Dialogues on Architecture

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Abstract

Dialogues on Architecture is a series of dialogues between researchers and practitioners, who are embracing the intellectual model of high technology and are involved in its advancement and application in architecture. Dialogue #4 focuses on the technology transfer between on- and off-Earth research and its impact on society, and in particular on industry and education. The dialogue takes place between Henriette Bier (HB), Paul Chan (PC), Advenit Makaya (AM), and Angelo Cervone (AC).

Keywords

Architecture, Construction, Robotics, In-Situ Resource Utilisation, Human-Computer and Human-Robot Interaction, Industry 4.0

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Dialogue #4

Technology Transfer between on- and off-Earth Research and its Impact on Industry and Education

HB: Even though buildings have been gradually incorporating some level of robotic aspects since the '70s (inter alia Eastman, 1972; Negroponte, 1975), building processes have been slow in adopting new technologies, which has a major impact on productivity and safety. Compared with other industries, building construction productivity has lagged behind and remained one of the most dangerous activities in the EU, involving more fatalities than any other sector[1].

One way of accelerating new technologies' adoption in building construction could be through technology transfer from off-Earth applications, which return benefits back to Earth applications in areas such as materials, advanced robotics, engineering, etc. Various projects such as the Foster and Partners' Lunar habitat, built using an autonomous swarm of robots,[2] or AI Space Factory's MARSHA habitat that used a biopolymer basalt composite material for 3D printing,[3] etc. are examples in which the potential of technology transfer is highlighted.

PC: The architecture, engineering, and construction (AEC) sector is known for its conservative outlook on innovation. As a mature sector with a long-established structure of professional roles and disciplines, ways of producing, constrained by a tight regulatory regime, are well entrenched. Not all of these constraints are necessarily bad. Clear roles and responsibilities coupled with a strong regulatory framework can safeguard against problems of health and safety, and stop buildings from collapsing. Thus, the fact that there are institutionalised ways of working should not be disregarded simply as resistance to technological change. There is a need to examine why current business models persist in the AEC sector.

The ongoing Covid-19 crisis has shown the potential of digital transformation in what is traditionally a sector characterised (to a greater or lesser extent) by on-site production. Hours of virtual meetings have replaced handshakes in the boardrooms with some suggesting that virtual engagements can create more equity and egalitarianism. Advanced robotics and drone technologies coupled with increasing sensing capabilities can help create a more resilient AEC sector by reducing reliance on conventional craft skills. Big Data analytics can unlock the puzzle to produce more liveable built environments in future cities. It seems that technological imagination never fails to amaze.

The Fourth Industrial Revolution (or Industry 4.0) is poised to transform the AEC sector. Through a constellation of technologies – ranging from robotics to advanced sensing, machine learning for Big Data analytics, augmented and virtual reality, and digital twins – Industry 4.0 promises greater efficiency in designing, constructing, and managing the built environment. In a recent McKinsey report, The Next Normal in Construction, the technological wonder of Industry 4.0, is laid out in their manifesto to turn the AEC sector into a truly global sector, offering customisable and on-demand solutions in a mass-production world.

1 Eurostat document: https://ec.europa.eu/eurostat/statistics-explained/index.php/Accidents_at_work_-_statistics_by_economic_activity

2 Link to Lunar habitat: https://www.fosterandpartners.com/projects/lunar-habitation/

3 Link to Marsha: https://www.aispacefactory.com/marsha

HB: No doubt that robotics can help the construction sector to not only increase productivity, sustainability, and thus profitability, but also deliver superior products and services at affordable prices. According to McKinsey[4] (2017), almost half the activities in the global economy have the potential to be automated but less than 5 percent of all occupations can be automated entirely. People will, thus, continue working alongside machines.

In terms of the process, the tasks that can be automated need to be first identified, then physical automation of those tasks and processes has to be implemented similarly to the way the car industry has automated its tasks and processes. Then data-driven automation relying on CPS,[5] involving not only Human-Computer but also Human-Robot Interaction (C/HRI), predictive analytics, and Machine Learning (ML), will follow. The human remains in the loop as there are tasks such as human-level pattern recognition as well as tasks requiring subjective assessment or high-level strategic planning. Once processes and activities that have high automation potential are identified, whole process sequences could be redefined. The labour skill shift will be a societal challenge and architects, construction engineers, and workers will need to develop skills suited for the automation age. New activities and jobs will be created for which retraining and skill-raising programmes will be important to support workers shifting to new roles.

Considering the expected labour skill shift, the question is also how academic education responds to the challenges of robotization and the subsequent requirement that architects, construction engineers, and workers develop new skills. Contrary to the preconception that robotization is not architecture related in its essence, the challenge is to understand the same way the modernist architects understood that the industrial revolution 2.0 and new materials fundamentally change architecture, that industrial revolution 3.0 and 4.0 with their robotic, AI, and IoT applications have a major impact on architecture, transforming not only its design and production but also its operation towards becoming a cyber-physically enhanced (production and operation) system.

In this context, accelerating the adoption of new technologies in building construction through technology transfer from off-Earth applications, which return benefits back to Earth applications in areas such as materials, advanced robotics, engineering, etc., needs further definition.

AM: Obviously, off-Earth infrastructure construction needs to respond to the limited manpower available for the construction operations, as well to the difficulty of verifying the items built on site. This requires making full use of existing and upcoming capabilities in the design and modelling of constructed parts, process modelling, process automation, in-process monitoring, as well as automation and robotic manufacturing. The collection and use of a substantial amount of data is also particularly relevant, to build models of the constructed elements, for monitoring of their behaviour and predictive maintenance. Those are key aspects of the ongoing development of Industry 4.0 and the associated technological capabilities. Off-Earth construction can therefore be an end user and a catalyst of such technological developments. Off-Earth construction can also, to some extent, be considered as the application of construction techniques which are routinely applied on Earth, to a different, more challenging environment. The wealth of experience and know-how from terrestrial industry can therefore be highly beneficial, if appropriate bridges can be

4 Mckinsey's report: https://www.mckinsey.com/~/media/mckinsey/featured%20insights/digital%20disruption/harnessing%20automation%20for%20a%20future%20that%20works/a-future-that-works-executive-summary-mgi-january-2017.ashx

5 CPS embed computer networks that monitor and control physical processes, with feedback loops between physical and computational processes.

established between space engineering and relevant terrestrial sectors such as architecture, construction, mining, and sustainable energy.

AC: On-Earth research is indeed fundamental to correctly prepare and plan the establishment of off-Earth habitats. Most currently envisaged programmes for the human exploration (or, in the longer term, even colonization) of extra-terrestrial celestial bodies need to be widely prepared by means of targeted activities on Earth, with two main objectives: the training of astronauts, and the demonstration/validation of technologies.

The Mars environment especially has a number of similarities with the terrestrial one, including a comparable duration of the day and a very similar seasonal alternation. This allows for very good test facilities to be set, with sufficiently relevant experimental conditions, in some specific locations on Earth. However, the results of these validation activities need to be scaled very carefully to also take into account the differences between the terrestrial and Martian conditions. The most important differences include, just as examples, the significantly lower gravity on Mars, the completely different composition and density of the atmosphere, and the extremely toxic nature of Martian regolith.

Ultimately, the most important technologies that will need to be developed and carefully demonstrated on Earth, in order to allow for the establishment of habitats on other celestial bodies, are: technologies for the in-situ extraction, production and utilization of materials (e.g. planetary mining, 3D printing, autonomous manipulation, etc.); body protection equipment and suits; facilities for the production of food/water and the recycling of human waste; sufficiently reliable power generation plants, including facilities for the production of rocket propellants.

Of course, the opposite is also true, with aspects of off-Earth research becoming relevant to on-Earth applications. This is nothing new; from the engineering point of view, space research has always experienced a continuous synergy with research for terrestrial applications, in a wide range of fields from medicine to air/road transportation, from innovative materials to computer software and hardware, to everyday products. Unsuspected products and technologies that come directly from space engineering developments include, just as examples: the LASIK surgery technique for vision correction (NASA Technology Transfer Program, 2003)[6]; innovative technologies for durable gold-plating of objects (NASA Technology Transfer Program, 2018[7]); super-strong materials for car tyres; water purification systems; and even special supplements for baby food.

When it comes to off-Earth space research, one aspect that needs to be taken very carefully into account is sustainability. Can human colonization of other, non-Terrestrial, planetary environments be considered sustainable at all? This is a very widely debated question, see for example: Levchenko et al., 2019; Smith et al., 2019; Anker, 2005. It is more an ethical and political question than a technical one, but it still has a huge impact on engineering aspects too; which materials can be brought from Earth, and which ones need to be procured and used directly on-site? To what extent can humans alter the planetary environment with constructions and habitats? What debris and how much of it can be left on an extra-terrestrial planet? All these questions have a direct impact on the development of technologies for off-Earth habitats.

PC: Similarly, for on-Earth applications, there are ethical questions that need to be raised with respect to determining what a world driven by algorithmic ways of designing will look like. Will this necessarily

6 Link to NASA website: https://spinoff.nasa.gov/spinoff2003/hm_1.html

7 Link to NASA website: https://spinoff.nasa.gov/Spinoff2018/ip_4.html

lead to more equality and diversity? Or will algorithms further embed existing inequalities? How will Industry 4.0 lead to better employment and societal outcomes? And how can society safeguard against technological mega-corporations controlling the narrative of building future cities? Technology is thus the question, not the answer.

HB: These questions need to be addressed and the challenge is to also introduce them in education in order to prepare future engineers for the challenges of the 21st century.

AM: Because off-Earth infrastructure construction and manufacturing can be best implemented in a multidisciplinary context - involving expertise in space engineering, planetary science, civil engineering, architecture, and advanced manufacturing - such multidisciplinary approach should be promoted in the education of future professionals involved in space infrastructure development. This could be achieved through concurrent engineering projects and by ensuring exposure of non-space students to space engineering aspects and space environment constraints, while making space engineering students are acquainted with topics such as human-centred design, psychological aspects, and spatial planning.

AC: Education has a crucial role in particular when it comes to outside-the-box, futuristic research as, for instance, in the final BSc project (called Design Synthesis Exercise) offered at the Aerospace Engineering faculty, Delft University of Technology, where groups of 10 students work full-time for 10 weeks on a design project proposed by academic staff of the faculty. In the framework of this course, several projects related to off-Earth research and planetary exploration were recently proposed, such as: the design and planning of a comprehensive programme for the human colonization of Mars; the design of a planetary protection mission against potentially hazardous asteroids (Radu et al., 2019), etc. These projects have led to extremely interesting, outside-the-box design ideas, taking advantage of the fresh mindset and creativity of young BSc students.

Another education element that allows for the exploration of off-Earth concepts and injecting new, exciting ideas in them is, of course, the MSc theses of students. An example is a thesis that focuses on a preliminary study of technologies for in-situ production of rocket propellant on the Moon. It is easy to imagine the potential game changer this would represent for interplanetary travel; it would be possible to build "re-fuelling stations" orbiting the Moon, limiting the demand for propellant required to be broughtfrom Earth and thus allowing for faster, better-performing travels to Mars or other planets (Schluter & Cowley, 2020). It's not a technology to be developed in the next few years – it will take a bit longer –but when developed it will bring disruptive advantages to (human) space travel. And these students, with their projects, will definitely be precursors to these disruptive technologies.

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