CONSTRAINTS TO DELIVERING LOW CARBON BUILDINGS IN HIGH-RISE HIGH-DENSITY CITIES

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Expected practical improvements in delivering low carbon buildings in high-rise high-density cities are still lagging behind those needed to meet global carbon reduction targets. This indicates that there could be a number of commonly prevalent constraints that hinder the delivery of low carbon buildings. Therefore, this paper aims to systematically identify and explore these constraints. The presented outcomes are based on a systematic literature review of published journal papers from 2001 to 2020 and the findings from a questionnaire survey covering seven cities in five contexts: namely, UAE (Dubai and Abu Dhabi), Qatar (Doha), Australia (Melbourne and Sydney), Singapore and Hong Kong. The systematic review led to the identification of 71 common constraints under 8 categories: namely, 'financial', 'market structure and supplies', 'policy and regulatory', 'knowledge, awareness and information', 'workforce and skills', 'technological', 'behavioural, social and cultural', and 'geographical and environmental'. While identifying the constraints common to the contexts of surveyed cities, the paper also presents the constraints specific to each context. The findings should assist decision making at both policy and project levels to accelerate the delivery of low carbon buildings by addressing and ameliorating the common constraints impeding their development in high-rise high-density cities.

Keywords: constraint; high-rise high-density city; low carbon building

INTRODUCTION

With increased rates of urbanisation, there is a world-wide move towards a low carbon urban environment in recent years (UNEP 2019). The more intensively urbanised and developed countries should elevate carbon reduction to a national priority because cities as a whole, account for more than 60% of the global greenhouse gas emissions and correspondingly consume a significant share (around 80%) of global material and energy supplies (Hunt and Watkiss 2011; UN-Habitat 2020). Among the various sectors, the buildings sector is a prime target for emission reduction, as buildings worldwide account for about one third of global greenhouse gas emissions and consume over one third of total produced energy (Mardiana and Riffat 2015). Moreover, research outcomes and energy/ carbon related international organisations (International Energy Agency [IEA], Regulatory Indicators for Sustainable Energy [RISE]) emphasise the rapid increase of energy demand and carbon emissions from building construction and building stock in high-rise high-density cities as a major issue. Many scholars have highlighted that delivering low carbon / zero carbon buildings is one of the most significant and 'extremely supporting' strategies towards

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achieving the environmental sustainability goals in the buildings sector (Isiadinso *et al.,* 2011; Shi *et al.,* 2015; Pan and Pan 2018). Currently, there is a rapid growth in the total building floor area globally (GABC 2019). Most of the developed countries with high-rise high-density cities are trying to reduce the energy usage and carbon emissions from their new constructions and existing building stock, through various micro level and macro level initiatives (Pan and Ning 2015). Yet, a notable reduction of carbon emission and energy usage of buildings is not evident in these countries (GABC 2019; IEA 2020). This establishes that there may be a number of underlying constraints which hinder the delivery of low carbon and energy efficient buildings in high-rise high-density cities even in well-developed countries with strong economies.

The relevant literature also reveals that moving towards low carbon buildings has been mostly retarded by various socio-technical constraints, rather than purely technological barriers or solely societal constraints. While a number of completed studies outline the barriers for energy saving and carbon emission reduction in buildings sector, there is a lack of research particularly focusing on the constraints to delivering low carbon buildings in high-rise high-density cities.

A systematic 'identification and analysis' of these constraints is beneficial to academics and practitioners to implement strategic efforts to effectively address these constraints and uptake the delivery of low carbon buildings in high-rise high-density cities. Hence, this study aimed to identify and assess the constraints to delivering low carbon buildings in high-rise high-density cities, with two main objectives: 1. To identify the common constraints to delivering low carbon buildings through a systematic literature review and 2. To assess the above identified constraints and specifically identify the constraints to delivering low carbon buildings in high-rise high-density cities through a questionnaire survey covering 7 cities in 5 different contexts; namely, Hong Kong, Singapore, UAE (Dubai and Abu Dhabi), Qatar (Doha) and Australia (Melbourne and Sydney). In this study, the word 'context' refers to a country or a region. The following sections convey the adopted methodology, analysis, results and conclusion.

RESEARCH METHODS

Based on the aforementioned aim and objectives, the following methodological approach was adopted in carrying out this study (Fig 1). As one of the most popular and comprehensive databases, the "Web of Science" yielded the highest number of documents for the keywords search in this study. Keywords used to search the titles of the relevant papers for this review are “(Barriers OR Constraints OR Challenges) AND (Energy OR Carbon) AND (Buildings OR Building)”. To ensure the quality, only the published articles in journals were considered for the literature review. Subsequently, a questionnaire survey was carried out using the constraints identified through the literature review, to capture the significant constraints to delivering low carbon buildings in selected high-rise high-density cities. The respondents were requested to complete a survey to rate the level of significance of the constraints identified through the systematic review, within the context of their exposure according to a Likert scale (from 1 to 5 representing “Insignificant”, “Somewhat insignificant”, “Neutral”, “Significant” and “Highly significant”). A “judgment sampling” approach was followed to select the respondents through personal contacts in the industry and academia. Furthermore, a representative sample was obtained, considering the targeted professional groups.

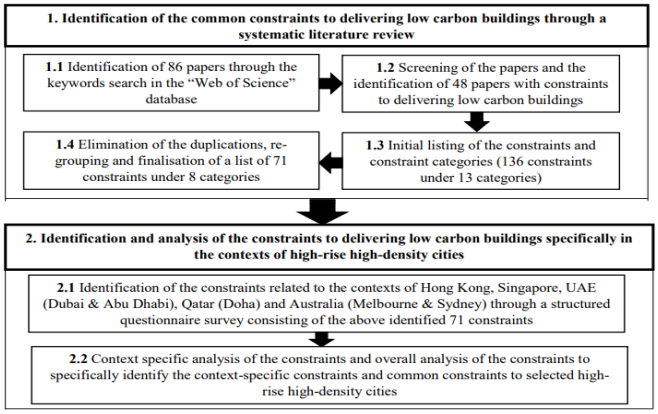


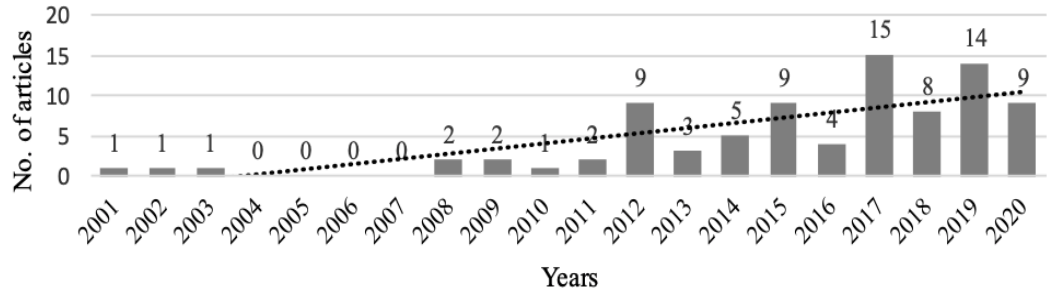
Fig 1: Research methods

RESULTS AND ANALYSIS

Systematic Literature Review

Fig 2 shows the number of publications from 2001 to 2020 relevant to the selected keywords. The graph shows an increasing trend of the number of publications on this topic which indicates that the attention of scholars was increasing over the recent years. Fig 3 shows the bibliometric network of co- authorship links among the most productive countries for the selected keywords. The node sizes are proportionate to the number of publications in the respective country. Accordingly, China and UK had 22 and 15 articles respectively. USA, Canada, Australia, Germany, Spain and Sweden were the other productive countries. This highlights an increasing attention towards identifying the constraints to delivering low carbon/energy buildings in these economically developed countries.

Fig 2: Number of publications from 2001 to 2020



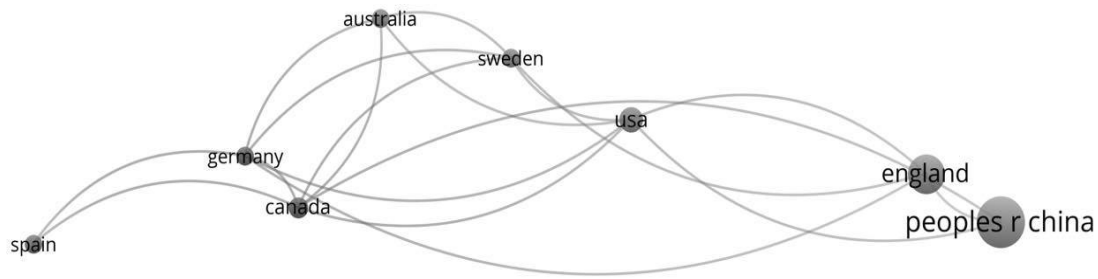


Fig 3: Co-authorship network of countries

Constraints to delivering low carbon/energy buildings were extracted after examining the content of the screened 48 papers from the literature search. The final list of 71 constraints under 8 categories are indicated in Table 1.

Table 1: List of constraints identified through the systematic literature review

Constraints	Publications*
Financial constraints- F1) Less interest of investors due to high initial cost and less financial gains, F2) Uncertainty of financial gains, F3) Lack of investment capital, F4) Expenses, additional responsibilities and time consumption related to energy and carbon compliance, F5) Split incentives, F6) Non-liquidity of low carbon and energy saving investments, F7) High labour costs, F8) Increased operational and maintenance costs and risks, F9) Complex procurement models and inappropriate approval procedures, F10) Difficulties in getting approvals and financial contribution when there are multiple owners	2,3,4,5,6,7,8, 10, 11, 12, 13, 14,15,16,17, 18, 24, 26, 27, 28, 29, 30, 32, 33, 34, 36, 38, 39, 40, 41, 43, 45, 46
Market structure and supply constraints- M1) Lack of low carbon materials, equipment and technology availability due to lack of suppliers, M2) Energy efficient and low carbon features of buildings are considered as not contributing to increase the market value of the property, M3) More concern on aesthetic appearance, M4) Lack of energy service companies (ESCO's), M5) Less availability of long-term warranties and insurances for low carbon/ energy efficient materials and equipment	3,6, 11, 26, 28, 29, 32, 41, 43
Policy and regulatory constraints- P1) Lack of national mandatory standards and regulations, P2) Lack of incentives from government and financial institutions, P3) Non availability of a carbon tax scheme, P4) Non availability of proper building carbon emission trading mechanisms, P5) Unclear incentives for the building material/equipment market, P6) Contradiction between energy/ carbon compliance and other compliance requirements, P7) Lack of promotion, P8) Unavailability of efficient energy/ carbon labelling schemes, P9) Lack of legal penalties due to non-compliance, P10) Less willingness of government to increase low carbon and energy efficiency investment, P11) Less priority for building energy and carbon reduction and management in national policies, P12) Tenant and staff priorities are considered over low energy and carbon initiatives, P13) No top management commitment and no priority in organisational vision and mission, P14) Organisational business models are not considering the integration of low carbon and energy efficient initiatives, P15) Low quality equipment and poor post sale services due to improper legalisation, P16) Penetration of low quality materials to the market due to improper legalisation, P17) Lack of collaboration between government departments, P18) Policy initiatives related to energy and carbon do not cover the whole life of a building, P19) Unavailability of a proper energy quota mechanism	1,2,3,4,5,6, 7,8,10,13,14, 15, 16, 18, 19, 22, 23, 24, 25, 26, 27, 28, 29, 30, 33, 36, 38, 39, 41, 46
Knowledge, awareness and information related constraints- K1) Lack of customised research and development, K2) Research outcomes are not effectively translated in to technology innovations, policy initiatives and industry practices, K3) Lack of usable energy and carbon data in buildings, K4) Weak energy feedback systems, K5) Less coordination between Management Company and tenants, K6) Not following collaborative design practices, K7) The integration between energy/ carbon in buildings and indoor environmental quality is not well established through research and customised studies, K8) Lack of motivation, awareness and knowledge of client, K9) Little knowledge of end-users about the consequences of their actions on carbon emissions and energy consumption, K10) Lack of proper education, experience sharing and training on energy efficient/ low carbon technologies and initiatives, K11) Stickiness to old technologies and methods in building construction and management, K12) Less experience and environmental awareness of professionals engaged throughout the building lifecycle	1, 2, 3,5,6, 7, 8, 9, 10, 11, 16, 17, 18, 20, 21, 26, 27, 28, 29, 32, 33, 37, 38, 39, 41, 42, 43, 44, 45, 46
Workforce and skills related constraints- W1) Workforce with less knowledge and technical expertise on new technological advancements, W2) Lack of professional staff resources and enterprise for implementing and assessing / auditing/ calculating carbon reductions and energy efficiency	1, 2, 4, 7, 8, 19, 26, 30, 36, 39, 43, 45

Technological constraints- T1) Lack of innovation and technology advancements, T2) Maintainability and operability issues, T3) Safety issues T4) Shortcomings of energy and carbon modelling tools for high-rise buildings, T5) Currently available modelling and simulation technologies are not perfectly feasible to take behaviour patterns, climate, cost effectiveness, etc... in to consideration simultaneously, T6) Construction companies are not up to the standards in terms of quality and strict construction practices, T7) Design strategies are focusing on a single building and neglects the interactions with the surrounding and the environment, T8) No proper user energy behaviour and demand analysis before designing, T9) Lack of production capability to produce cost effective energy efficient and low carbon products, T10) Inconsistencies and uncertainties in energy/ carbon calculation methods, T11) Lack of pilot projects, T12) Incompatibilities with new technologies due to existing building conditions, T13) Building façade materials contribute to increase the urban heat island effect, T14) Complexity of technology	2, 3, 4, 7, 12, 14, 15, 17, 18, 20, 22, 28, 29, 34, 35, 37, 38, 41, 43, 44, 45, 46, 48
Behavioural, social and cultural constraints- B1) Staff/ visitor/ customer satisfaction and acceptance related issues, B2) High energy lifestyle, B3) Conventional and negative attitudes of clients and owners towards low carbon investment, B4) Poor corporate culture which separates environmental performances and business improvement decisions, B5) Differences and uncertainties in energy behaviour patterns of occupants	2, 3, 4, 12, 16, 17, 18, 29, 31, 32, 36, 38, 39, 45
Geographical and environmental constraints- G1) Urban environment and the proximity of surrounding buildings, G2) Difficulties to model /investigate the microclimate due to different atmospheric conditions with the altitude of building, G3) Logistical challenges due to geographic locations, G4) Lack of space to install onsite renewable energy technologies	12, 18, 24, 31, 34, 38, 39, 43, 44, 47, 48

*List of citations for the respective numbers of publications: 2- (Afshari *et al.,* 2016), 3-(Zhang and Wang 2013), 4-(Du *et al.,* 2014), 6-(Baek and Park 2012), 7-(Wang *et al.,* 2016), 8-(Tuominen *et al.,* 2012), 12-(Bertone *et al.,* 2018), 16-(Cherrafi *et al.,* 2017), 17-(Iwaro and Mwasha 2010), 18-(Rock *et al.,* 2019), 26-(Shen *et al.,* 2018), 28- (Li *et al.,* 2019), 29- (Zhang *et al.,* 2017), 32-(Ng *et al.,* 2013), 38-(Yeatts *et al.,* 2017), 39-(Alam *et al.,* 2019), 41-(Gupta *et al.,* 2017), 43-(Masrom *et al.,* 2017), 45-(Cagno *et al.,* 2014), 46-(Vogel *et al.,* 2015)

The relevant papers (mentioned by the respective numbers) of the following lead authors were also referenced in compiling above list of constraints, but space constrained their full citation in this paper: 1- Cattano, C., 5- Sudhakara Reddy, 9- Gerrish, T., 10-Persson J., 11-Olazabal, M., 13-Andrić, I., 14-Zhang, X., 15- Abdellah, R., 19- Biekša, D., 20-Ucci, M., 21-Jiang, M., 22-Attia, S., 23- Thollander, P., 24-Williams, K., 25- Pitts, A., 27-Häkkinen, T., 30- Nižetić, S., 31- Oregi, X., 33-Paiho, S., 34- Dadzie, J., 35-Geissler, S., 36-Kangas, H., 37-Pan, W., 40-Szumilo, N., 42-Yu, Z., 44-Yu, C., 47- Xing, R., 48-Zhao, Y.

Questionnaire Survey Covering Seven Cities in Five Contexts

From the selected cities, 128 responses were gathered for the questionnaire survey. Accordingly, 31, 30, 24, 22, and 21 responses were collected from Hong Kong, UAE (Dubai and Abu Dhabi), Australia (Sydney and Melbourne), Qatar (Doha) and Singapore respectively. Among the respondents, 18% were Engineers, 15.6% were Educationalists, 14% were Government Officials, 13.2% were Project Managers, 12.5% were Consultants and 26.5% were from other related professions. 25.7% of the respondents had experiences for more than 20 years while 11.7%, 15.6%, 29.7%, and 17.2% of respondents had 16-20, 11-15, 6-10 and 0-5 years of experiences respectively. According to the adopted Likert scale, the responses 1 and 2 denote that a particular constraint is 'not significant' and a response of 3 indicates a 'neutral' view. Responses 4 and 5 indicate that the constraint is 'significant' to the context. Hence, for the context specific analysis, the constraints with over 75% of '4 or 5' responses (without considering the responses of 3 for the calculation) were identified as 'significant' to a particular context. A similar approach was used by Shen *et al. (*2016)

and Gan *et al. (*2018) in their studies. Subsequent to the context specific analysis, the overall mean ratings of the responses were also calculated for each constraint, taking all the 128 responses as the sample to further analyse the overall significance levels of the constraints (see Table 2).

Table 2: Constraints to delivering low carbon buildings in selected 7 cities in 5 contexts

Constraints	*Significance in each context					Overall mean value	Significant and Common
	Qatar	UAE	Australia	Singapore	Hong Kong		
F1- Less interest of investors due to high initial cost and less financial gains	✓	✓	✓	✓	✓	4.06	Yes
F2- Uncertainty of financial gains	✓	✓	×	✓	✓	3.81	Yes
F3- Lack of investment capital	✓	✓	✓	×	✓	3.87	Yes
F6- Non-liquidity of low carbon and energy saving investments	✓	×	×	✓	×	2.95	No
M1- Lack of low carbon materials, equipment, and technology availability due to lack of suppliers	✓	✓	×	×	×	3.24	No
M3- More concern on aesthetic appearance	✓	✓	✓	×	×	3.31	No
M5- Less availability of long-term warranties and insurances for low carbon/ energy efficient materials and equipment	✓	×	×	✓	×	3.29	No
P1- Lack of national mandatory standards and regulations	✓	✓	✓	×	✓	3.98	Yes
P2- Lack of incentives from government and financial institutions	✓	✓	✓	×	✓	3.89	Yes
P3- Non-availability of a carbon tax scheme	✓	✓	×	×	✓	3.68	No
P4- Non-availability of proper building carbon emission trading mechanisms	×	×	✓	✓	×	3.28	No
P5- Unclear incentives for the building material/equipment market	×	✓	✓	✓	✓	4.04	Yes
P7- Lack of promotion	✓	✓	×	×	×	3.21	No
P9- Lack of legal penalties due to non-compliance	✓	✓	✓	×	✓	3.78	Yes
P13- No top management commitment and no priority in organisational vision and mission	✓	×	×	×	✓	3.04	No
P14- Organisational business models are not considering the integration of low carbon and energy efficient initiatives	✓	✓	✓	✓	×	3.71	Yes
P17- Lack of collaboration between government departments	✓	✓	✓	×	✓	3.90	Yes
P18- Policy initiatives related to energy and carbon do not cover the whole life of a building	✓	✓	✓	×	✓	3.78	Yes
K2- Research outcomes are not effectively translated into technology innovations, policy initiatives and industry practices	✓	✓	✓	×	✓	3.99	Yes
K3- Lack of usable energy and carbon data in buildings	✓	×	✓	✓	✓	3.76	Yes
K4- Weak energy feedback systems	✓	×	✓	×	×	3.15	No
K5- Less coordination between Management Company and tenants	✓	×	✓	✓	×	3.45	No
K8- Lack of motivation, awareness and knowledge of client	✓	✓	×	×	✓	3.59	No
K9- Little knowledge of end-users about the consequences of their actions on carbon emissions and energy consumption	✓	✓	✓	×	✓	3.74	Yes
K10- Lack of proper education, experience sharing and training on energy efficient/ low carbon initiatives,	✓	✓	×	×	×	3.47	No
K11- Stickiness to old technologies and methods in building construction and management	×	✓	×	✓	×	3.56	No

K12- Less experience and environmental awareness of professionals engaged throughout the building lifecycle	✓	×	✓	✓	×	3.58	No
W1- Workforce with less knowledge and technical expertise on new technological advancements	✓	✓	✓	✓	×	3.70	Yes
W2- Lack of professional staff resources and enterprise for implementing and assessing / auditing/ calculating carbon reductions and energy efficiency	×	✓	✓	✓	×	3.59	No
T2- Maintainability and operability issues	✓	×	✓	✓	✓	3.71	Yes
T6- Construction companies are not up to the standards in terms of quality and strict construction practices	✓	✓	×	✓	×	3.42	No
T7- Design strategies are focusing on a single building and neglects the interactions with the surrounding environment	×	×	✓	✓	×	3.45	No
T10- Inconsistencies and uncertainties in energy/ carbon calculation	✓	×	✓	✓	×	3.46	No
T11- Lack of pilot projects	✓	✓	×	×	×	3.10	No
T12- Incompatibilities with new technologies due to existing building conditions	✓	✓	✓	✓	✓	3.95	Yes
T14- Complexity of technology	✓	✓	✓	×	×	3.40	No
B2- High energy lifestyle	✓	✓	✓	✓	✓	3.82	Yes
B4- Poor corporate culture which separates environmental performances and business improvement decisions	✓	×	✓	✓	✓	3.69	Yes
B5- Differences and uncertainties in energy behaviour patterns of occupants	×	×	×	✓	✓	3.17	No
G1- Urban environment and the proximity of surrounding buildings	×	×	×	✓	✓	3.29	No
G2- Difficulties to model/investigate the microclimate due to different atmospheric conditions with the altitude of building	✓	✓	×	×	×	3.25	No
G4- Lack of space to install onsite renewable energy technologies	✓	✓	✓	✓	✓	3.83	Yes

*'✓' / '×' denotes that the respective constraint is 'significant' / 'not-significant'

Twenty-two constraints out of 71 were identified as 'not significant' to all 5 contexts. Seven constraints were identified as 'significant' to only one context. Table 2 presents the remaining 42 constraints which were identified as common to 2 or more contexts. Among the constraints represented in Table 2, there are 19 constraints which were identified as common to 4 or more contexts. Only 4 constraints were identified as common to all 5 contexts.

Overall mean ratings of these constraints are also presented in Table 2 for the comparative representation of context specific significance and the overall significance identified through the questionnaire survey. Among the 42 constraints in Table 2, there are 18 constraints with a mean rating value less than 3.5. The overall mean ratings of these constraints are closer to the value of 3 (neutral) than to the value of 4 (significant). Hence, these constraints were identified as not having an overall significant impact on hindering the delivery of low carbon buildings in the selected contexts.

After comparing the findings of both the context wise analysis and the overall mean ratings, 52 constraints out of 71 were identified as not common to 4 or more contexts and also having a less significant mean rating value. Accordingly, 19 constraints were identified as common to 4 or more contexts and also having an overall mean rating value of above 3.5. Accordingly, the constraints F1, F2, F3, P1, P2, P5, P9, P14, P17, P18, K2, K3, K9, W1, T2, T12, B2, B4 and G4 were identified as 'common' and

'significant' constraints which hinder the delivery of low carbon buildings in the selected 7 high-rise high-density cities in 5 contexts (see Table 2).

CONCLUSIONS

High-rise high-density cities account for a significant portion of the global carbon emissions. Despite the various commitments to reduce carbon emissions in the building sector, a number of socio-technical constraints still hinder the delivery of low carbon buildings in such cities. The literature review showed that the majority of previous scholars have frequently discussed financial, policy and regulatory, knowledge, and technological constraints as the most commonly encountered constraints to delivering low carbon/energy buildings in general over the past 20 years. The recent literature further suggests that the levels of significance of these constraints are different from one context to another. Nevertheless, a majority of the referred articles were based on developed countries with high-rise high-density cities. Hence it was evident that the identified constraints were affecting the delivery of low carbon buildings even in these developed countries in the recent years.

The findings of the questionnaire survey specifically revealed that some of these constraints identified through the literature review still prevail, albeit to different degrees, in the selected contexts. Nineteen constraints were identified as common and significant constraints to the selected contexts. Confirming the findings of the literature, financial constraints (such as high initial cost, limited access to capital, less / uncertain financial gains), policy and regulatory constraints (such as lack of: mandatory standards, incentives, legal penalties, taxes, etc.), lack of knowledge and awareness, lack of skills, lack of motivation, lack of collaboration, and technological constraints were commonly identified in the selected contexts. In addition, behavioural constraints and space limitations were also identified as significant to the selected contexts. However, the mean ratings for these 'significant' constraints were close to the value of '4' and none of the constraints were rated close to the value of '5' which emphasises that these constraints are not rated as 'highly significant' when considering the selected contexts together as a one sample. This implies that as developed countries, these countries might have taken considerable efforts to overcome these constraints and uptake the delivery of low carbon buildings. Even though the constraints are not rated as critical and highly significant, the respondents have concluded that there is still a significant impact of these constraints to delivering low carbon buildings.

Since the identified constraints represent the status of only 7 cities in 5 selected contexts, validating the constraints in several other contexts will be beneficial in a future stage to further enhance the scope of the findings. A further exploration of the reasons for the context specific constraints will be beneficial to implement customised strategies to overcome the constraints. All the countries selected for the current study are economically developed countries. Testing the significance of these 71 constraints in the contexts of a sample of developing countries will provide an opportunity to comparatively analyse the relative significance of these constraints to delivering low carbon buildings between 'developed' and 'developing' countries. Meanwhile, the findings of this paper would benefit researchers, national policy makers and responsible stakeholders in this field by presenting significant common constraints, hence enabling them to seek solutions to accelerate the delivery of low carbon buildings by addressing the constraints.

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