatives) and C20 (a poor corporate culture which separates environmental performances and business improvement decisions) were identified as significant constraints common to the selected countries/regions. Not obtaining priority status for energy/carbon reduction at the organisational level (due to the primary focus on core-business activities), not having strong authority for decision-making and setting goals on energy efficiency improvement/carbon emission reduction, and the high initial cost for advanced energy/carbon efficient systems are major issues arising at the organisational level. Even though some organisations consider installing energy-efficient plants and equipment, there is a lack of attention to adopting continuous energy management approaches due to the additional workload and expenses. Mandates and sufficient incentives from the government sector and financial institutions are highly significant in directing organisations to adopt low-carbon approaches. In addition to the adoption of mandated compliance procedures, organisations and industries should also have proactive and self-motivated commitments to improving energy efficiency, reducing energy consumption, and minimising GHG emissions from their building stock. Accordingly, internal compliance procedures and energy/carbon policies should be developed by considering the nature of the core business and related procedures, for which organisations should incorporate energy saving and carbon reduction into their internal business models. Accordingly, Alam et al. [13] and Gupta et al. [33] also highlighted the importance of incorporating energy efficiency and carbon reduction into an organisation's internal economic model.

Appropriate delegation of responsibilities among the relevant employees (facility managers, energy managers, supervisors, and other responsible personnel on respective plants and systems) is an important step towards reducing operational stage energy usage and carbon emissions. This leads to proper management of buildings, their systems, and components, and, thereby, to achieving the optimum energy/carbon performances. Adopting sustainable maintenance procedures is another important step towards minimising operational carbon emissions from buildings. Furthermore, relevant responsible employees should take a proactive lead in establishing an energy-efficient/low-carbon culture within organisations. Gupta et al. [33] highlighted that the proper distribution of authority among the officers or managers helps in the timely implementation of energy and carbon-related policies and the proper utilisation of funds in an organisation.

Organisational internal funding models should be developed to support investments in energy-efficient and low-carbon initiatives. The organisational procurement procedures should also be developed to consider the options of life cycle cost analysis and life cycle environment impact analysis in procuring new systems and components [13].

Responsible personnel in building operations (facility managers, energy managers, maintenance engineers), with the guidance of their clients/owners, should target generating, processing, and analysing the building-level data related to energy usage, carbon emissions, behaviour patterns, equipment/system performances, etc. The services of energy services companies (ESCOs) or specialised consultants can also be obtained to effectively carry out these data generation and analyses. Subsequently, innovative building-specific initiatives (e.g., phasing out less efficient systems, demand management, load shedding, adjustment of operational procedures, investments in new energy/carbon efficient systems, adopting energy management systems) should be determined based on the generated data and information.

5. Conclusions

This study targeted to identify and explore suitable strategies for accelerating the delivery of LCBs by overcoming the common and significant constraints to delivering LCBs in high-rise, high-density cities.

Based on this study findings, strategies for accelerating the delivery of LCBs were identified and are recommended under six categories, namely, policy implementation, building energy/carbon data utilisation, awareness raising/training, technology advancement, incentives, and organisational level commitments. The strategies related to energy/carbon policy development, standardisation, codes and certifications, mandatory regulations, financial incentives, and technology adoption had the ability to influence a majority of the driving constraints. When these driving constraints are addressed or mitigated through these significant strategic approaches, it contributes to reducing the required efforts in addressing the intermediate and dependent constraints.

Policy and regulatory sector stakeholders were identified to have the highest influencing ability in overcoming the constraints of delivering LCBs. Other stakeholders were important in operationalising governmental actions. However, according to the overall discussions of stakeholder involvement and collaboration in accelerating LCB delivery, the stakeholders/stakeholder classes, contractors, consultants, financial sector, clients/owners, educational, training and research institutions, property and facility managers, manufacturers, accreditation and standardisation bodies, and energy and environmental service providers, were identified as having a significant influencing ability in implementing most of the strategies.

This study also adds to the SNA knowledge domain itself by extending the SNA two-mode applications to analyse connections of strategies and constraints to delivering LCBs. Moreover, the sequential ISM and SNA integrated methodological approach utilised in the present study contributes to the knowledge domains of respective research methods by providing prospective integrated analysis approaches for future researchers. Furthermore, the identified strategies provide important guidance to the relevant practitioners to determine suitable approaches to accelerate the delivery of LCBs by prioritising the required actions and identifying the responsible stakeholders/stakeholder classes in implementing these strategies. More importantly, this study provides an integrated, innovative approach to address the constraints by considering their driving and dependence characteristics. Accordingly, this study shows that an integrated systems approach, which considers the interdependencies among multiple sectors (e.g., policy level, project level, financing sector), is more suitable than traditional discrete/disconnected ad hoc attempts for addressing specific constraints in accelerating the delivery of LCBs.

Due to the difficulty in administering prolonged interviews and due to the time constraints, required stakeholder involvement and collaboration aspects were not discussed by specifically relating to each strategy. Therefore, future research can include a comprehensive stakeholder engagement and collaboration analysis for implementing the identified strategies. In order to fulfil the aim of the present study, the strategies for addressing the common constraints in delivering LCB to high-rise, high-density cities were identified based on data from a typical sample. Testing these strategies on yet another high-rise, high-density city would be a logical next step but may ideally require a longitudinal study in that city with close cooperation with all those involved. Such accessibility to the key stakeholders, longitudinal data availability, time, and resources were unavailable in this study for such a follow-up. However, such testing, followed by fine-tuning such strategies for specific cities/regions (as case studies) and then preparing city or region-specific strategic plans to accelerate the delivery of LCBs, are suggested as useful future research directions.

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