The application scenarios of smart construction objects (SCOs) in construction

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Abstract: The primary aim of this study is to investigate the application scenarios of smart construction objects (SCOs). SCOs are construction resources (e.g. machinery, device, and materials) that are made “smart” by augmenting them with technologies conferring autonomy, awareness, and the ability to interact with their vicinity. The research starts from a brief review of recent developments of smart technology in different industrial sectors including construction. Based on the definition and properties of SCOs, interviews and site visits are conducted to investigate how SCOs could be applied under different scenarios of the construction industry. Perspectives for future studies are proposed in order to fully realise their potentials. The research encourages a wider adoption of SCOs and smart technologies in improving current construction practices. It also provides academia with a platform for further exploring the innovative uses of SCOs in construction

Keywords: Smart construction objects, Smart technology, Information management, Application scenarios, Construction

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1 Background

The construction industry is calling for changes with the help of technology. A series of influential construction industry reports such as the Latham Report [1], the Egan Report [2], and the Tang Report [3], have been published to elucidate some of the deep-rooted problems in construction, e.g. adversarial attitudes, fragmentation, discontinuity, and labor shortage. Technical and managerial innovations have been quested for solving these problems at an industry level [4]. Therefore, new construction management technologies and concepts, particularly smart construction, relating to Sensing technologies, Augmented Reality (AR), Building Information Modelling (BIM), Internet of Things (IoT) have emerged against this background.

The construction industry shall be more intelligent through the adoption of technologies as mentioned above. The tenet underpinning this thread of research is that human beings, with their intelligence and cognitive abilities, are central decision-makers; in the construction process, determining the use of construction resources such as materials and machinery. Whilst this people-centric decision-making model makes sense in construction, it must also be acknowledged that human beings are not infallible when it comes to processing information and making informed decisions [5]. In this context, human intelligence shows deficiencies (such as being slower and more error-prone) when compared with artificial intelligence (AI) [6].

To meet the even-heightened demand of information management for future construction, smarter technologies or decision-making models that deviating from traditional people centric ones could be reasonably envisaged. Ideally, the construction resources (e.g. materials, precast components and machinery) should be made “smart” by augmented them with ubiquitous smartness including sensing, processing and communication abilities so as to enhance information management for construction. Therefore, to meet the challenge in construction industry, Smart Construction Object (SCO) is introduced as a way to embed “intelligence” into construction recourses in order to assist construction management.

The primary aim of this study is to investigate the potential application scenarios of SCOs in construction. The rest of the paper comprises of five sections. In Section 2, the developments of smart objects in different industrial sectors including construction are reviewed. Definition and properties of SCOs are presented in Section 3. Based on data collected from site visits and interviews conducted for construction personnel on site, four typical scenario cases that illustrate the potential applications of SCOs are demonstrated with their respective property diagrams in Section 4. SCOs under some of the proposed scenarios have been under development and testing. Therefore, next in Section 5, current development of SCOs and future studies are briefly introduced for fully realizing the potentials. Finally, conclusions are drawn.

2 Literature review

2.1 Smart objects

The trend to implant smartness to everyday objects is originated from the concept of “ubiquitous computing”, which was first put forward in the Computer Science Laboratory (CSL) of the Xerox Palo Alto Research Center (PARC) in early 1988. The idea of ubiquitous computing is to shift the paradigm of “one person-one desktop computer” to a new form where computers are spread ubiquitously and invisibly into the everyday objects of our lives [7]. Ubiquitous computing operates as a rationale for the trend of transplanting “smartness” into everyday artifacts, which can be defined as “a non-computational physical entity with established purpose, appearance and use in everyday experience" [8]. Smart objects emerge with the purpose to provide added-values of information processing and exchanging to everyday object while its original appearance and functions will not be restricted or compromised [8]. Instead of the invention of new artifacts with computational intelligence, everyday artifacts could be augmented with the ability of computer to gather, process and exchange digital information. The concept of "smart objects" is developing along with their unique properties as shown in table 1.

Table 1.The properties of smart objects (SOs)

Properties of smart objects (SOs)	
Contact-awareness	The ability to perceive surrounding environment [8][9], and to provide condition information [9][10][11]
Interactivity	The ability of ad hoc information sharing [8][10] and communication with people/other smart objects [9][11][12]
Autonomy	The ability to conduct self-directed actions [9]
Traceability	The ability to discover where they are [11] and provide unique identification [10]
Record-keeping	The ability to describe what happens to them in the past [11]
Representativeness	Possessing programming model and functions inside smart objects [12]

A consensual typology of SOs is yet to be agreed but efforts have been paid to developing it in various industries. To improve living quality of human beings, smart wall is designed to convey information and atmosphere when perceiving different people passing by [13]. To help occupants escape from fire, a smart fire response guide (FireGuide) is developed to alert occupants as well as to advise the fastest safe escape route [14]. In transportation industry, a driver assistance systems (DAS) was designed to assist inexperienced drivers and to indicate dangerous situation ahead with the help of intelligent vehicles and smart road infrastructure [15]. In medical industry, the coat of doctor is made smart with a wearable user interface that could be controlled by gestures [16]. The smart coat could provide updated information of patient by interacting with RFID tags on patients and smart bedside display [16].

2.2 Smart objects in construction

Although the development of smart objects have been continuously progressing in other industries, the concept and technology of smart object can hardly be indiscriminately imitated from other industries to the construction industry. Most construction works are project-based with varying workflows. Unlike production-based industries, there is neither standard procedure nor prototype for mass production for the construction industry. At the meantime, the construction work is communication-intensive. Under the contracting and layers of sub-contracting system, manifold parties need to cooperate and exchange updated information. Thus it is assumed that there is no routine assembly line in construction. In addition, construction work is large in scale and non-reversible, for which flexible and interoperable solutions are commonly in need. Therefore, smart objects that are tailor-made for construction are needed to cater for the specialty of the construction industry.

In the construction industry, while not directly using the term "smart object", there are a few studies proposing some devices augmented with smartness to facilitate construction work. To facilitate construction work in different stages and for different purposes, these studies have addressed one or more properties that smart objects possess, including the autonomy to act, the awareness to capture real-time information and the ability to communicate.

For supply chain management, the focus is to utilize the sensor network and auto-ID tags such as RFID tag to provide real-time information. The significance of real-time information in construction supply chain management have been proposed and tested through simulations [17]. The just-in-time delivery enabled by RFID and sensors network in the case study of Shin et al. [18] proves to enhance the time efficiency by 32% compared to the traditional method. Cho et al. [19] develops a vertical material delivery framework for a liftcar, also relying on the RFID and sensor network.

For on-site construction, the SO-related research mainly covers studies on automation and context-awareness. Contour Crafting (CC) is an example for autonomously fabricating various kinds of superstructures of building [20]. Another way to autonomously construct the superstructure of buildings is to use robots, which are controlled by computers [21] or other kinds of stimulus on site [22]. On the other hand, context-aware information and real-time data that are captured on-site are used to facilitate on-site management, such as providing context-specific information to workers [23], locating construction components on-site [24] and updating simulation models [25].

In construction facility management and safety management, there have been prototypes of smart objects where equipment or plants are augmented with additional functions. For example, it has been suggested that rented plants be equipped with a pay-per-use unit to calculate rental cost based on actual use [26]. For worker health and safety, methods of detecting the vibration of construction tools have been developed [9]. With context-awareness, a collision-prevention method is also proposed to assist crane operators to avoid collision in operation [27].

Despite these research efforts, SCOs and their definition, properties, applications, representations, and prospects have never been systematically explored. Single or scattered smart objects that have been proposed are not enough to exert the full potential of smart objects. It is necessary to steer toward a panoramic and interconnected smartness in construction industry. To do so requires examination of the inheritable properties of SOs from other industries and incorporation of properties addressing the heterogeneity of construction under the construction application scenarios.

3 Smart construction objects (SCOs)

A Smart Construction Object (SCO) is a step towards the ubiquitous computing and ubiquitous smartness in construction contexts. SCOs are construction resources (e.g. materials/precast components and machinery) that are made “smart” by augmented them with sensing, processing and communication abilities so as to enable better decision-making in construction [28]. In earlier study of Niu et al [28], there are three core properties for a SCO to function, which are awareness, communicativeness and autonomy. As demonstrated in Figure 1, each of the properties can be developed to different levels. Each type of the awareness, communicativeness and autonomy are summarized in Table 2.

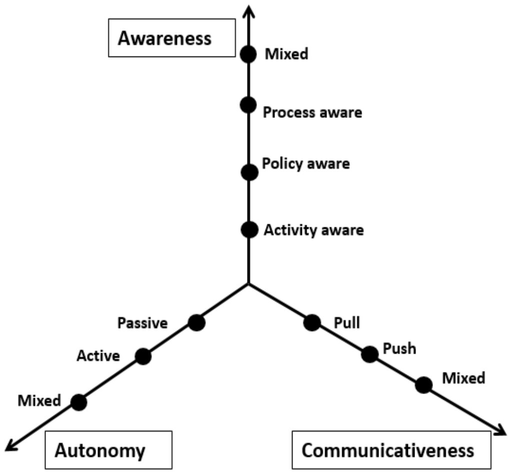

Figure 1. SCO property diagram outlining the three core properties of SCOs

Table 2.Properties of SCOs

Awareness	**The ability of SCOs to sense and log the real-time condition of SCOs and the surrounding environment**
Activity-aware	To understand and make record when certain type of activity or event is triggered
Policy-aware	To understand to what extent the real-time condition or activity comply with rules and regulations
Process-aware	To understand and recognize the workflow and transition between construction activities
Mixed	To have more than one type of above awareness
Communicativeness	**The ability of a SCO to share information with managerial personnel or other SCOs**
Pull	To provide information on requests
Push	To proactively send updated information or make alert in a regular interval
Mixed	To have both pull and push communicativeness
Autonomy	**The ability of SCOs to alert people for actions or to take autonomous actions**
Passive	To make alerts to people and to assist people in making decision and taking actions
Active	To take self-directed actions proactively based on change of conditions
Mixed	To have both passive and active autonomy

4 Application Scenarios of SCOs

Utilizing the properties of a SCO, the smartness that the SCO contains could optimize working procedures and performance in the construction industry under various circumstances. In this study, pilot interviews are conducted to collect information on current needs and problems faced by the construction industry. Based on data collected from interviews, the potential applications of SCOs are proposed in four scenarios, using the SCO property diagram. The proposed application scenarios are then calibrated by site visits and further discussions with construction personnel, which are introduced with the SCO diagrams as follows.

4.1 Component tracking

Tracking and checking construction materials/components is extremely important in construction. The procedure could be enhanced by embedding smartness into transported materials, transporting vehicles, and checking points to different extents, respectively. The material supply chain of the construction industry is complex but vitally important to on-site work management and cost control. Multiple parties including the suppliers, material distributors, project managers and workers on-site are involved in the transporting process, where the materials might be stored in several transfer depots temporarily. High cost and serious delay may incur when either there is a delay by shortage of materials or on-site warehouse runs out of space by overly stockpiled inventory. Therefore, in time logistic information is of key importance to inventory management and site management.

One option is to augment each component or each piece of material to be SCOs with awareness so that they can sense and push the information of their real-time location all the way. However, considering the massive quantity of construction materials, another more cost-efficient way is also proposed. Materials or prefabricated components could be tagged individually or in batch with smart tags (e.g. RFID) with unique ID and production information. Then, smartness is embedded to the vehicles and possibly the transfer depots. Smart construction vehicles could read and log the information at each time of loading and unloading by activity awareness. Besides, when entering and leaving a transfer depot, the tracking record is updated by active autonomy. Meanwhile, as each transportation record is logged in to the memory unit of a SCO. The track-record could be pulled anytime so as to facilitate the regular inventory checking at any time required. Compared to the amount counted by human each time, the SCO log would provide more objective proof to reduce potential disputes by discrepancies. Unlike traditional practices, SCOs have awareness and autonomy, and can interact with the vicinity

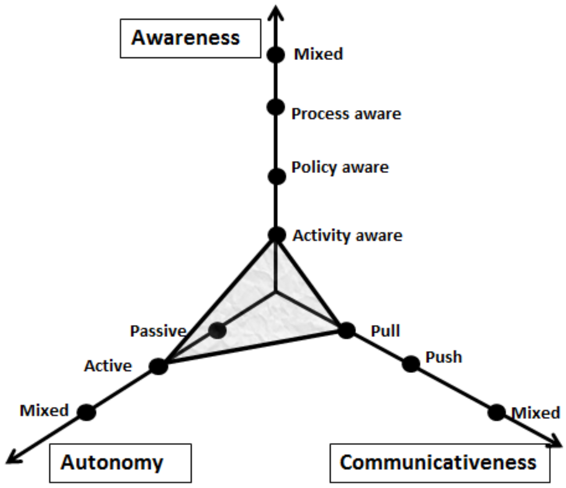

Figure 2.SCO property diagram for component tracking scenario

(2) Safety management

Condition monitoring using SCO may contribute to the safety control on construction site. For example, on construction sites there are environment factors that may harm the health of workers, such as Particulate Matter (PM), noise, vibration etc. Some of the factors are non-perceptible for human beings. Threshold below the maximum human bearing limits can be input into smart tools, helmet or other wearable devices. With policy awareness, these SCOs could sense the condition and changes in environment. Below the threshold, SCO just push the real-time condition to user interface for normal monitoring. Once the threshold is broke, SCO automatically make alert people for further action.

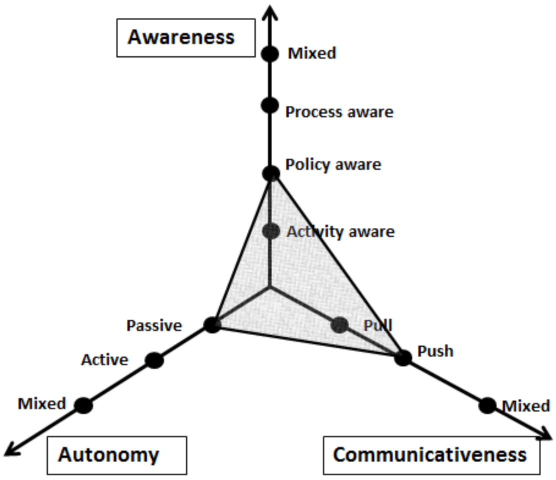

Figure 3.SCO property diagram for safety management scenario

(3) Procedure guiding

The process awareness is extremely useful to guide delicate workflow on site, such as on-site assembly of prefabricated components and cooperation between machines. The workflow consists of activities that are linked by transition point [12]. At every transition point, SCO may choose and redirect the workflow based on information from sensors or human input.

Taking the on-site installation of prefabricated components as an example, smart prefabricated component may guide tower crane in the assembly process to locate the precise assembly location and to avoid possible clashes, by sending the information of real-time position to the tower crane on requests. After the smart prefabricated components getting the destination location, the feedback will trigger the smart tower crane entering into the next procedure, i.e., searching for next target component to be installed. The communications between the smart prefabricated components and the smart tower crane relies on them pulling information from each other. By active autonomy, the smart tower crane would automatically find the optimum route and hoist the components from initial storage area to designated installation area. When the component arrives destination successfully, an alert will be sent back to the control center using passive autonomy.

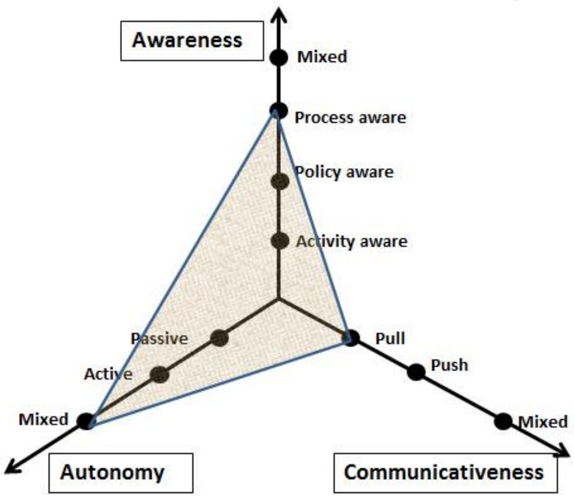

Figure 4.SCO property diagram for procedure guiding scenario

(4) Facility management

Condition monitoring using SCO may also contribute to the facility management. Tools and plants augmented with activity awareness could record the actual operating duration and frequency. By recording the actual using rate of tools and plants, it could assist the estimation of the service life of device. For some plants that may impose danger when getting scrapped, such as tower crane, an alert will be triggered when the usage reaches certain times. So the operator may examine, repair or change a new device before any hazard occurs. Meanwhile, estimation of the service life of device could also assist the cost control. A pay-per-use unit proposed by Fitton et al. [26] is to augment tools or plants with activity awareness to record the usage. Pulling out actual usage then could be adopted as a new way to calculate rental cost [26].

Building maintenance serve as a crucial part for the life-cycle facility management. By integrating smartness to some building components that are unapproachable by human after construction, it may provide information that can hardly be obtained before. For example, once the construction work is completed, the condition of piles and foundations can be hardly monitored by human. Under this condition, policy awareness to sense real-time locations could be embedded into piles and foundations that are driven below the ground where the foundation base is poor or subject to frequent earthquakes. When the shifting or settlement effect reaches threshold, timely alert will be made to offer sufficient time for maintenance or evacuation. For monitoring purpose, the SCOs under the building maintenance scenario may possess a mixed type of communicativeness. On normal working condition, the SCOs push the real-time status of building in a regular interval. When property manager would like to look into the status record at particular time spot, the track-record can also be pulled out.

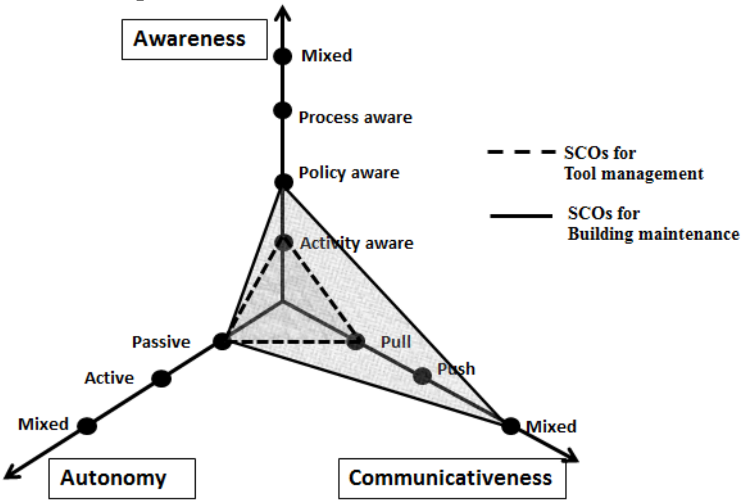

Figure 5.SCO property diagram for facility management scenario

5 Discussion

The four typical scenarios discussed above provide a picture of potential applications of SCOs and their smart properties. Among these scenarios, the prototype of SCOs for component tracking and installation procedure guiding are currently under a pilot development and testing. Testing and application feedbacks will be presented and discussed in future studies. Nevertheless, the application scenarios are by no means exhaustive. There are numerous construction scenarios, on-site or off-site, requiring the augmented capabilities of sensing, processing, computing, networking, and reacting to alleviate human beings' incapability in decision-making. With probable increasing needs, the application of SCOs might be further explored for additional level of details. It is also envisaged that SCOs that with dynamic combinations of properties would be tailor-made to cater for different working conditions.

6 Conclusions

Smart Construction Object is proposed to be the evolved generation of traditional construction object and the basic element t in future construction. Augmented with the properties of awareness, communicativeness, and autonomy, SCOs are capable of sensing, communicating, and automatically taking actions in addition to performing its original function. This paper envisages the promise for SCOs to be implemented in the construction industry. The application scenarios investigated in this study assist researchers to understand the essence of SCO, and help the application designers to select context to implement the smartness and use of SCO. In the effort to substantiate the claim, we are working on the technical aspects of the three core properties of SCOs with deeper understandings in the context of construction industry. A scenario-based pilot study of SCO is under development. The working cases with SCO application details are envisaged to be presented in future studies.

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