BIM and Automation of Building Operations in Japan: Observations on the State-of-the-Art in Research and Its Orientation

Jeferson Shin-Iti Shigaki(✉) and Tomonari Yashiro

Institute of Industrial Science, The University of Tokyo, Tokyo, Japan
jshigaki@iis.u-tokyo.ac.jp

Abstract. Japan has long-term automation experience in several manufacturing industries. Recently, players of the real estate and building sector have turned strategic attention and research investments to the automation of building operations, aware of the business relevance of the occupancy phase of facilities. This investigation analyzed R&D programs and experimental projects in Japan to foresee the role of BIM in the automation of building operations. A survey of disclosed information helped to understand the trends in automation research with the adoption of digital technologies for immediate and future use. Appliances from electronics manufacturers have been incorporated into complex cyber-physical systems to communicate with the built facility through a BIM-IoT framework. The evolution of ICT has influenced building management systems attributes which require new definitions of the set of data to be delivered and maintained by project players. There is recent evidence of efforts to turn BIM as the platform that creates, manages and also stores information for future BIM-FM uses, even though the integration with BAS/BEMS is not fully solved. Finally, this study identified connections between prior construction automation achievements by Japanese contractors and future orientation related to the technological challenge of context-awareness and servitization.

Keywords: BIM · Automation · Building operation · BAS · BEMS · IoT

1 Introduction

1.1 Context of Building Automation in Japan

Japan has long-term automation experience in several manufacturing industries. Over the last four decades, construction companies have invested in the development of construction robots and automated building construction systems [1]. Recently, players of the real estate and building sectors including owners, developers, general contractors, building service subcontractors, energy service providers, electronics manufacturers, home appliance retailers, and ICT vendors have turned attention to the automation of building operations, aware of the business relevance of the building's occupancy phase. Therefore, this investigation aimed to observe State-of-the-art research on BIM and Automation of Building Operations in Japan and its orientation.

E. Toledo Santos and S. Scheer (Eds.): ICCCBE 2020, LNCE 98, pp. 879–894, 2021.
https://doi.org/10.1007/978-3-030-51295-8_61

Building operation expenses vary greatly depending on how managers operate, repair and renew facilities. In addition to energy savings, building automation has promised to increase safety, comfort and quality of life of occupiers. Users empowered by technologies can easily access and control devices and systems through the internet. Thence, construction companies have strived to provide product-service systems; and the automation of buildings operation became part of this strategic shift.

In Japan, the idea of Building Automation Systems (BAS) often links with Building Energy Management Systems (BEMS). Despite covering specific functions, residence-oriented HEMS (Home Energy Management System) has become attainable for the general public both as a concept and as a commercial solution. According to the Yano Research Institute [2], the estimated worth for domestic BEMS/BAS market in Japan for Fiscal Year 2019 was 140bi JPY (1.28bi USD). Drivers for sales were the increased demand for construction of new buildings following the redevelopment of major cities such as Tokyo, Nagoya and Osaka and the context of Olympic Games Tokyo 2020. Accordingly, despite drastic cost reduction with the adoption of international standard protocols (i.e. BACnet® and LonWorks®) and stronger competition with new vendors, the market tends to keep rising due to an increase of new buildings. In the future, the market will shift from new buildings to renovation projects of existing facilities as new functions and services with cutting-edge technologies are improved for these projects.

Recent automation research orientation also relates to a strategic policy known as Society 5.0 [3]. The national authority aims at creating a society where they can resolve various social challenges by incorporating the innovations of the fourth industrial revolution into every industry and social life. The deployment of IoT, Big Data, AI, Robot and Sharing Economy would lead Japan to realize a “super-smart society”, continuously creating new values and services, making people’s life more comfortable and sustainable. The abundant accumulation of real data and technology cultivated from “monozukuri” are advantages that make Society 5.0 possible. The Japanese Government has supported Zero Energy Houses (ZEH) and smart communities’ initiatives as part of the carbon emission reduction commitment, and it is implementing subsidies for the installation of HEMS in households by 2030 [4].

1.2 Context of Building Automation in Japan

There are many direct and indirect players involved with R&D in Building Automation and Control Systems in Japan. It ranges from Governmental agencies to technology institutes or R&D departments of construction, manufacturing and services companies. It also covers academic societies and research institutes which provide consultancy and manage research partnerships and consortiums.

The Building Automation Association (BAA) was established in 1997, first as a point of contact for the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) with the building automation industry [5]. In 2011, it became a general incorporated association with electronics manufacturing and control system services companies aiming the further development of the industry. Besides conducting research and educational activities on relevant topics either guided by the Government or identified by the sector, it organizes industry-wide meetings and disseminates information.

The Japan Smart Community Alliance (JSCA) was established in 2010 to support the future growth of Japan's leading energy-saving and new energy technologies, as well as to promote collaboration between the public and private sectors [6]. Four working groups conduct research and collaboration activities: International Strategy, International Standardization, Roadmap, and Smart House and Building. Activities encompass the identification of technology, policy and market trends and the development of strategies to support Japanese companies. In cooperation with the Ministry of Economy, Trade and Industry (METI), the alliance works on studying global trends in standardization, future preparedness through roadmaps developing scenarios for next-generation societies and further dissemination of smart buildings.

The challenge of researching building automation is admittedly tough. So, despite the competition, industry players have ever more worked together. One finds in their partners the market understanding in specific business branches, background experience within the area of application or similar type of technological solution, technical information to solve engineering integration problems, and enhanced capital investment capacity.

In some cases, the provider of HEMS and the house manufacturer belong to the same business group such as PanaHome and Panasonic [7]. Similarly, NTT Facilities took advantage of its real estate, telecommunication and computer systems background in developing its BAS/BEMS solution [8]. The "NTT Data I System" is open network-compatible enabling multi-vendor support for lower-cost realization through BACnet® and LonWorks®. The BAS Partners Portal is a channel providing further technical and commercial information [9]. In other cases, partnerships already exist from other product sectors and were built out again for developing solutions for the automation of building operations as Denso Co. with Toyota Housing Co. and Misawa Homes [10].

Moreover, companies collaborate for specific objectives in demonstration experiments which can involve a Governmental agency and or universities. One example is the Smart House HEMS prototype developed by Fujitsu with Tokyo Electric Power Company Holdings (TECPO) also involving Waseda University Advanced Collaborative Research Organization for Smart Society within a project by the METI's Agency for Natural Resources and Energy [11].

For a long time, Japanese manufacturing companies have adopted an in-house technology development strategy. Nevertheless, the formation of the associations above suggests that such a complex problem should be faced by cooperative organizations to speed up the accomplishment of business objectives. Together, they may not only share the technological infrastructure but the background knowledge to engineer integrated solutions which depend on multiple players to perform adequately.

2 Methodology

2.1 Sources of Information and General Procedure

The approach consisted of a literature exploration conducted through surveying disclosed information from relevant players of the Japanese construction, electronics manufacturing and operation service industries. The reason for using disclosed information is that some development programs still undergo without a commercial solution or are kept in industrial secrecy. Nevertheless, Governmental agencies have promoted general concepts; while industry associations have diffused BAS/BEMS technology information aiming to expand the market. Some companies released their 'visions' and have received valuable feedback to improve their R&D programs. Consultancy firms and research institutes have published insightful articles giving a hint on the direction of current R&D efforts. Findings of this paper are primarily based on the observation of publicized information and focus on the strategic bias of on-going research rather than technical output details.

As a secondary source of information, a survey on the J-Stage Platform [12] intended to overview the debate in Japan from an academic perspective. The objective was to find specific integration solutions between BIM and BAS/BEMS or interoperability research findings in this area. Therefore, the keywords used were "BIM" AND "BAS" OR "BEMS" OR "HEMS" all in alphabetic characters because even in Japan, it is common to refer to these terms in Romanized writing. All publication types were admitted, both in Japanese and English. The subject areas were limited to "Engineering and Technology", including Architecture and Civil Engineering, and Electrical and Electronic Engineering. However, this search resulted in nine documents from which just one was considered relevant after excluding unavailable documents and papers from non-related engineering fields. That paper described the situation of BACS development and briefly pointed out the challenge of creating data models linking BACS and BIM [13].

A search with "BIM" AND "IoT" resulted in another ten documents related to its application for site management or structure performance monitoring; thus, not related to the automation of building operations. A search excluding the term "BIM" resulted in a higher amount of publications, especially in the electronics field, but their scope did not meet the objective of this exploration. These keywords were also found in the titles of technical papers in magazines of construction companies. Although only a few were available online, it suggested on-going developments and their research orientation.

2.2 Identification of Major Research Streams

Despite the initial purpose of this investigation in identifying R&D programs concerned with BIM and BAS/BEMS systems integration, most findings related to the advancement of BAS/BEMS technologies and its potential applicability as commercially deployable solutions regardless of a BIM orientation. Building Automation research in Japan is closer to IoT-related societies rather than the BIM community.

Therefore, the main differences between Japan and overseas possibly rely on the context and structure of research initiatives rather than the technical outputs. In a sense, Japan is striving to adopt international standards based on the commonly agreed problem of heterogeneity [5, 6]. Yet, many initiatives are the result of a collaboration between domestic partners toward the accomplishment of national policies.

There are two main streams for R&D efforts.

New technology development research: Intend to consolidate and expand markets with the creation of cutting-edge technologies (technology push); and reduce acquisition, installation, operation and maintenance costs (response to market pull). Service provision and sustainability tenets have focused on improving usability and user interface of systems as well as designing marketable solutions for inexperienced potential users. Technology development may be held internally or in partnership with providers holding specific expertise in a field of application.

Technology management for solving threats raised with emerging technologies: problems raising with the deployment of new technologies may represent serious hazards for users, society, and the building automation business itself. Despite risk mitigation is managed during technology development, some problems not expected in early conceptual stages express real threats for its sustainability and endurance.

These streams, however, do not disconnect from each other. For instance, 'Technological domain' research for advancing hardware, software, network systems of BA are closer to the technology development stream but implies strategic make-or-buy decisions. Then, despite the technical nuance of security problems, R&D on 'Cybersecurity issues' have emphasized their management implications along with the efforts to advance technology. Besides, 'Response to lifestyle change' may first sound closer to the management stream, it deals with solving information exchange pitfalls between devices of multiple vendors to expand the market.

Such type of dynamic interaction is an intrinsic characteristic of Japanese industrial technology research in line with its unique approach to managing the creation of new knowledge [14]. Another peculiarity observed in this investigation is the propensity and ability to cross the industry boundaries; so, companies are open to using diverse technologies to create new products that transform markets [15]. The cases presented below demonstrate how the Japanese industry has managed to advance in this field.

3 Research in Automation of Building Operation in Japan

3.1 Technological Domain and In-house Technology Development

Japanese automobile companies tended to adopt an in-house automation technology development strategy, which was not only a low-cost but had several advantages. These included using internal know-how to design machinery "with just enough functions" compatible with the Gemba, increased control over maintenance, and easier functional expansion [16]. The building sector first conducted automation research turned to improve production processes. Construction companies strived to automate construction operations by adapting robotic technologies to satisfy specific operation conditions. Site automation efforts mostly resulted in single-task types of robots [17].

Obayashi Corporation started to develop the Automated Building Construction System (ABCS) in the 1980s to increase productivity and improve the working environment resulting in climbing mechanisms, welding robots and other site technologies [18]. Meanwhile, Shimizu Corporation worked on fireproofing spray robots, decommissioning robots for nuclear power plants and even robots for space programs [19]. These activities took place at R&D departments, referred to as Technology Research Institutes, which can reutilize prior automation experiences for new research aiming at the operation phase.

However, the characteristics of research programs have changed. The former generation was mechanic-oriented, with most devices installed in a fixed location. Old versions of HEMS were arranged in relatively closed architecture networks and struggled with interoperability issues. In turn, the current generation is ICT-oriented and strives to be movable and far-reaching. They are more flexible and easier to communicate through Open Systems. Smart objects, such as self-operating windows and housekeeping buddies, incorporate robotics, IoT and AI features.

Construction companies owning a real estate investment division have merged background knowledge to set visions of the Next Generation building operations. Facilities managers have worked closer to R&D to explore the potential use of BIM data in the operation phase. They not necessarily adopt off-the-shelf CAFM platforms but develop custom solutions “with just enough functions” which are exchangeable with their existing databases.

One change is that technology development, predominantly held in-house or with companies of the same group, is gradually conducted with external strategic partners holding specific know-how and infrastructure. As an example, recently Kajima Corporation began to provide Building Management services utilizing a “Kajima Smart BM” platform to predict energy consumption and equipment malfunctioning, improving operations and reducing running costs [20].

Traditionally, building operation data had been stored for a short period due to the limited capacity of monitoring equipment. In this new system, data collected from BAS, BEMS and multiple IoT sensors are automatically stored in the cloud to be then analyzed using AI. For the development of this platform, the two companies of the Kajima Group (one for construction and other for integrated facilities management) combined their knowledge and technology to build data infrastructure and implement Microsoft Azure receiving full technical support of Microsoft Japan.

3.2 Response to Lifestyle Change at Various Scales

Society 5.0 has raised public attention and has fostered R&D investments to the realization of Smart Cities and Smart Buildings. Japan has also strived to contribute to the UN’s Sustainable Development Goals (SDG). The popularization of the concept and potential benefits of ZEH by families has accelerated the improvement of HEMS both in technological and commercial ways. Such energy and environmental policies have oriented research efforts in various levels, from building parts, building units and urban scales. Home appliance manufacturers, builders and real estate companies have used the flag of ZEH and Automation as a way of promoting healthy and convenient lifestyles, making their customer feel they are continuously contributing to the environment and saving energy costs.

LIXIL, a building materials and component maker, has developed the “IoT-Home Link”. Various IoT devices connect with the “Life-Assist”, from where one can check the status of the house and remotely control it from a single smartphone application [21]. The assist rule function combines a life scene and a trigger to take actions with sensors and actuators connected to building parts or equipment configured to behave according to a desired lifestyle or automatically respond to critical situations. House manufacturers, such as Sekisui Heim [22] and Daiwa House [23], have prepared advertisement materials highlighting the benefits of HEMS, provide easy explanation during visiting sessions, and distribute user-friendly manuals for using their products.

Applications of performance-oriented solutions have affected architectural planning. Therefore, the physical and spatial characteristics of the building are made ready for the installation of devices, movement of equipment and adequate operation of network systems. Building automation demands flexible designs for maintenance, the occasional substitution of controlling devices and eventual transit of surveying machines for system updates. Yet, research on smart services robots might change the image of automation of building operations.

In the urban scale, Toyota just revealed the plan to build the "Woven City", a fully connected ecosystem prototype at the base of Mt. Fuji [24]. The vision of making the city a "living laboratory" is audacious even for Japanese standards. Toyota sees the project as an opportunity to develop future technologies for the city's infrastructure. The digital operating system presumes advancing interdisciplinary technologies, so they plan to collaborate with commercial and academic partners and attract scientist and researchers to work together. The breadth of technologies and industries covered by the group enables the exploration of new forms of urbanity changing the way of inhabiting and navigating cities.

3.3 Cybersecurity Issues and the Involvement of Multiple Players

Previous generations of Building Control Systems were not easily targeted by cyber-attacks because they have been separated from the internet or used system-specific protocols. However, it is no longer possible to ignore cybersecurity issues since system designs increasingly assume external connections for new functionalities.

Aware of its potential threat to the consolidation and expansion of systems for building operations, the Ministry of Economy, Trade and Industry (METI) organized a sub-working group to specifically discuss cybersecurity measures for building systems under the Industrial Cybersecurity Study Group WG1 [25]. In March 2019, this group released a draft entitled "Guidelines for cyber-physical security measures in building systems", providing comprehensive guidelines to building users and services providers, as well as countermeasures against identified threats at each stage of the building lifecycle. Members of this group included academics, local authorities, general contractors, and companies and associations of the real estate, insurance, telecommunication, electronics and automation service sectors. These measures, however, covered BACS systems and do not encompass BIM or BIM-BAS yet.

4 Cases of Research and Development Initiatives

4.1 Electronics Manufacturers Consortium: ECHONET

ECHONET (Energy Conservation & Homecare Network) Consortium was established in 1997 to promote the standardization of home network infrastructure technology. It strives to interconnect household appliance, residential equipment, sensors, controllers and other devices from multiple vendors. Take part of the consortium seven managing members (Hitachi, Mitsubishi Electric, NTT, Panasonic, Sharp, TEPCO, and Toshiba), 166 general members and 32 academic members. It has strengthened partnerships with other organizations to disseminate HEMS and IoT Smart House.

In 2011, the Consortium released the ECHONET Lite Specifications (Fig. 1). which are compatible with standard protocols in Japan and overseas. After that, they launched ECHONET Lite AIF (Application Interface) specifications aiming to improve interoperability between vendors. The international standard for ECHONET Lite AIF is approved under ISO/IEC 14543-4-3 and IEC 62934 [26]. Between 2012 and 2019, 705 devices acquired the ECHONET Lite certifications. Meanwhile, 478 AIF certifications were conceded (217 for devices and 261 for controllers). The consortium estimates the number of ECHONET Lite specification compliant products exceed 48 mi units by 2017 [27]. The Government understands this plan encourages people to introduce HEMS and strengthen competitive advantages of Japanese products in the international market.

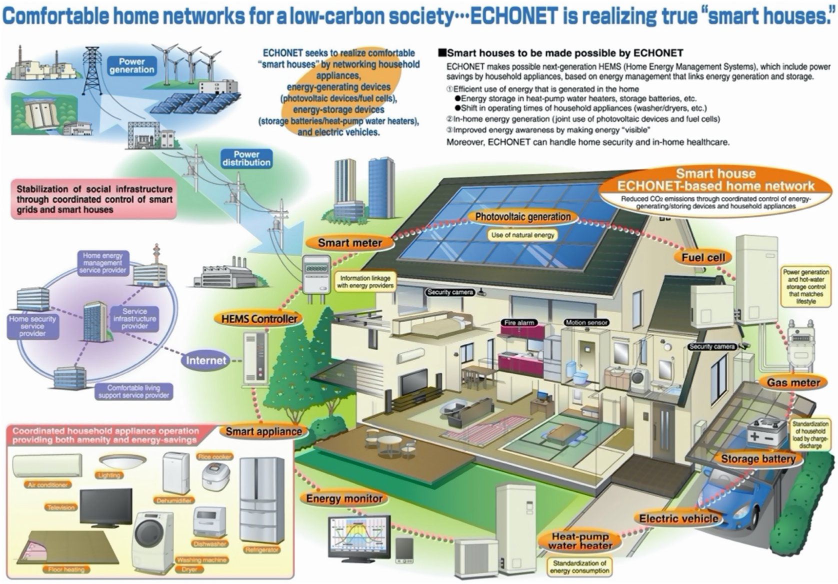

Fig. 1. ECHONET-based smart house concept (Source: ECHONET).

4.2 Joint Demonstration Experimental Project: COMMA HOUSE

The COMMA HOUSE (COMfort MAnagement House) initiated in August 2011 as a joint demonstration experimental house project between LIXIL and the Institute of Industrial Science of The University of Tokyo with several industry research partners (i.e. Toshiba Solutions Co., NEC Co., Family Net Japan Co., Tokyo Electric Power, Nomura Research Institute) and contributors [28]. It aimed to establish and demonstrate concepts and technologies for smart houses that would become popular by 2020. The intent of wisely increasing energy-saving performance incorporates HEMS to optimally control domestic machines and equipment to make it a Zero Energy Building (ZEB). The prototype was built at The University of Tokyo (Fig. 2).

Fig. 2. COMMA HOUSE prototype (photo: author).

This project works on the specificities of "Domestic IoT" in comparison with Industrial IoT with a prototyping orientation. It attempts to deploy atypical combinations of things to meet the needs of everyday life through the concept of an "Open System". Such a term alludes to the successful Japanese experience on open systems for building production. Nevertheless, here, the idea is to safely and quickly connect home appliances of diverse manufacturers flexibly responding to the various needs of users. In other words, it re-signifies the concept for the building operation phase while considering the current technology challenges and with end-user consideration.

The technical approach for ubiquitous connectivity in the COMMA HOUSE was the adoption of a Web-API method. It is different from "local integrators" since it is not an application but an interface for applications to operate things through multiple communication protocols. The IoT Special Study Group actively disseminated information about the central idea of Web-API to the IETF (Internet Engineering Task Force), which influenced de-facto standards [29]. An internet-draft entitled "Problems in and among industries for the prompt realization of IoT and safety considerations" report findings including some obtained through the COMMA HOUSE project [30].

4.3 Development by a Large Contractor: Obayashi's WellnessBOX®

Obayashi has developed the WellnessBOX®, a Smart Building Management System utilizing IoT-AI [31]. Demonstration operation started in office buildings in December 2017. The system aims to realize optimal building management while improving the wellness of workers. The strategy of providing wellness for building occupiers follows the need of work-style reforms in a society struggling with the decline of the working-age population.

WellnessBOX® uses IoT technology to transmit individual comfort information obtained through building equipment sensors and location information of building users using beacons through the internet. By using AI technology, this Building Management System provides an optimal environment for individual users and realizes energy saving due to the fine-grained building control using information stored in the cloud. Moreover, it helps to reduce the load on facilities managers since building equipment settings can are adjustable from remote locations according to the user's needs (Fig. 3).

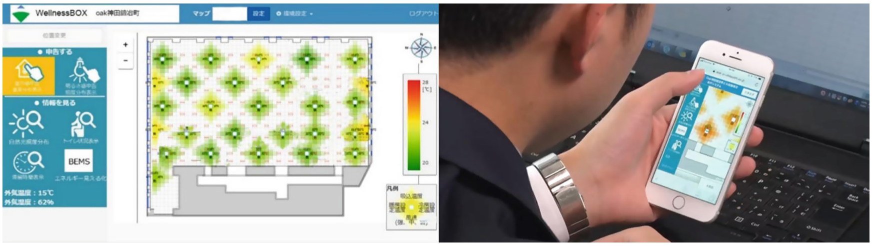

Fig. 3. WellnessBOX® operation screen of AC control (source: Obayashi).

The system has three main features. The first is a "user menu" to improve wellness in terms of comfort, health, convenience and security, evaluating and controlling the building and indoor environment. The second feature is "opening environment information of the building in use". Management information in thousands of points is obtained from standardized sensors to make possible the control of lighting and air conditioning to provide a comfortable environment for each user. And the third is the "provision of one-stop service". Although BAS directly controls building equipment but retrieves operation and control information from the cloud. Therefore, users can enjoy a variety of services through their smartphones, even use from remote locations.

Information on operation conditions obtained from the WellnessBOX® can exchange with a BIM platform also developed by Obayashi. BIMWill® utilizes the BIM model at the time of construction to improve the prediction accuracy of equipment deterioration and update timing of preventive maintenance before failures occur. Thus, by combining both systems, the organization have the potential to develop building management services utilizing a Digital Twin.

5 Research Orientation and the Future Role of BIM

5.1 BIM Preparedness to Expand Automation Functions

Despite the expectations of identifying technical solutions or hints for BIM and BAS/BEMS integration, this is still an open problem. There is evidence on the awareness of the potential of BIM for FM and Automation of Building Operations. Nonetheless, the availability of deployable solutions is still scarce. Prior research initiatives conducted mainly by electronics-related organizations dedicated to connecting physical devices to BAS/BEMS from an IoT perspective regardless of BIM.

Those researches tending to an 'electronics-orientation' focused on standardization for improving interoperability are not in a much different direction compared to the latest works carried out overseas, as in [32]. About BIM and IoT integration, Japanese R&D held by industrial players tends to be less comprehensive in scope and more function-specific compared with Western academic research such as [33, 34]. Although technical details remain concealed, Obayashi's WellnessBOX® and BIMWill® solutions seem to be unique with the merit of testing in real facilities. Nevertheless, in Japan, it could not be found any report covering BIM and BAS exchange explicitly using BACnet® and IFC as in [35].

Lately, Japanese companies and researchers have also considered BIM-IoT frameworks. Discussions often touch future scenarios with Digital Twins, exploring possibilities for automation with BIM and IoT and Robotics, encompassing Common Data Environment, Web Services, and API. However, there are some fundamental questions not yet solved. These are 'How to collect and use BIM data for building automation purposes', 'How to integrate BIM workflow with physical equipment?' and 'How to build and collect digital data in such a way it can be accessed by different stakeholders?'. These questions imply in further research within the realm of the two streams mentioned before: new technology development research and technology management for solving threats raised with emerging technologies.

5.2 The Challenge of 'Context Awareness' and BIM-Linked Robots

R&D in construction automation has gradually advanced in BIM and Robotic integration. Shimizu's Robo-Buddy Multipurpose Robot (one of the three developments of "Shmz Smart Site" system along with Robo-Carrier and Robo-Welder) detects its location using lasers by referencing BIM information to move to the designated work location and install ceiling and floors grid frames [36]. Real-time spatial data obtained from sensors is compared with other spatial data acquired from BIM models.

Moving to the operation phases, connecting position information with BIM models would expand new possibilities to improve FM systems. However, context awareness is still a tough challenge that not embedded in service robots. The accuracy of position information required will demand the further development of technologies as well as real-time communication mechanisms with these robots in indoor spaces.

Research might also explore educating robots about spatial context to make them able to safely perform certain operations within the building during the occupancy phase. In addition to networked devices fixed in building objects (including those with moving capabilities), the Next-Generation R&D pursues giving them the ability to freely move around the building, such as autonomous vehicles, to increase the breadth and convenience of services and improve operational management.

Part of these efforts has related to indoor positing technology. By improving navigation capabilities, facilities managers can think and develop a new set of service applications. NTT DATA Corporation and Narita International Airport partnered to release “NariNAVI”, an airport navigation app using high-precision indoor location information technology (BLE beacons and geomagnetic signals) to real-time navigation in indoor spaces [37].

In turn, larges-scale infrastructure projects developed within a BIM workflow may benefit from context-awareness capabilities to monitor and manage operations with a lifecycle management perspective. In Japan, BIM for Civil Engineering projects, such as road structures, is commonly named CIM (Construction Information Modelling, different to CIM as City Information Modeling as used in other countries). The CIM Implementation Guidelines (for infrastructure projects) by the MLIT suggests that CIM models are suitable for acquiring 3D terrain data obtained through Mobile mapping systems to support decision-making on road improvement and repair works and prevent the omission of inspection work in the future [38].

Context-awareness also fits the urban scale. BIM is a component of the ‘digital city’ in the cyberspace which needs to connect with things and people in the physical space. Geospatial data collected from sensors are expected to connect with GIS datasets and BIM data, expanding the scope of management possibilities. Smart communities supported with a Digital Twin will enable the automation of urban equipment operations communicating with buildings and objects; and thus, expand the impact in people’s daily life and contribute to achieving environmental goals. The interaction of automation in building scale and city-scale will require communication mechanisms that are not clear yet but are under consideration.

6 Discussion and Conclusion

This paper introduced a prospect of research in the automation of building operations by observations on Japanese R&D programs and experimental projects. The outcome was finding that automation research takes part in servitization strategies in a broad sense. Technology advancement programs come along with technology management efforts for solving threats raised with emerging technologies and focus on value creation from a lifecycle perspective. The structure and prior knowledge of Japanese companies in related areas influence the scope and orientation of R&D programs as well as the configuration of collaboration schemes.

Guidelines provided by the Government and industry associations, or joint efforts have exerted influence over the characteristics of R&D programs. On this basis, companies and research institutes have built frameworks to set an effective strategy to support future society and ensure business competitiveness. However, despite the intention of integrating BIM data with automation systems, such as BAS/BEMS and, especially, HEMS which has attracted attention after the plans encouraging ZEH, there is scarce evidence of research progress in this area from the disclosed information. The compendium of research initiatives extracted from non-academic media helped to illustrate the situation, especially for the non-Japanese speaking community.

Instead of adopting off-the-shelf automation tools, there is an apparent trend in the development of custom solutions, either held in-house or with strategic partners. After companies become more experienced with BIM in planning, design and construction phases and built more robust databases, BIM applications for BA and FM purposes are likely to become more common.

Recent achievements of mobility research in technologies to recognize the space and provide intelligence to machines have been a source of inspiration for the building sector. In the recent past, Japanese automobile production systems inspired a new model of managing the construction site in terms of both machine technology and management philosophy. Now, the breadth of AI-powered services and the technological solutions developed for communicating the cyberspace with the physical space became inputs in the creation of intelligent operating building components as well as indoor services robots for performing complex tasks.

As a tentative conclusion, current R&D efforts in Japan are under change and reflect background experience and the organizational structure for automation research in related areas. There are new drivers, such as those policies and goals related to Society 5.0, modifying the orientation of upcoming programs. Besides, key players such as real estate and facilities managers are more attentive to the potential value of automation in the operation phase of the building lifecycle. A provisional representation of the Japanese R&D orientation is drawn below and expresses the probable new wave of automation development investment (Fig. 4).

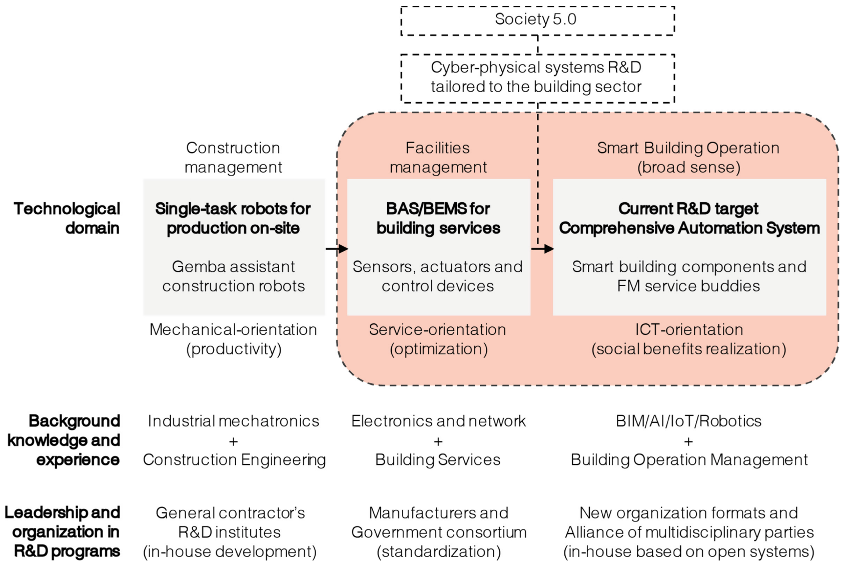

Fig. 4. Background and orientation for Japanese R&D in smart building operation.

In the first stage, mechanical-oriented construction robotics research learned from the successful Japanese Monozukuri to tackle productivity and quality issues. Construction companies began to engineer specific robots to perform construction operations and automate assembly works in the complicated conditions of the Gemba out of controlled factories. Such mechanical orientation moved to an electronics orientation as the focuses moved from improving construction management to facilities management employing automation gadgets. However, physical devices and networks systems involved in BAS/BEMS required solutions from several players to communicate with each other. Current R&D have strived automation solutions to the realization of Smart Buildings. Its ICT-orientation encompasses a set of technologies to support building lifecycle management, from smart operating components to service assistant robots.

Despite the historical and ongoing achievements of Japanese R&D programs, audacious projects at the scale of Toyota's Woven City are an exception today compared with the construction automation research storm in Japan 1980s. However, Japanese construction companies have great potential to develop breakthrough solutions based on consolidated R&D structure, investment and experience. Despite the meaningful outcomes of Kaizen culture, the magnitude of the challenges calls for a more disruptive R&D strategy attitude, such a fostering Kaikaku, to maintain Japanese research in a global leadership position. Collaboration arrangements have built to overcome such a complex challenge.

One example is the partnership between Kajima and Microsoft to offer a new platform for building management services with AI. Another indicative of change is the just-announced technical cooperation between construction giants Kajima and Takenaka for advancing construction robotics and IoT. The "Construction RX (Robotics Transformation) Project" is the first comprehensive collaboration after some joint research on specific themes [39].

Based on the observations above, future developments shall keep exploring the integration of BIM and IoT with upcoming building automation systems. An advantage of Japanese general contractors is their potential to benefit from the expertise of business units under the same corporate group and the possibility to use robust databases. However, the realization of BIM integration with automation systems for building operations is yet not widely diffused as commercial service at the moment. Further research shall re-examine the progress and effects of the current initiatives.

References

1. Bock, T., Linner, T.: Robot-Oriented Design: Design and Management Tools for the Deployment of Automation and Robotics in Construction. Cambridge University Press, New York (2015)
2. Yano Research Institute Ltd.: BEMS & BAS Market in Japan: Key Research Findings (2019). https://www.yanoresearch.com/en/press-release/show/press_id/2204. Accessed 13 Jan 2020
3. Government of Japan: Realizing Society 5.0. https://www.japan.go.jp/abenomics/_userdata/abenomics/pdf/society_5.0.pdf. Accessed 13 Jan 2020
4. National Institute for Environmental Studies: Environmental Technology Commentary on HEMS. http://tenbou.nies.go.jp/science/description/detail.php?id=17. Accessed 31 Jan 2020. (in Japanese)
5. Building Automation Association: Business Plan. http://ba-system.org/business_plan/. Accessed 31 Jan 2020. (in Japanese)

6. Japan Smart Community Alliance. https://www.smart-japan.org/english/about/index.html. Accessed 31 Jan 2020
7. Panasonic: About HEMS. https://sumai.panasonic.jp/aiseg/hems/index.html. Accessed 31 Jan 2020. (in Japanese)
8. NTT Facilities: Building Integrated Management Systems. https://www.ntt-f.co.jp/service/fm/mon_basbems/. Accessed 31 Jan 2020. (in Japanese)
9. NTT East Japan: BAS Partners Portal. https://www.bas-partners.com. Accessed 31 Jan 2020. (in Japanese)
10. Denso: Denso Develops Home Energy Management Systems. http://www.globaldenso.com/en/newsreleases/111207-01.html. Accessed 31 Jan 2020
11. Fujitsu Journal: Developing Smart Houses with HEMS Using Electricity to Suit People's Lifestyles. https://journal.jp.fujitsu.com/en/2016/02/24/01/. Accessed 31 Jan 2020
12. J-STAGE: Advanced Search. https://www.jstage.jst.go.jp/search/global/_search/-char/en. Accessed 31 Jan 2020
13. Nakahara, N.: The state-of-the-art BACS development at the ISO TC205/WG3. J. Inst. Electr. Install. Eng. Japan **33**(2), 87–91 (2013). (in Japanese)
14. Nonaka, I., Takeuchi, H.: The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation. Oxford University Press, New York (1995)
15. Kodama, F.: Technology Fusion and the New R&D. Harvard Business Review, Brighton (1992)
16. Fujimoto, T.: Introduction to Production Management II – Production Resources and Technology Management. Nihon Keizai Shimbun Inc., Tokyo (2001). (in Japanese)
17. Bock, T.: The future of construction automation: technological disruption and the upcoming ubiquity of robotics. Autom. Constr. **59**, 113–121 (2015)
18. Kudoh, R.: Implementation of an automated building construction system. In: Proceedings of the 13th International CIB World Building Congress Research and Technology, pp. 17–28. CIB, Amsterdam (1995)
19. Yoshida, T.: A short history of construction robots research & development in a Japanese company. In: Proceedings of the 23rd International Symposium on Automation and Robotics in Construction ISARC 2006, pp. 188–193. IAARC, Amsterdam (2006)
20. Kajima Corporation: Provision of building management services utilizing a new platform: Kajima Smart BM. https://www.kajima.co.jp/news/press/201912/pdf/4a1-j.pdf. Accessed 31 Jan 2020. (in Japanese)
21. LIXIL: IoT Home Link. https://www.lixil.co.jp/lineup/zehiot/iot/. Accessed 31 Jan 2020. (in Japanese)
22. Heim, S.: Ohisama HEMS. https://sekisuiheim.com/ohisama/hems/. Accessed 31 Jan 2020. (in Japanese)
23. Daiwa House: Smart Eco possibilities link D-HEMS. https://www.daiwahouse.co.jp/jutaku/smarthouse/dhems.html. Accessed 31 Jan 2020. (in Japanese)
24. TOYOTA: Toyota to Building Prototype City of the Future. https://global.toyota/en/newsroom/corporate/31171023.html. Accessed 31 Jan 2020
25. METI: Guidelines for cyber-physical security measures in building systems - First Draft. https://www.meti.go.jp/press/2018/03/20190311001/20190311001-2.pdf. Accessed 31 Jan 2020
26. METI: ECHONET Lite Application Communication Interface (AIF) Specifications. https://www.meti.go.jp/english/press/2019/0206_002.html. Accessed 31 Jan 2020
27. ECHONET Consortium. https://echonet.jp/about_en/. Accessed 31 Jan 2020
28. COMMA HOUSE: COMfort MAnagement House. http://www.commahouse.iis.u-tokyo.ac.jp/english/index.html. Accessed 31 Jan 2020

29. Yashiro, T., Baba, H.: A Book to Understand Domestic IoT: Innovation that Connects Things of Life with the Internet and its Challenges. Impress R&D Next Publishing, Tokyo (2017). (in Japanese)
30. IETE: Problems in and among industries for the prompt realization of IoT and safety considerations. https://tools.ietf.org/id/draft-baba-iot-problems-06.html. Accessed 31 Jan 2020
31. Obayashi Corporation: Applying WellnessBOX, a smart building management system utilizing IoT-AI to office buildings in Tokyo for the first time. https://www.obayashi.co.jp/news/detail/iotaiwellnessbox.html. Accessed 31 Jan 2020. (in Japanese)
32. Domingues, P., Carreira, P., Vieira, R., Kastner, W.: Building automation systems: concepts and technology review. Comput. Stand. Interf. **45**, 1–12 (2016)
33. Dave, B., Buda, A., Nurminen, A., Främling, K.: A framework for integrating BIM and IoT through open standards. Autom. Constr. **95**, 35–45 (2018)
34. Gao, X., Pishdad-Bozorgi, P.: BIM-enabled facilities operation and maintenance: a review. Adv. Eng. Inform. **39**, 227–247 (2019)
35. Tang, S., Shelden, D.R., Eastman, C.M., Pishdad-Bozorgi, P., Gao, X.: BIM assisted Building Automation System information exchange using BACnet and IFC. Autom. Constr. **110**, 1–14 (2020)
36. Shimizu Corporation: Robots under Autonomous Control at Robot Lab. https://www.shimz.co.jp/en/company/about/news-release/2018/2018006.htm. Accessed 31 Jan 2020
37. NTT DATA: Japan's First High-Precision Indoor Positioning Driven by Geomagnetic Technology Used at Narita Airport. https://www.nttdata.com/global/en/media/press-release/2018/october/japans-first-high-precision-indoor-positioning-driven. Accessed 31 Jan 2020
38. MLIT: CIM Implementation Guideline (Draft) Part 1 – Common. https://www.mlit.go.jp/tec/it/pdf/guide01.pdf. Accessed 31 Jan 2020. (in Japanese)
39. Nihon Keizai Shimbun, Kajima and Takenaka collaborate on technology development - labour shortage solved by labour saving. https://www.nikkei.com/news/print-article/?R_FLG=0&bf=0&ng=DGXMZO55028750Q0A130C2X12000. Accessed 31 Jan 2020. (in Japanese)