Smart Construction Objects (SCOs):

An alternative way to smart construction

By Dr Wilson Lu, The University of Hong Kong

The slow development of AI in construction

Recent years have witnessed a resurgence of interest in artificial intelligent (AI) and robotics, normally putting under the common nomenclature of “smart construction”. According to Kurzweil et al. (1990),AI is “the art of creating machines that perform functions that require intelligence when performed by people”, while robotics can be perceived as a branch of AI development. As an academic discipline, AI began in the 1950s and has experienced a winding development. Compared to the omnipotent image of AI seen in science fiction, e.g. the Terminator, or the lovely Wall. E, some stunning breakthroughs more relevant to our daily life have been newly achieved. For example, in a 2011 game of Jeopardy, IBM’s Watson supercomputer as AI defeated the game’s two highest ever grossing champions. While in 2017, the AI program AlphaGo defeated the world’s grandmasters of the ancient Chinese game, Go. Many industries from Wall Street trading to manufacturing are examining the threats and opportunities brought by AI and robotics.

Construction is no exception. Unlike the stereotype that construction is slow in embracing new technologies, the sector is strenuously exploring AI and robotics, with a view to making construction a safer, greener, and a more productive workplace. Robotic systems have been developed for assisting special on-site construction tasks such as automatic laying of tiles (Westkamper et al. 2000), automatic fabrication of building structures on site (Khoshnevis 2004), and helping workers to handle heavy materials (Lee et al., 2006). Local contractors are reported to be developing robots for curtain wall installation or other oneroustasks. Nevertheless, despite the continuously growing interests in robotics and smart construction, few applicationscan actually reachthe implementation stage, let alone put into daily operationin construction. There is widespread frustration in the industry in respect of AI and robotics applications in construction.

The explanations are manifold. First, construction components are particularly heavy, not lending themselves to be easily handled by any robots. They are not like “sowing shoes or clothes”. An extreme example is the immersed tube tunnel elements in the recently completed Hong Kong-Zhuhai-Macau bridge. A single element is as heavy as 6000 tons. To lift and install it is a world-class challenge in its own right, no matter what robots one imagines. Another reason lies in the heterogeneous and fragmented nature of construction. When robotic arms and automation systems are applied to the manufacturing industry, where identical products are made in a fixed production line, they can function effectively and efficiently by following standard and repeating workflows. In contrast, every construction project is unique and faces incessantvariations each day. An applicable robot on a construction site must cope with the complexity of adynamically changing construction process, making it impossible to directly transplant the mature manufacturing robotic systems into construction. Thirdly, too often, existing smart construction solutions emphasize the adaption of the existing working environment or procedures to accommodate new technologies rather than the other way around. For example, research and investment is being put into the development of mobile platforms, manipulators, and advanced control systems on construction sites in order to cater forthe operation of robots (Zied 2007). Likewise, robot oriented design (ROD) has been proposed as a strategy for reengineering conventional construction processesand redesigning construction details in a way that facilitates the implementation of construction robots (Bock 2007). However, the radical changes caused by these fundamental process redesigns can be intrusive and sometimes interruptive to workers accustomed to traditional construction workflows, thus attenuating their inclination to accept the new technologies (Liu et al. 2018).

At the University of Hong Kong, a research team specialized in smart construction are developingan interesting and clever approach called “smart construction objects (SCOs)”. Instead of continuously inventing and bringing in new artifacts for construction personnel to learn, SCO aims to find an alternative way of achieving smart construction by making existing construction resources and objects smarter. Similar to many existing technologies, SCO makes full use of existing smart technologies, such as Building Information Modeling (BIM), Internet of Things (IoTs), robotics, sensing, computing, automation, big data analytics, and machine learning in the constructioncontext. What is particularly unique is it advancesless disruptive ways of introducing these technologies into the existing construction practice in order to minimize changes to established work routines. The team encapsulates the concept under the title of “i-Core” and won a prestigious Construction Industry Council (CIC) Innovation Award 2015.

Smart construction object (SCO) and i-Core

SCOs are defined as construction resources that are made “smart” by augmenting them with smart properties. Here the construction resources could be machinery, tools, device, materials, components, and even temporary or permanent structures. The core smart properties of SCOs are awareness, communicativeness, and autonomy. Awareness denotes the ability of SCOs to sense and log their real-time condition and that of the surrounding vicinity. Communicativeness denotes the ability to output information, e.g. via ad-hoc networking obtained through its awareness. Autonomy refers to the ability to take self-directed action or alert people of necessaryfurther action based on preset rules. Whilst these SCOs demonstrateintelligence similar to that found in some existing robotic systems, what makes them different is SCOs’capacityto maintain the traditional functions and appearance of the construction recourses they rely on. For example, a smart excavator may be able to locate and report

Awardees (first row) with judges and the then Chief Executive of Hong Kong, Leung Chun-ying in the Government House (second row)

its real-time position without demanding extra room while still performing the excavation job.

It is particularly challenging to customize "smartness" into real-life construction practices that are often procedure-specific, project-specific, and company-specific. Therefore, the research team developed the i-Core prototype to innovatively encapsulate the smartness. i-Core denotes a standalone, programmable, and extendable integrated chip that can be implanted to construction machinery, devices, and materials. Similar to a central processing unit (CPU) of a computer, i-Core turns dead-weight construction components and plants into SCOs and makes smart construction possible. Various modules can be integrated into i-Core in order to meet the changing needs on construction sites and achieve different functions. These modules are extensible, which can be customized case by case.

Case scenarios

With strong support from the Hong Kong Housing Authority, Gammon Construction and their suppliers, the research team has explored and tested SCOs with the underlying i-Core prototype. i-Cores are embedded or attached to a few chosen construction components and machines to make them into SCOs, facilitatingthe process in logistics and supply chain management (LSCM), occupational health and safety (OHS) management, productivity management, etc.

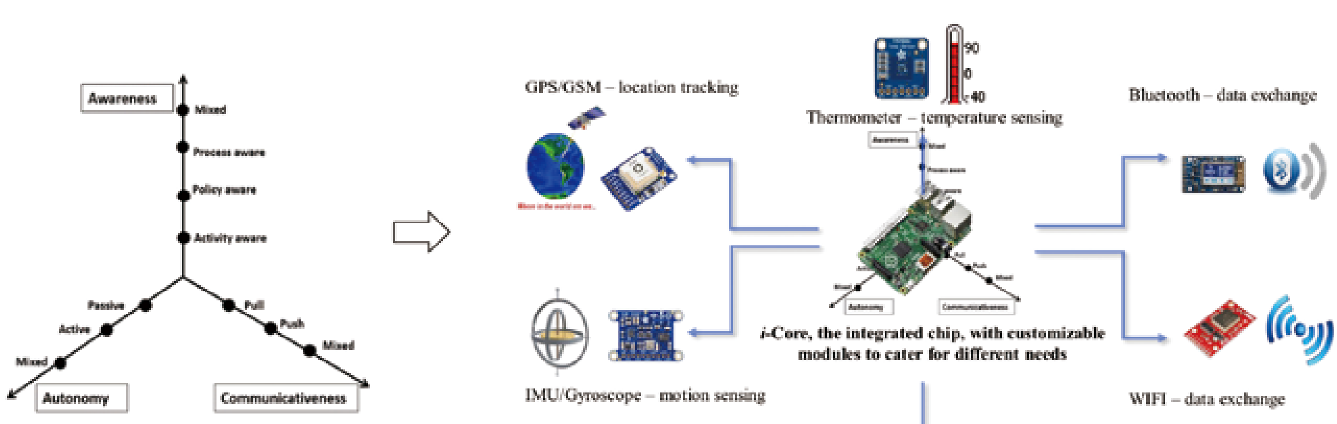
Smart prefabricated components

By making prefabricated components into SCOs, the research team developed an SCO-enabled management platform to facilitate logistics and supply chain management in prefabrication housing production. An i-Core prototype has been developed with the ability to sense its real-time location and synchronize the location data to the web-based user interface (Figure 3). A Global Positioning System (GPS) tracker and a GSM (Global System for Mobile Communication) module with respective antennas have been integrated into i-Core to enable the real-time sensing and communicating abilities. Each i-Core is incorporated into a black box design, which can be embedded in the surface recess of a prefabricated component when loaded for shipping. Thus, damage can be avoided during loading and unloading, while the black box can be demounted for reuse. The hole left after removal of the black box can be filled with concrete when the component is assembled.

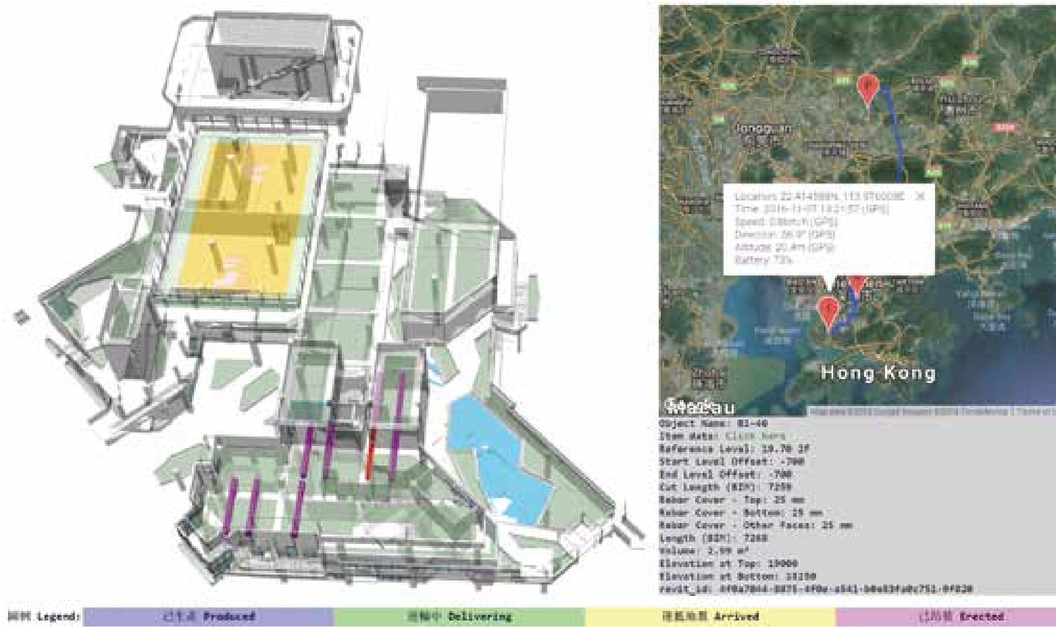
When a prefabricated component is embedded with i-Core, it becomes a SCO. Each SCO is assigned a unique identification code associated with the basic design parameters. When linked to Google Maps, the real-time position of each SCOcanbe simultaneously plotted on the interactive map. The BIM has also been incorporated in the online user interface. The delivery status of each SCO can be indicated in the BIM. Different colors indicate different status of SCOs, such as 'in production,' 'delivering,' 'arrived,' etc. When SCOs enter into the predefined areas, the component color in the BIM will be automatically changed without manual input.

Smart tower cranes

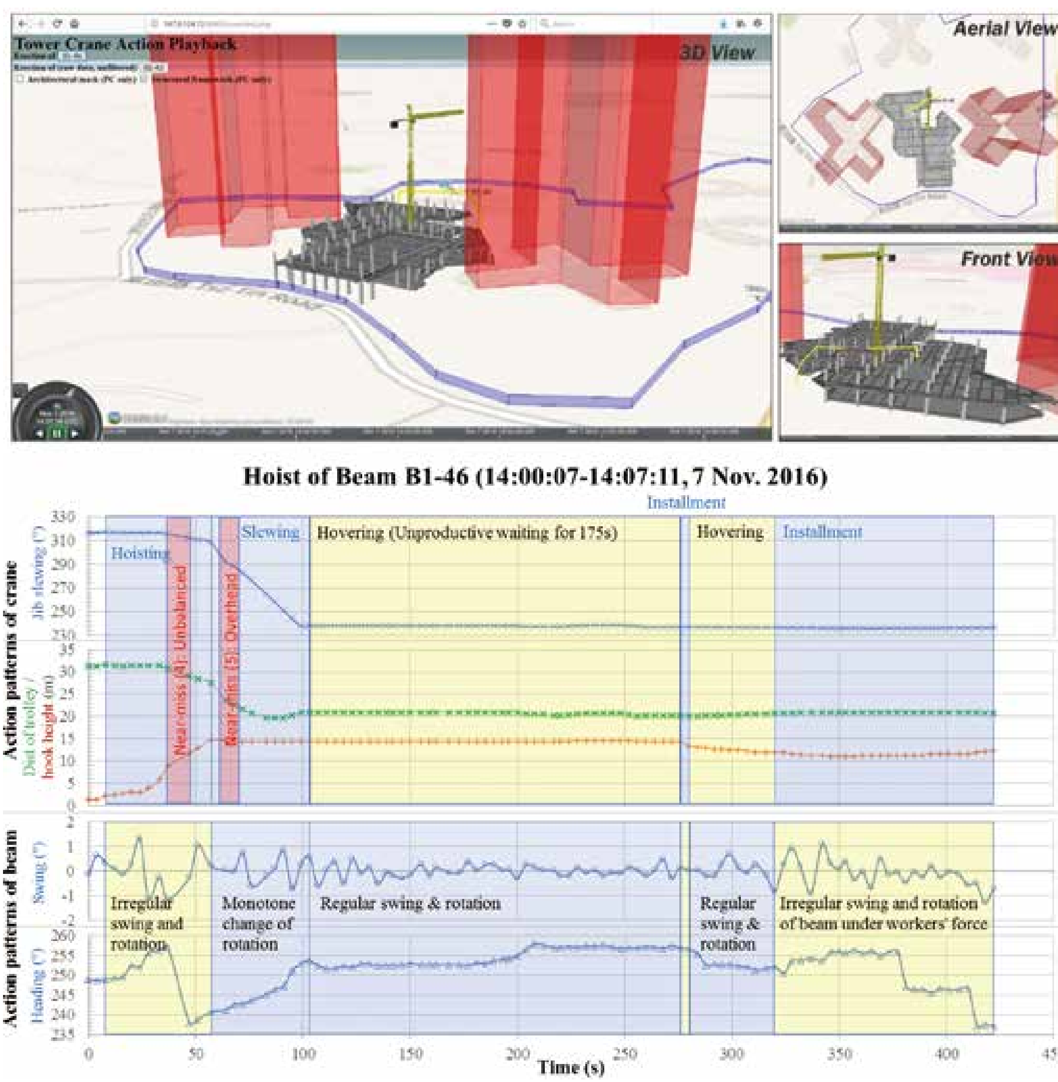
Making tower cranes into SCOs could enable the real-time monitoring and control of crane operations, while the data captured by the smart tower crane could further facilitate data analysis in OHS management and productivity management. To make a tower crane into a SCO, the research team developed a series of i-Cores, each consisting of a microcontroller, an inertial measurement unit (IMU), a GPS module, a barometer, a tensometer, an anemometer, and a GSM module. These i-Cores were mounted to the key components of an on-site tower crane, including the jib, the trolley, and the



From SCOs to i-Core, an integrated chip of smart properties



The user interface with BIM and an interactive map



The user interface with BIM and data visualization modules

hook, while collecting real-time operation data, such as the height of the hook, the loading of the hook, the slewing angle of the jib, and the travelling distance of the trolley, etc.

A user interface was developed to visualize the operations and the conditions of the smart tower crane in a real-time manner. The background is a "cyber" construction site reproduced from the real site with the BIM of a building under construction and a 3D tower crane model. Based on the live data sent back from the i-Cores, the 3D tower crane model will reproduce the motions of the tower crane simultaneously with two extra views, the aerial and front, for easier perception. In parallel with the "cyber" tower crane operation is the visualisation of data transmitted back from the i-Cores. Figure 4 illustrates the visualized dataset for the field test. With the aid of pattern recognition algorithms, near-miss events, unproductive operations, or other hidden operation patterns can be identified from the dataset, serving as a solid reference for OHS management and productivity management.

Theoretical contribution, challenges and prospects

While indeed the research team is accepting collaborations from the industry to further develop SCO-based solutions, the purpose of this article is to highlight SCO as an alternative model of smart construction that both practitioners and researchers might not be consciously aware of. Unlike the advocacy of 'full' AI, SCO keeps humans in the knowledge loop and active in the process, although some routine or clearly rule-based decisions can be made by SCOs autonomously. It is thus more realistic than 'full' AI. Unlike the advocacy of 'disruptive technology,' SCOaims not to alter the existing functionalities of construction objects, but to make them more intelligent via the awareness, communicativeness, and autonomy capabilities captured within i-Core. In this way, smart construction can be achieved with minimal interference inexisting construction processes and such solutions can be more easily accepted by frontline construction personnel. It aligns with the argument that a successful smart construction system is one that causes the least interruption to accepted processes (Niu et al. 2016).Unlike the advocacyof developing a complex, powerful, and centralized AI system, SCO-enabled smart construction is decentralized to the specific construction tasks so it, similar to the IoTs, can increase the responsiveness to the challenge of the construction tasks. In so doing it can also deal with the aforementioned heterogeneity and fragmentation of construction by extending or customizing its smart properties.

SCOs, with their core smart properties, present a new vision for future smart construction.Given the fact that SCOs are in the early days of their development, there are technical hurdles, e.g. on-site locating for awareness, ad-hoc networking for communicativeness, machine learning algorithm for autonomy, and interoperability and robustness of the technologies, making SCOs yet to be widely applicable in current construction practices. In addition to the hurdles, there are other non-technical challenges, in particular, the acceptance of AI, organization readiness, cultural changes, and the new cost to be overcome. Nevertheless, by overcoming these challenges, it is envisaged that SCOs will gradually supersede traditional construction objects to become the basic elements of construction in the future, thus enabling a safer, greener, more efficient, and effective construction industry thanhas been seen before.

About the author

Dr Wilson Lu is based in the Department of Real Estate and Construction, Faculty of Architecture at the University of Hong Kong. His research interests include BIM, smart construction, big data in construction waste management, and international construction. Email: wilsonlu@hku.hk, Tel: (852) 2859 7981.

References

- Khoshnevis, B (2004). Automated construction by contour crafting- related robotics and information technologies. Automation in construction, 13(1), 5-19
- Kurzweil, R (2010). The Singularity is Near. Gerald Duckworth & Co
- Kurzweil, R, Richter, R, Kurzweil, R, and Schneider, M L (1990). The Age of Intelligent Machines (Vol. 579) Cambridge: MIT press.
- Lee, KY, Lee, SY, Choi, JH Lee, SH, and Han, CS (2006). The application of the human-robot cooperative system for construction robot manipulating and installing heavy materials. SICE-ICASE International Joint Conference, Busan, Korea
- Liu, D, Lu, W, and Niu, Y (2018). Extended Technology-Acceptance Model to make smart construction systems successful. Journal of Construction Engineering and Management, 144(6): 04018035
- Niu, Y, Lu, W, Liu, D, Chen, K, Anumba, C, and Huang, G G (2016). An SCO-enabled logistics and supply chain - management system in construction. Journal of Construction Engineering and Management, 143(3), 04016103
- Niu, Y, Lu, W, Chen, K, Huang, G G, and Anumba, C (2015). Smart construction objects. Journal of Computing in Civil Engineering, 04015070
- Westkamper, E Schraft, DD, and Laier, P (2000). Robot System for Automated Tiling on Prefabricated Construction Elements.31st Symposium on Robotics (ISR 2000)
- Woudhuysen, J and Abley, I (2004). Why Is Construction so Backward?. Wiley Academy
- Zied, K (2007). An Augmented Framework for Practical Development of Construction Robots. International Journal of Advanced Robotic Systems, 4(4), 477-500