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Issues concerning IoT adoption for energy and comfort management in intelligent buildings in India

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ABSTRACT
User-centric, localized energy and comfort management solutions that are essential in commercial buildings are realized by IoT enabled building management systems, involving networked sensors and artificial intelligence-based data processing. This paper employs the Delphi method to identify the major issues concerning IoT adoption in India and examines these across the value chain, specific to energy and comfort management in intelligent buildings. The Delphi exercise involved 3 expert-panels, consisting of a total of 24 subject matter experts representing all important stakeholders across the intelligent building value chain. A total of 140 issues have been identified, grouped across 8 themes, and ranked, leading to the development of an 'IoT adoption index'. A subset of the issues has been identified using two inputs from the literature, viz., key performance indicators of intelligent buildings and the business model canvas. The results can be practically used by the stakeholders while evaluating IoT systems for deployment in their projects. Further, the results should be useful in the context of intelligent buildings also in other emerging economies having similar climatic conditions.

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Internet of things; intelligent buildings; energy efficiency; occupant comfort; technology adoption

1. The background

In office spaces, Heating Ventilation and Air-Conditioning (HVAC) systems consume up to 40% and lighting up to 17% of the overall energy expense (Minoli, Sohraby, and Occhiogrosso 2017) and a large proportion of occupants are dissatisfied with the built spaces they occupy (Jia et al. 2018). Similar to the *setsuden* conditions in Japan, the Indian government is considering energy efficient comfort [EEC] measures. To quote an example, the consideration to implement a higher thermal comfort set-point [e.g. 24°C] can bring savings of about INR 100 Billion [US Dollar 1.3 Billion, approximately] annually (Saraswathy 2019).

In recent years, the notion of Intelligent Buildings (IBs) reflects (1) Digital technologies enabling intelligence, (2) Building responding to occupants' physical, social and mental well-being, and (3) Economic use of resources (e.g. energy) enabling sustainability. In addition, the focus of IBs is shifting towards self-learning ability and the interactions between occupants and their environment (Clements-Croome 2013).

Information and Communication Technology (ICT), incorporating embedded systems, automated control systems and other advanced technology bricks are a key element in IBs (Clements-Croome and Croome 2004). Internet of Things (IoT) can be defined as 'interconnection of

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sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications' (Tang et al. 2019). Systems development based on ICTs and particularly on IoT are enablers for a broad range of monitoring and control actions in a built space making IBs a reality (Victoria et al. 2014). IoT is starting to penetrate the buildings market in recent years. Industry and Academia experts are arriving at benefits, drawbacks and challenges associated with IoT through actual implementation. Recently, products from firms like IBM, Amazon, Intel, Google, and Apple for the buildings industry are indicating the future industry trend (Jia et al. 2019). Applications such as crowdsensing, wherein large numbers of building occupants through their smart devices such as mobile phones, smart watches and other means providing data to building systems can leverage IoT technology (Minoli, Sohraby, and Occhiogrosso 2017). IoT implementation in buildings can enhance comfort [thermal, visual, acoustic, indoor air quality] while bringing energy savings (Bajer 2018).

2. Review of applications of IoT in IBs

The core element in an IB is the Building Management System (BMS) which monitors and controls functional subsystems such as Heating, Ventilation, and Air-Conditioning (HVAC), lighting, power supply and security. Historically, HVAC, Lighting, and other such sub-systems were operating in silos with their own protocols, networks, and cabling systems. This was found to have lower efficiency and redundancy from both deployment and operation phases (Minoli, Sohraby, and Occhiogrosso 2017). Table 1summarizes the features of IoT enabled BMSs with respect to early generation BMSs (Minoli, Sohraby, and Occhiogrosso 2017; Bajer 2018).

These technological advancements bring in significant impact on the IB key performance indicators (KPIs) (Ghaffarianhoseini et al. 2016), viz., (1) Economic and Cost Efficiency, (2) Smartness and Technology Awareness, 3. Personal and Social Sensitivity, and 4. Environmental Responsiveness. Table 2 summarizes the benefits that are possible with IoT enabled BMSs (Clements-Croome 2013; Lazarova-Molnar and Mohamed 2016; Minoli, Sohraby, and Occhiogrosso 2017; Bajer 2018).

Furthermore, Building Information Modeling (BIM) applied during the operational phase of an IB can integrate building 3D models (e.g. dimensions, space, location, etc.) with facilities data (e.g.

Table 1. Features of IoT enabled BMS.

Aspect	Early generation BMS	IoT enabled BMS
Architecture	For each function (e.g. lighting, HVAC etc.) a dedicated infrastructure	A multi-system approach with integrated functions – infrastructure is shared by functions (e.g. lighting and HVAC using a common sensor, a common network, and the same cloud).
	Standalone Type	Open, Networked Type
Perceptive Layer (nodes or sensors)	Specific and tied to a function	1. Shared across functions (e.g. temperature sensor used by HVAC and fire control functions), 2. Localized sensing capabilities enabling zone-wise control
Network Layer (communication infrastructure)	Multiple network protocols (KNX, BACnet, etc.)	Internet protocols (IP) mainly (e.g. HTTPs)
	Relatively low security features	Advanced security features
Application Layer (data processing and visualization)	Data analysis contained within each function	1. Cloud based, handling multiple data sources; 2. Fog computing where in data are processed at the sensing edge; 3. Graphical user interface and data visualization in user mobile devices; 4. Big data processing anddata analytics enabled; 5. Remote access and control; 6. Ability to utilize personal mobile devices to gather occupant specific data (e.g. comfort, location, type of activity, etc.)

Table 2. Impact of IoT enabled BMS on IB KPIs.

IB KPIs	Benefits of IoT enabled BMS
Smartness and Technology Awareness	1. Significant opportunity to collect data in real time from occupants on comfort; 2. The plethora of sensor nodes can assist the expert system to be closer to reality in terms of reaching local comfort control and energy consumption; 3. Centralized data analytics with data sources of various functions (HVAC, lighting, etc.) improving the predictability of building performance; 4. Data visualization in the smart devices of users, improving the awareness of building performance. Remote access and control for users (building owner, facilities manager, etc)
Economic and Cost Efficiency	Perceptive layer (e.g. sensor nodes) and other network infrastructure shared across functions, eliminating redundancy and hence saving costs.
Personal and Social Sensitivity	1. People Centric Sensing: Ability to utilize personal mobile devices to gather occupant specific data (e.g. comfort, location, type of activity etc.) leading to personalized comfort, bringing well-being of occupants; 2. Localized sensing capabilities enabling zone-wise comfort control leading to better occupant comfort experiences
Environmental Responsiveness	IoT assisted energy savings, implying reduction in life cycle energy costs of the building.

sensor data, traceability, etc.), bringing out visualization of real-time energy and comfort data. This also enables localized or zonal comfort level settings bringing in energy cost savings (Tang et al. 2019). Current standards such as BACnet [developed by ASHRAE], Echelon, etc., involve some form of recurring costs such as licensing fee, renewal fee, royalty fee, maintenance fee, etc., and there is interest to reduce these expenses (Lilis et al. 2017). Further, the falling trend of sensor price, and increasing wireless transmission capacity drives the technical adoption of IoT systems in IBs. Overall, IoT-based applications are opening up a growing market for IBs through new business models such as ‘building as a service provider’ (Le, Le Tuan, and Tuan 2019).

The following examples in Table 3, illustrate the on-going efforts in the area of comfort and energy management in IBs with IoT.

2.1. IoT adoption in the IBs market

In the evolution of IBs, IoT has a very large role to play. Recently, various fields have witnessed considerable technological advancements to improve the adoption of IoT systems on the bases of systems protocol standardization, safety and security of wireless systems, cloud level data integration, etc., (Bajer 2018).

The construction industry has been slow in adopting ICT, and often easily available and accessible technologies are not fully leveraged (Ahuja, Yang, and Shankar 2009) despite recent years witnessing a price reduction trend in the sensors industry (Riggins and Wamba 2015), increased data transmission capacity of present-day wireless sensors networks and large volume data processing capability in a real-time fashion (Riggins and Wamba 2015).

Table 4 summarizes the uncertainties associated with IoT adoption in IBs. The collected issues from the literature review are grouped using the IB key performance indicators (KPIs) proposed by Clements-Croome’s work (Ghaffarianhoseini et al. 2016), encompassing (1) Economic and Cost Efficiency related, (2) Smartness and Technology Awareness related, (3) Personal and Social Sensitivity related, and (4) Environmental Responsiveness related aspects. Market and industry forces related inputs have been separately grouped.

From the literature, it is apparent that IoT has good potential in IBs to reduce energy consumption while improving comfort, well-being and productivity, without compromising sustainability. But, due to its inherent challenges, it is necessary to investigate the issues affecting its adoption.

Based on our literature review the following 4 aspects are observed as the gaps.

(1) IoT adoption barriers in IBs are yet to be established through standard qualitative and quantitative research methods.

Table 3. Comfort and energy management in IBs – IoT examples.

Project/Product	Description	Reference	Availability in India/Presence of Equivalents
CityExplorer	1. A platform for energy and comfort management, based on Home Automation Modules (HAMs) and Supervisory Control and Data Acquisition System (SCADA); 2. Suggests zone preferences of occupants based on their comfort preferences, combining the comfort setting with an energy saving strategy, along with air-quality control	Victoria et al. (2014)	Not yet
Dimmer and Fleximeter	IB energy management systems capable of handling heterogeneous IoT devices and a large volume of data processing	Patti and Acquaviva (2016)	Certain startups (e.g. Smartify, 75F etc.) offering an IoT occupant app to control zonal comfort (thermal and visual) – at the initial stages of market penetration
1. Matilda Smart House* (University of Florida), 2. MIT Smart House*, 3. Aware Home* (Georgia Institute of Technology)	1. Intelligent built spaces that are context aware in terms of their occupants' demands and activities; 2. Enabled through wireless sensor networks and artificial intelligence – timely response to the occupant preferences	Ghaffarianhoseini et al. (2016)	
Adaptive Facades and Sensing Wall	Embedded sensors and wireless networks which can gather temperature data from the skin of the building with a view to assess thermal gain/loss and visualizing this information in real time	Zarzycki (2016) and Zarzycki (2018)	Not yet
BEMOSS (Virginia Tech & U.S. Department of Energy)	1. Building energy management open source solution, with plug and play features; 2. Interoperability in terms of communication protocols and data exchange protocols; 3. Remote monitoring and control, with open architecture for IoT manufacturers to integrate their devices seamlessly	Pipattanasomporn et al. (2015)	Not Yet
Smart Energy Efficient Middleware for Public Spaces (SEEMPubS)	1. Leverages ICT monitoring and control for energy savings in buildings; 2. Using a custom middleware, and BIM visualization it integrates commercially available devices with the existing BMS	Acquaviva et al. (2012)	Not Yet
Zonal Thermal Comfort algorithm based on real world occupancy data (Tata Consultancy Services)	A predictive control method for energy efficient thermal comfort in open offices in hot-humid climates leveraging HVAC sensor data	Nagarathinam et al. (2017)	No wide implementation reported in indian market yet

*Considered owing to potential extendibility to office space meeting rooms.

(2) IoT adoption needs to be studied:
   (a) with a specific focus on comfort and energy management in IB office spaces.
   (b) for indoor environment quality in hot and humid and highly luminous geography IBs.
   (c) specific to Indian IB market and industry eco-system.

Table 4. Uncertainties in IoT implementation in IBs.

Criteria	Uncertainties in IoT implementation in IBs*	Reference
Smartness and Technology Awareness Related	Information silos: Vendor specific software systems with their own cloud-based data storage – such silos duplicating sensors	Bajer (2018)
	Large IoT Players like Google, Amazon, and Apple introducing proprietary protocols, whereas KNX and BACnet, the prevalent ICT protocols provide gateways for interoperability (accommodating other communication protocols)	Bajer (2018)
	Technical Hurdles: 1. Heterogeneity of devices (large number of devices of various makes and communication modes); 2. Scalability (common protocols, tracing methods, etc.); 3. Reliability of wireless communication (data transfer speeds, data loss, etc.); 4. Low power consumption; 5. Self-configuring devices (owing to scale and complexity); 6. Data management (volume, speed, format, etc.); 7. Security and privacy protection, etc.	Brachman (2013)
	Physical positioning of sensors in installation, accuracy of various sensor types etc.	Rinaldi et al. (2018)
Economic and Cost Efficiency Related	1. ICT is high cost investment for construction phase in India; 2. Risk aversion to shift between digital technologies	Ahuja, Yang, and Shankar (2009)
	Distributed actuators in addition to sensors for localized comfort increase cost	Lilis et al. (2017)
	Integrated automated systems, ending up consuming more energy than necessary	Ghaffarianhoseini et al. (2016)
	First and recurring costs: 1. IoT systems requiring high installation and maintenance costs; 2. Additional BMS licensing fees	Rafiq et al. (2017)
	Buildings being complex systems incorporating new technologies takes time, effort and in turn cost	Jia et al. (2018)
Personal and Social Sensitivity Related	Advanced user activity profiling and pattern tracking models showing capability to predict stochastic behavior of building occupants more accurately (questioning the need for IoT sensing at multitudes of nodes)	Lilis et al. (2017)
	Risk perceptions of user privacy, data security and trust	Hsinchun, Chiang, and Storey (2012)
	Playful and aesthetic nature of IoT not yet leveraged in deployment	Knutsen (2014)
Environmental Responsiveness Related	Lesser battery life of IoT devices calling for periodic replacement – implies 275 million battery changes a day globally	Wan et al. (2017)
Business Proposition and Market-Industry Forces Related	IoT startups unable to make solid business cases for IBs	Bajer (2018)
	Absence of government policy measures implies fragmented business deployments not encouraged	Ye et al. (2008)
	Current BMS systems having many working examples with well-established profitability information	Lilis et al. (2017)
	Lack of clear business models that can lead to customer interest to invest in	Zanella et al. (2014)
	Industry specific challenges (In US context): 1. Too many standards and legislations; 2. Building sector is slow in adopting new technologies; 3. Un-agile processes with construction firms; 4. Fear of regulation changes; 5. Poor information sharing between co-developing firms etc.	Ma, Badi, and Jorgensen (2016)

*No specific IoT adoption study concerning operation phase of Indian IB market could be found.

Also, it is evident that IoT implementation in India is at a nascent stage and penetration is yet to take place. In India, since EEC is being seen as a necessary condition in buildings (Saraswathy 2019), a system-level study assessing the issues that affect the adoption of IoT systems specific to EEC in IBs is absolutely important. This is a strong justification for this work.

2.2. Gaining expert views – application of the Delphi method

Given the above discussion, the status of technology use, and the need to determine the impact of various issues on the adoption and use of IoT technology in IBs, the value of obtaining experts' inputs should be amply clear. The necessity of obtaining these inputs would be enhanced by considering the value-chain context. Occupants could be surveyed to gain responses about comfort and behavior in their built work spaces, and they would be able to respond to questions concerning their engagement with IoT-based comfort control systems. However, they would not be able to offer useful inputs concerning the entire value-chain, and issues concerning the adoption of those systems. Hence, the relevant knowledge should be obtained from experts in the field, with the possibility of facilitating a consensus. The Delphi Method allows many experts or 'informed' individuals in related disciplines to observe specific protocols and interact with each other via a questionnaire for contributing information, knowledge and judgments to a problem area they would be familiar with. The interactions involving the Delphi Method are primarily based on the principle of anonymity which enables maintaining a condition in which none of the respondents would know the others during the Delphi exercise. This condition encourages the participants to put forth their views frankly and explicitly without any biases or conflicts while sharing their responses. It also enables them to change their views smoothly, and without any loss of face, after receiving other participants' views anonymously. The following features of the Delphi Method make it suitable for group decision-making and encouraging consensus (Giannarou and Zervas 2014).

- Iteration – enables experts to reconsider and rethink on their views and opinions based on additional information presented in each iteration.
- Controlled feedback – statistical and qualitative representation of the experts' views in order to facilitate review and restatement by each expert across the iterations.
- Statistical consensus – statistical representation of the strength of the consensus, or near consensus, arrived at by the expert group.

The Delphi method is apt for situations where historical data about a complex problem are not available and in-depth insights are sought for solving a problem at hand (Gupta and Clarke 1996; Kalaian and Shah 2006). The query on why IoT solutions are installed, commissioned and operated in IBs is relatively new in the Indian context, where such a value proposition is yet to gain momentum among building stakeholders. Also, as Delphi does not necessarily require face-to-face discussions and maintains anonymity of participants, problems such as group conflict and individual dominance can be avoided (Gupta and Clarke 1996). As this survey involved international and Indian experts, there was little or no need for face-to-face discussions, and this led to cost savings. Also, as the expert list contained customers, academic collaborators, system integrators and in-house experts, anonymity was ensured from the start. This also ensured that on-going business relationships were unaffected. Above all, the interdisciplinary nature of the problem statement could be covered well with the diverse list of experts from various fields related to IBs.

The overall methodology of this research work is shown in Figure 1. Following the Delphi exercise, the study aims to develop an IoT adoption measure and provides qualitative insights on issues that are significant in the Indian context. It is also implied that the outcomes of this study are extendable to similar environments such as emerging economies, hot climates, etc.

2.3. Expert panel selection

In this study, experts are required to be knowledgeable in the area of IBs. One of the crucial aspects of the Delphi Method is to identify and select appropriate experts for the panel of respondents. An effective expert selection process would ensure the outcome validity of the study. The Delphi guidelines suggest the following four criteria for selecting an expert: (i) knowledge and experience in the

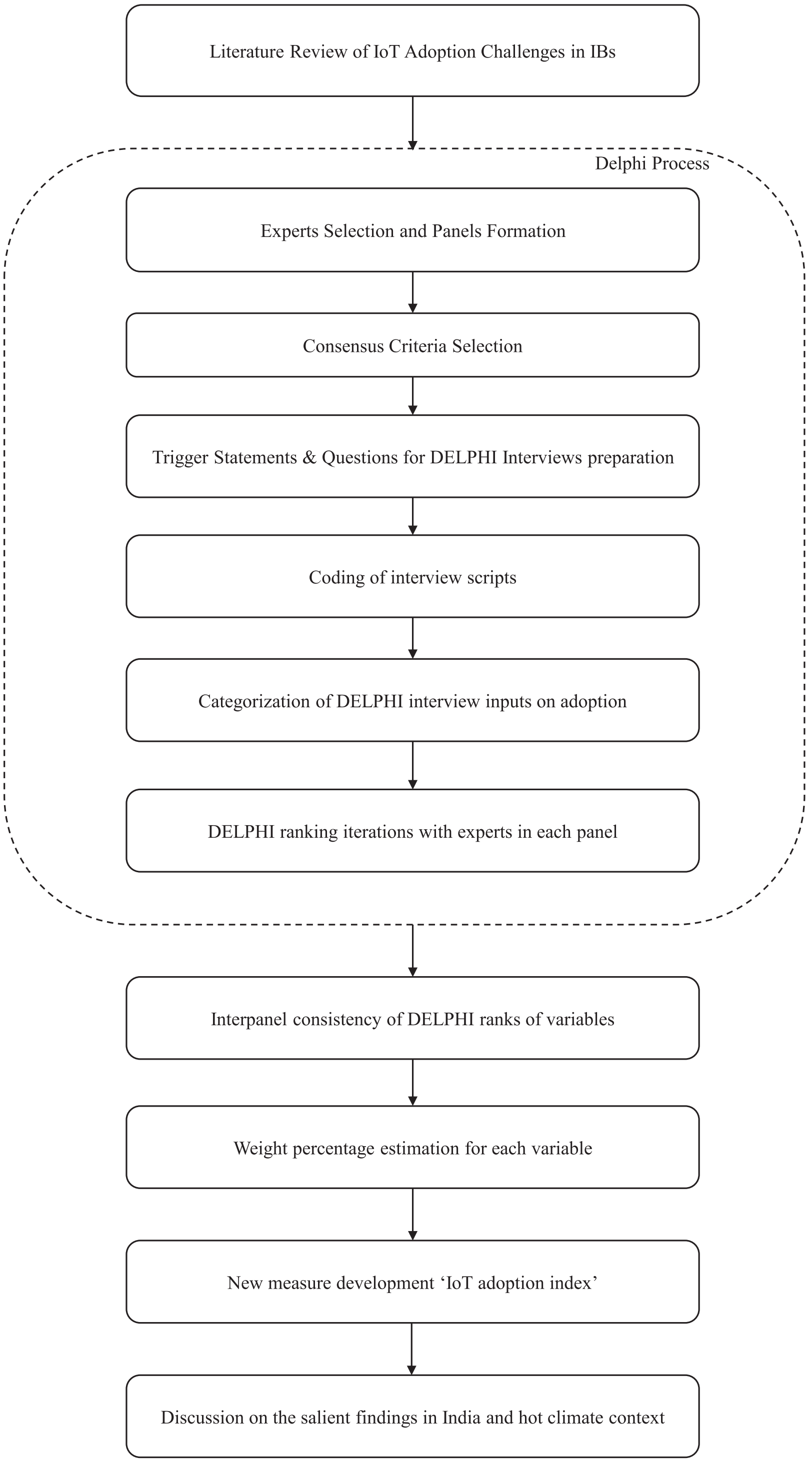

Figure 1. Research methodology overview.

areas that pertain to the problem statement, (ii) willingness to participate, (iii) allocation of sufficient time (to participate), and (iv) effective communication skills (Xia and Chan 2012). Before contacting and choosing respondents into the Delphi panel, the following two preconditions were laid, and the respondents had to fulfill any one or both.

(1) They had to be working or advising in the construction value chain: architect, builder, construction product supplier, ICT solution supplier, facilities management, sustainability consultant, etc.
(2) They had to be associated with IBs across any stage of their life cycle, viz., construction, operation and maintenance, and decommissioning and demolition.

30 experts who fulfilled the pre-conditions as mentioned above were contacted, and 24 agreed to participate. The areas of expertise of the Delphi panel members included building/office space owners, architects, construction product manufacturers, construction management specialists (e.g. contractors, project managers, etc), facility managers/HVAC specialists, IoT/AI solution architects, building science specialists, sustainability consultants, etc., and the panelists are equally spread across these areas.

The experts selected into the Delphi panel represent a sufficiently wide spectrum of specializations that contribute to the life cycle of IBs, and could provide a balanced view for the Delphi study. The recommended minimum panel size for Delphi is between 7 and 20 (Giannarou and Zervas 2014). In this study, we have 24 panelists. We have identified three panels of 8 members each, by picking one expert each from each area of expertise mentioned above. This has enabled an across-panels analysis that has yielded some insights into the distribution of responses.

The Delphi panel included industry professionals as well as researchers working in educational and research institutions. Figure 2 presents the frequency distribution of the respondent's years of work experience.

In addition, the substantial work experience, job positions and relevant firms of the Delphi panel experts ensured the validity of the results of the Delphi study. The frequency distribution of the experts' job positions is given in Figure 3.

2.4. Consensus criteria for Delphi

The objective of the Delphi study is to facilitate the experts to reach consensus, or at least move towards consensus, on the responses to each item of the Delphi questionnaire. Although a common approach to measure or indicate consensus does not exist across Delphi researchers, frequency distributions, standard deviations, or the interquartile ranges have been used to measure the extent of agreement reached. In certain cases, the percentage of respondents agreeing with each other on the response to a specific Delphi question is defined, which was fixed at 51%, i.e. a simple majority, by some researchers. In contrast, there are situations wherein a predefined distance from the mean or median has also been considered (Giannarou and Zervas 2014).

The present paper uses three measures to assess consensus among the experts. These measures are: (i) the interquartile range, (ii) the standard deviation and (iii) the lower limit of 51% percentage of respondents associated with the 'highly important' or 'strongly agreeing' category. Additionally, a 10-point scale is used in this study to assess the degree of agreement (Giannarou and Zervas 2014).

3. Data collection and ranking process

Phase 1: Delphi study for listing the variables/concepts pertaining to IBs

This phase involves collecting individual expert's opinions pertaining to variables that drive, influence, or impede IoT implementation in IBs. A two-fold approach defines IBs by identifying user requirements and technology considerations (So, Wong, and Wong 2001). This is used as

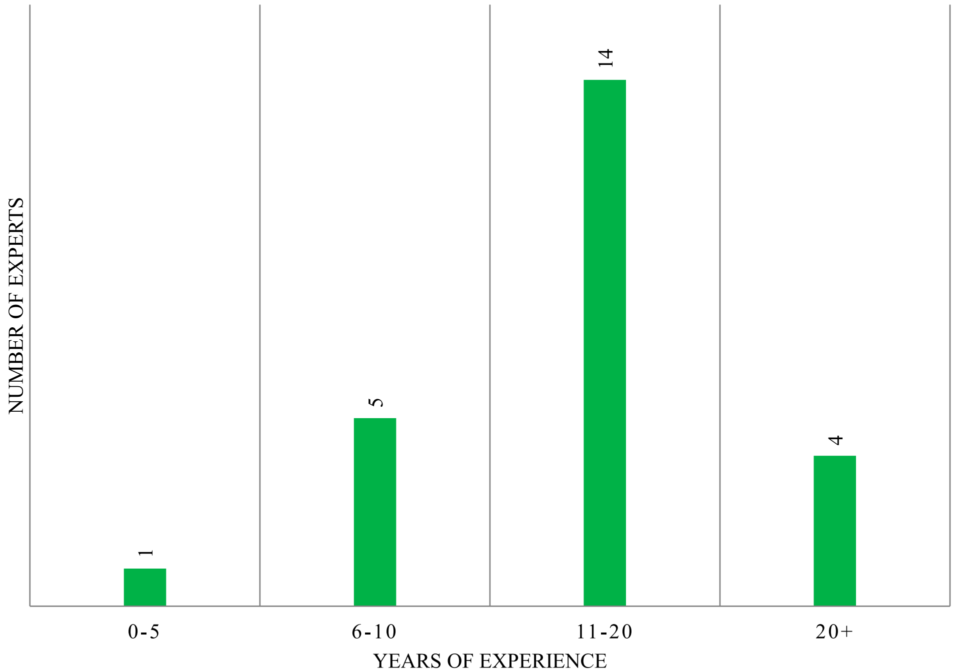

Figure 2. Work experience data of the DELPHI study panel experts.

the base for framing the trigger statements and Delphi questions (see Table 5) for the expert panel. A summary of 'IoT enabled BMS' from literature was presented to the panelists at the beginning of interview phase.

All the 24 experts forming 3 panels as mentioned earlier, responded to the Delphi study, which yielded a total of 140 inputs each corresponding to an issue. These were analyzed in detail and a list of variables/concepts/comments was arrived at using the 'in vivo coding' method. These were then consolidated, and grouped as shown in Figure 4.

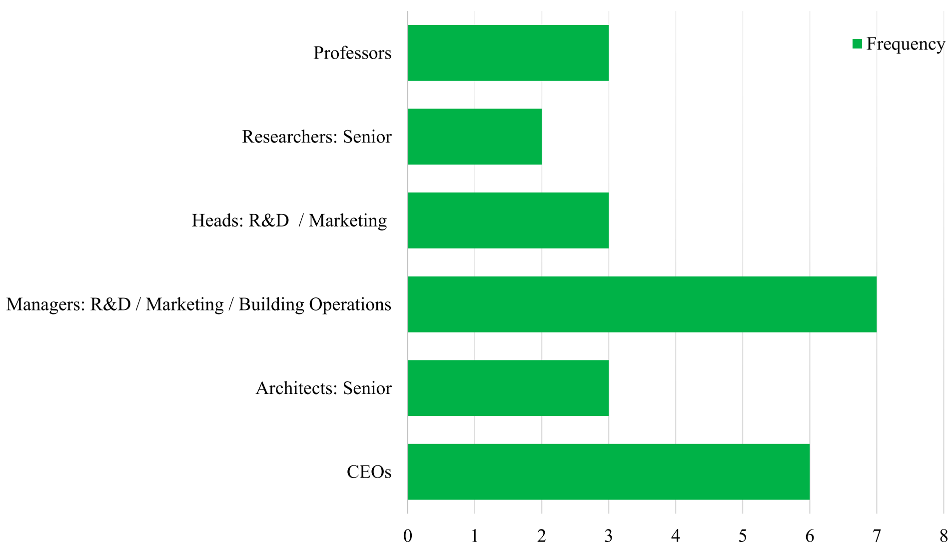

Figure 3. Panel experts' roles in their firms.

Table 5. Trigger statements and questions.[1]

User requirements	Intelligent building definition elements (M)	Trigger statement (TS) and Delphi question (DQ)
	M1: Environment Friendliness – health and energy conservation	TS1: 'It is important for intelligent buildings to be environmentally friendly in terms of carbon footprint and life cycle energy'; DQ1: What are the environmental parameters that can affect IoT adoption in intelligent buildings?
	M2: Space utilization and flexibility	TS2: 'It is important for intelligent buildings to enable increased space utilization with flexibility'; DQ2: What are the space related parameters that can affect IoT adoption in intelligent buildings?
	M3: Cost Effectiveness – operation phase	TS3: 'It is important for intelligent buildings to be cost effective during the operation phase'; DQ3: What are the operational cost related parameters that can affect IoT adoption in intelligent buildings?
	M4: Human Comfort	TS4: 'It is important for intelligent buildings to ascertain occupant comfort (thermal, visual, air quality, acoustic etc.)'; DQ4: What are the comfort related parameters that can affect IoT adoption in intelligent buildings?
	M5: Working Efficiency	TS5: 'It is important for intelligent buildings to have a higher working efficiency'; DQ5: What are the working efficiency related parameters that can affect IoT adoption in intelligent buildings?
	M6: Safety and Security	TS6: 'It is important for intelligent buildings to ensure safety and security of occupants and assets'; DQ6: What are the safety and security related parameters that can affect IoT adoption in intelligent buildings?
	M7: Culture	TS7: 'It is important for intelligent buildings to be aiding in the culture aspect, e.g. privacy, co-creation workspaces, outside view, etc., of their occupants'; DQ7: What are the culture related parameters that can affect IoT adoption in intelligent buildings?
	M8: Image of high technology	TS8: 'Intelligent buildings are often associated with high technology image'; DQ8: What are the technology image related parameters that can affect IoT adoption in intelligent buildings?
	M9: Construction process and structure	TS9: 'It is important for intelligent buildings to be compatible with construction processes and structure'; DQ9: What are the construction phase and structure design related parameters that can affect IoT adoption in intelligent buildings?
	M10: Health and Sanitation	TS10: 'It is important for intelligent buildings to ensure the health of occupants and proper sanitation'; DQ10: What are the health and sanitation related parameters that can affect IoT adoption in intelligent buildings?
Consideration of Technology	Internet of Things	TS11: Internet of Things involves multiple technologies: 1. Sensing Systems, 2. Wireless Communication, 3. Cloud Computing, etc. Each of these has its own pros and cons (e.g. remote monitoring vs. data security); DQ11: What are the technology-related parameters that can affect IoT adoption in intelligent buildings?

Phase 2 – Round 1 Delphi rating: Ratings obtained from the panelists

All the experts' inputs were selected for further consideration in this phase to initiate the process of consensus building among the expert panelists regarding the importance of each variable/concept/comment. In order to investigate the level of importance of each input, a 10-point interval scale was used with rank 0 implying 'least important' and rank 9 implying 'most important'.

Phase 2 – Round 2 Delphi rating: Ratings from Panelists following feedback and revision

For all the variables/concepts/comments for which the responses did not converge in Round 1, Round 2 was conducted. The full range of responses to each question was presented to each expert, pointing to the respective expert's response position within the full range. This facilitated each expert to review each response in relation to others', and consider making revisions in any response if felt necessary. For panel 1, 56.3% of the variables had converged in Round 1; for

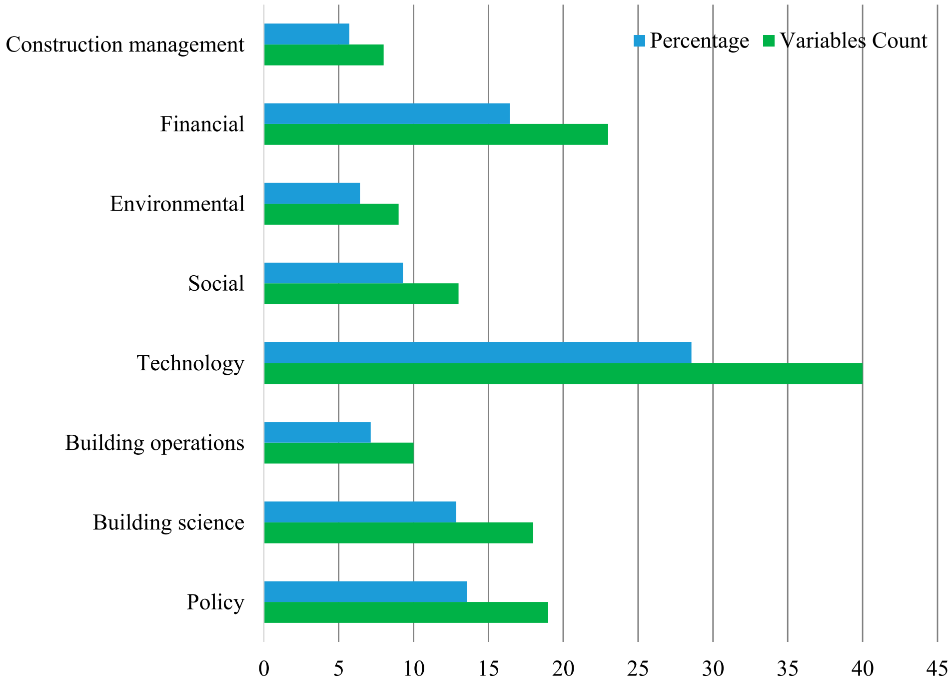

Figure 4. Groups formed using panelists' inputs.

panel 2, 72.4% of the variables had converged. But, for panel 3 only 27.6% of the variables converged in Round 1.

Phase 2 – Round 3 Delphi rating: Ratings from Panelists following Round 1 feedback and revision

For panel 1 and 2, all the concepts converged in Round 2. For panel 3, 24.1% of the variables had still not converged. Hence, round 3 was conducted for panel 3, and this resulted in convergence.

4. Discussion

Since this technology is relatively new and has huge potential to revolutionize the IBs market, analyzing multiple systemic aspects can shed more light on the challenges of technology adoption and use. The inter-panel agreement consistency was assessed using the interrater reliability (IRR) statistic and ANOVA. The IRR was greater than 95% for the three panel combinations. In the results of the ANOVA, the absolute deviation of the converged rating of each issue from the overall panel mean is used as a measure. The p-value of 0.931 (> 0.05) and F-statistic of 0.072 (F-critical = 3.017) indicated superior consistency among the panels in terms of the homogeneity of responses to the 11 Delphi trigger statements and questions. Figure 5 shows the converged ranking of all the issues assessed by the experts across all 3 panels. The issues identified in literature review are found to be falling in the 'highly important' category.

The new India specific issues identified are categorized using two well-known frameworks. The first is the IB KPIs proposed by Clements-Croome's work (Ghaffarianhoseini et al. 2016), covering (1) Economic and Cost Efficiency related, (2) Smartness and Technology Awareness related, (3) Personal and Social Sensitivity related, and (4) Environmental Responsiveness related. The second is the 'business model canvas' (BMC) a tool through which firms assess (1) value creation and (2) revenue generation potential (Le, Le Tuan, and Tuan 2019). Figure 6 shows the key issues that surfaced in the Indian context and their mapping on to the IB KPIs and BMC frameworks.

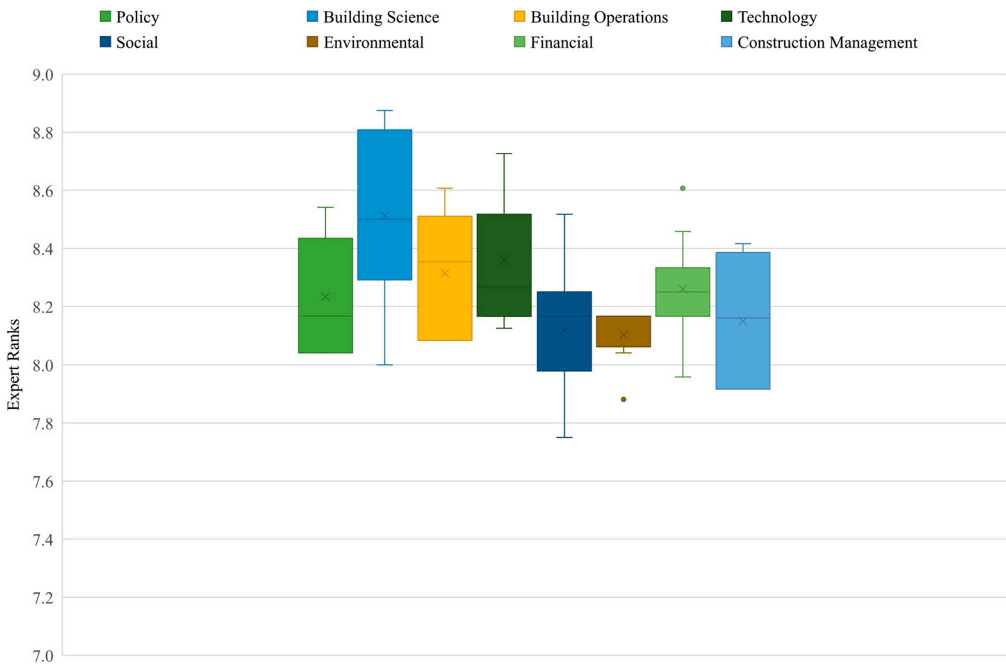

Figure 5. Consolidated ranks – converged DELPHI.

The following insights based on the DELPHI briefs are outcomes of detailed interactions with the experts.

4.1. Economic and cost efficiency related

Offices in India, are looking at means to cut energy costs and are investigating higher HVAC set points (Saraswathy 2019), close to the upper limit mentioned in guideline (26°C). However, this practice is in a nascent stage and not enough benchmarking has taken place. It has certainly not become a best practice among building owners. Experts have recommended widespread usage of such an 'Energy Efficient Thermal Comfort (EETC)' strategy as a good means to drive sensor adoption. Specific discomfort scenarios such as a near glass façade seating, and users entering from a hot ambient environment and taking time to reach an acceptable comfort level are unique to hot-humid climates and IoT systems can develop learning algorithms and finetune their responses accordingly. This will lead to customers realizing the real value of IoT and AI. Also, for EEC to become a best practice, the government has to offer energy tariff subsidies so as to encourage the small and medium-sized firms to implement in their buildings. Without such a seeding, diffusion of this practice and the associated IoT sensors, will face uncertainties. In addition, government bodies should develop measures and estimates for EETC in the Indian context, for example, 'per area or per occupant average energy consumption at a given EETC set temperature'. Also, there are skeptics who question whether wider diffusion of IoT sensors can resolve specific hot-highly luminous climate challenges such as asymmetric thermal-visual comfort in IBs with glass facades. In addition, questions like whether increased sensing can cut costs of the passive devices installed (e.g. light shelves) often arise.

Also, experts made additions to the concerns reported in literature on maintenance costs associated with IoT installation (Rafiq et al. 2017). For small and medium-sized firms (SMFs) in India, these recurring costs are still not in their mind, and may be perceived negatively if the cost savings realized in the first few months of installation are not significantly high. In this context, poor

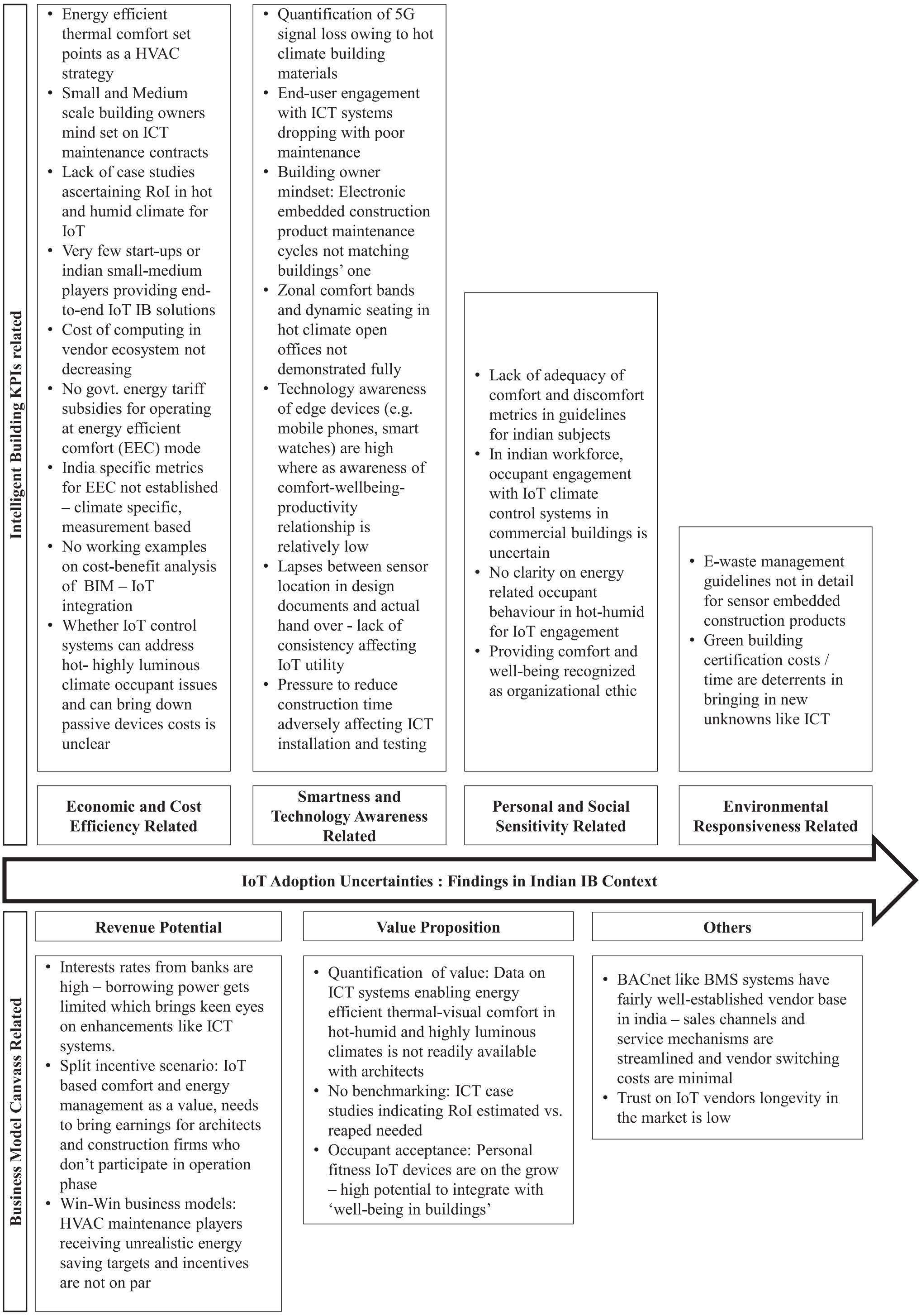

Figure 6. Key India specific issues – classification with IB KPIs and BMC.

maintenance of sensing systems in India is also an associated threat. If the occupants do not find the sensing systems, working then their levels of engagement with the IoT systems will drop steeply implying cost savings forecasted will further drop.

Information silos within comfort control systems such as lighting not communicating with HVAC, present a technology challenge in the current scheme of sensing (Bajer 2018). This disconnect due to silos-based functioning increases sensing entropy as well as system costs. While IoT can resolve this issue with cloud services, system integrators in India are keen to have synchronized upgradability and serviceability, meaning upgrading one sub-system should not affect its interoperability with others. There seems to be 'risk averse' behavior in engaging with maintenance cycles when interoperability issues are likely.

Another challenge reported in literature, that IB ICT market is currently controlled by large players (Bajer 2018) is true in Indian market. Regarding this, panels opined that SMF customers will find that their bargaining power with large ICT players is weak. In their view, more and more India-based IoT startups offering end-to-end IoT solutions at a lower cost are the need of the hour. It is expected that these players will have a simplified organization structure with lesser overhead costs that their offers will be cost-competitive, leading to perfect competition in the market.

In light of the RoI issues found in literature (Rafiq et al. 2017), new details were brought out from expert panels. Some of the notable ones are, (1) Large IT firms, the first movers need to generate data on performance and usefulness, (2) Need for Hot–Humid–Highly Luminous climate-specific case studies, and (3) Need for shifting focus on real building measurements than performing mere simulations.

Experts who participated from the IoT firms also stated that the cost of computing does not seem to be reducing with time in India, in specific initial and recurring expenses pertaining to manpower, training, data centers maintenance, and software licensing, etc.

4.2. Smartness and technology awareness related

New advancements in communication technology such as 5G are finding their entry into IBs (Motlagh et al. 2020). While panels acknowledged that Indian IBs might have a direct entry to 5G, extensive testing of 5G in the context of hot climate buildings needs to be done. Certain materials such as metal-composite panels mounted on facade and metallic coatings on glass for heat reflection, tend to affect signal strength in buildings. As there cannot be a tradeoff between comfort and communication in a modern-age building, these materials will have to be tested and enhanced further for favoring IoT communication.

Also, to fully reap the benefits of IoT sensing in an open office environment, zonal comfort bands, dynamic seating allocation, etc., are needed as complementary practices, and case studies discussing the practical difficulties of doing these in the Indian and hot climates will be needed. Otherwise such proposals that appear in literatures (Nagarathinam et al. 2017) stand the risk of being considered theoretical, as there will be many unknowns in implementing them in real life. Falling in line with the literature, in India too, there are often lapses between sensor location in design documents and in actual hand over (Rinaldi et al. 2018). Panels added that the effect worsens when it comes to zonal comfort bands, a key practice to reap the benefit of IoT monitoring. Hence, disciplining the 'design to realization' phase (e.g. HVAC lines routing, sensors and actuators positioning, etc.) is of paramount importance in India, or else the image of IoT could be dented.

The panel experts also expressed that, in India there is tremendous pressure for handing over buildings in time by reducing the construction time as much as possible. This often means that ICT installation and testing could be done for just protocol or certification sake. This affects the credibility of IoT systems once the operation phase starts and building facility managers are often not sufficiently knowledgeable to pinpoint the root causes of this likely low performance.

In the context of embedded sensors in construction products, construction firms have set a certain lifetime expectation for their products in customers' minds. With sensor integration, such products will possibly need replacement or repair in a shorter time. In customers' minds, replacing construction products four to five times along the life cycle of the building will not be perceived well.

In regards to 'technology awareness' in the Indian context, the usage of edge devices (e.g. mobile phones and smart watches) is high, whereas awareness of the 'comfort-wellbeing-productivity' relationship in buildings is relatively low. Hence, end-users should be educated first that a comfortable office environment would ensure their well-being, both mentally and physically, boosting their productivity at work. More data on Indian buildings are needed to create end-user pull. Also, according to the responding experts, occupants are excited about their smart watches and mobile phones, and will automatically share their comfort preferences and feedback with the IoT BMS periodically. However, occupants seem to be doubtful about the effectiveness of the IoT BMS AI control algorithms, which would need to operate based on individual preferences.

Among the other aspects, architects in the panel highlighted that although IoT technology is a clear differentiator in their offer, wireless technologies face perception challenges such as data loss, signal strength, privacy, data security, etc., in the minds of building owners as pointed out in other parts of the globe (Hsinchun, Chiang, and Storey 2012). This could be made worse in India as system integrators do not have satisfactory answers to change this perception with case study-based data. Case studies in various commercial segments (IT offices, office spaces in factories, R&D lab offices, etc.,) need to be developed to retire these perception risks.

Further, universal 'building science' concerns such as, developing fuzzy measures of comfort on an individual basis, and addressing occupant perception of the uniformity of HVAC set points have also surfaced.

4.3. Personal and social sensitivity related

Climate specific established metrics for comfort and discomfort of typical Indian occupants is an urgent and important need. At present the HVAC approach in India is 'fixed temperature', for e.g. 24 +/−1°C for all seasons across the country (Saraswathy 2019). Expert panels pointed out that adaptive comfort data (HVAC set points as a function of ambient air temperature) generated in hot-humid regions of the country are not yet followed as a practice in buildings. Implementation rigor of adaptive comfort standards has a potential to reduce energy costs and will call for increased spatial monitoring in hot climates.

Another relevant aspect is user design (Knutsen 2014). In this context, panels pointed out hot climate-specific 'energy-related occupant behavior' as a key differentiator. For example, occasionally occupants when entering from outside tend to set the air-conditioning temperature as low as 16°C for a few minutes to feel comfortable and such a behavior has a large impact on the energy consumed. On similar lines, in highly luminous climates, it's common for occupants to face glare issues when they are located close to the glass facade and they respond in certain ways to manage this, for e.g. by lowering curtains. Most often in offices, they do not remind themselves to raise the curtains up when the glare disappears. Such unique behaviors can be captured and converted into a value proposition for sub-systems assisted by an application that runs in the occupants' smart devices. Presently, an exhaustive listing of such 'energy-related occupant behavior' in the Indian context is not available with architects. Also, the young workforce in Indian IT offices is expected to be busy with project schedules, and receiving feedback on comfort levels, preferences, activities, etc., could be challenging. Novel approaches, such as gamification are needed to create social interactions between occupants for enabling them to share their comfort data.

Above all, from the employees' point of view, providing comfort and well-being needs to be recognized as an organizational ethic and this is missing in practice in many places. This view is not just from SMFs, but also from large firms, as shared by an expert in one of the panels.

4.4. Environmental responsiveness related

The challenges in this category seem to be unique to the Indian context as can be observed from the sparseness of literature. End of building life is a critical aspect from the sustainability angle, and most Indian building owners are unaware of the scenarios associated with it, as it is easily 15–20 years away in the future and there are not many examples around to observe and learn from. Certain experts felt that in the Indian construction industry, sustainability guidelines for recycling electronics embedded products can be more detailed. Certain other experts felt that sustainability consultants are often hired to gain certifications from government bodies such as GRIHA, IGBC, and BEE as these processes can get cumbersome involving heavy paperwork, which, in turn, involve additional costs and effort. In such a scenario, IoT comfort monitoring related documentation, safety clearances, etc., can make the process increasingly cumbersome and there could be new unknowns in the whole process.

4.5. Business model – revenue potential related

Adding to the high first cost and borrowing concerns pointed out (Ma, Badi, and Jorgensen 2016; Rafiq et al. 2017), the panels indicated that bank interest rates for loans are relatively higher in emerging economies. This emphasizes first cost reduction to stay low on borrowed capital. Hence, ICT like systems are scrutinized multiple times for RoI estimates before approval. This process could end up with negative decisions on high priced advanced ICT systems purchase.

In addition to business model effectiveness to attract end customers (Zanella et al. 2014), challenges in sharing incentives within the value chain have been reported in Delphi. Facility management contractors often complain that they receive unrealistic energy-saving targets and the incentives are not on par. To solve this, business models such as incentives based on actual savings, deserve consideration. Even design phase players like architects can get recurring revenues based on year on year energy savings in IBs. Incentivizing all players in the value chain through apt business models will lead to joint ownership at all stages. This will boost tight commissioning protocols adherence, ensuring comfort and energy efficiency at the time of hand-over, and right maintenance interventions while operating.

In response to the finding that ICT is a heavy investment in the Indian construction sector (Ahuja, Yang, and Shankar 2009), panels viewed that there is an inclination towards advanced climate control technologies when they observe a direct relationship between comfort and workforce longevity or productivity. This is despite the Indian market being price sensitive and SMFs being keen to pursue cost minimization. In addition, business models such as ‘pay as you use’ or ‘rent an IoT system’ tried in limited spaces such as meeting rooms are a good starting point. This will give the customer a feel for the cost-benefit ratio, and with appropriate upgrade and scale up plans, can increase adoption in steps. Nevertheless, with the current down turn in the economy, cost cutting is the new norm and hence uncertainty will prevail on market pull for advanced ICT solutions.

4.6. Business model – value proposition related

To add to the earlier work pointing to lack of business cases (Bajer 2018), building owners in India express that ICT systems’ capabilities to enable EEC in hot-humid and highly luminous climates should be expressed with adequate data. Architects often seem to quote case studies from other countries and cold climates which may not be relevant for effecting savings in the Indian context.

For IoT solutions, end-user acceptance is a key aspect for market penetration, and occupants are the consumers of comfort in buildings. In India, personal fitness IoT devices usage has picked up in recent years. When integrated with ‘well-being in buildings’, such devices could deliver a higher value proposition for their users. To add to this, panels viewed that large IoT players in the IB market are closed in terms of external apps using their data (for visualizing occupant activities, comfort preferences, satisfaction levels, etc.,) to create work-place experience. This leads to less and less innovation and business activity in the IoT application layer level.

4.7. Business model – other issues

In this context, IoT startups in India are showing lack of (1) financial stability, (2) Performance consistency, and (3) Longevity. A vanishing trend of IoT startups is not uncommon in emerging economies. Some of them operate for just 3–5 years. Considering building life spans of around 20 years, IoT startups' longevity is of concern in India. In comparison, the vendor base of current BMS systems seems very stable (Lilis et al. 2017). The current BMS solution players (non-IoT) in the Indian market have fairly well-established sales channels and service mechanisms. To add to this, panels opined that vendor switching costs are minimal, retiring the risk of entering a lock-in with large IB IoT players.

This study proposes a new measure called 'IoT adoption index', which is based on the weights percent for each issue and its consequent expression. The index should be calculated using Equation (1), which is based on the data in Figure 5. Depending upon variations in real life scenarios, other issues can be appropriately included along with their respective weights percentages.

$$\text{IoT Adoption Index (IoTAdIn)} = \sum_{i=1}^{n} DI_i W_i \tag{1}$$

where $i \rightarrow 1\text{–}140$ DI_i – DELPHI Inputs W_i – Weight percent = Product of (Sum of input-scores for the range considered and average score of the 'i'th input)/100.

5. Theoretical and managerial contributions

Most research studies have focused on the technology bottlenecks pertaining to IoT. This paper has focused at a system level to provide various stakeholders a multi-dimensional view of the potential risks in their IB projects. Also, the study provides an adapted management framework based on IB KPIs and BMC to comprehensively list the India-specific risks and uncertainties.

On the methodology front, this study has employed three independent Delphi panels, primarily to gain robustness in the data analysis concerning IoT adoption in IB comfort and energy management. High impact issues were identified based on screening for scores ≥8 in each of the three panels. This study has used an exhaustive number of issues (about 140 clear and consistent ones). This outcome is therefore comprehensive or systemic in nature. It improves our understanding of the underlying IoT adoption phenomena. Also, a new measure 'IoT adoption index' in the IBs context has been proposed.

Apparently, such a detailed study, involving a wholistic set of issues and corresponding expert inputs, has not been reported elsewhere. This study is perhaps the first work addressing IoT adoption in the Indian buildings market.

6. Conclusions

IoT solutions can overcome certain limitations of traditional IBs. India being an information technology hub, IoT based energy and comfort management systems are expected to evolve rapidly in the coming years in the buildings market. Despite significant market opportunities in the growing construction sector of India, IoT is seemingly faced with diffusion challenges.

In this context, a Delphi study has been performed to determine the important issues that affect the adoption of IoT systems specific to EEC in IBs. The 3-panel, 3-round Delphi study involved 24 subject matter experts from all the entities across the IB value chain. This Delphi study has resulted in a list of 140 issues grouped into 8 themes and has provided them quantitative ranks. An IoT adoption index (IoTAdIn) has been developed based on the issues and their weights obtained from the Delphi study. It can be used by stakeholders while implementing IoT systems in their projects. The issues specific to the Indian context are classified using IB KPIs and BMC.

The path to adoption starts with IoT firms focusing on the value propositions. In hot-humid climate contexts, occupants are faced with unique comfort challenges and they exhibit certain 'energy and comfort-related behavior' in offices. We suggest that the Indian market needs to consider these two aspects as novel value propositions. The next important aspect is revenue potential. Since the market is price sensitive, and has not seen many bench-marking studies on RoI, strategies such as piloting in a sub-building level are essential to keep the first costs minimal for the building owner while demonstrating benefits such as energy savings and comfort improvement. In addition, win-win business models for revenue sharing between multiple value chain players such as architects, construction firms, and facilities management professionals are essential. Such business models should ensure earnings for players from the concept phase also. In addition, from the customers' view point, quantifying RoI is a key enabler: country-specific, climate-specific (hot-humid), *in-situ* measurement-based data on cost benefit ratio are absolutely essential for diffusion of this technology.

On cost effectiveness, EEC initiatives sprouting across the country in large IT offices are a good sign. However, more benchmarking case studies quantifying IoT value are essential. The issues such as increasing computing costs, lack of IoT vendor stability and longevity, lack of quality emphasis for ICT during hand-over, and lack of subsidies for EETC, should be addressed to realize the full potential of this opportunity.

On technology awareness, educating office occupants on comfort and its implications for productivity and well-being is essential. This will engage them through their smart devices for sharing their comfort data and preferences both quantitatively and qualitatively. While there are unknowns such as hot climate building materials impacting 5G signal quality, there are known issues that should be tackled. They include (1) poor maintenance of IoT leading to lack of interest, (2) Implementing zonal comfort bands and solving practical issues, and (3) clean construction practices such as tight adherence to design drawings.

The government should also develop best practices regarding, (1) Comfort and discomfort measures for specific climates across the country, (2) E-waste management guidelines for IB end of life, (3) Lighter and faster certification processes, and (4) Insisting firms to implement comfort as an organizational ethic.

Such a collaborative effort by IoT firms, value chain players, customers and government can boost IoT based energy and comfort management systems in India's IBs market. This work also provides a priority list for stakeholders on the key issues to be tackled for commercializing IoT solutions in IBs.

It is to be noted that while this work is performed in India, the conclusions can possibly be extended to similar markets (e.g. other emerging economies) and climates (e.g. hot-humid-highly luminous).

Note

1. The intelligent building definition elements (M) have been referred to from So, Wong, and Wong (2001). The trigger statements and Delphi questions have been formulated by the authors.

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No potential conflict of interest was reported by the author(s).

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